UCF Senior Design 1

Title: U.P.R.I.G.H.T.
User Position Recognition Integrated Guiding Height Table

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Initial Project Document and Group Identification

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Chapter 1 - Executive Summary

A plague stalks the cubicles of the world's workplaces. While an office job would seem to be a safe occupation with little to no risk of injury, sedentary workspaces are a significant source of workplace injuries. Repetitive days of sitting and staring at a computer screen leads directly to lower back pain and other repetitive stress injuries over time. In extreme but not uncommon cases, these injuries can result in disability. This has severe adverse effects on the economy and the lives of workers everywhere. Solutions addressing these problems not only fill an important niche and stand to make significant amounts of money, but also could significantly improve the lives of people who have been stricken by these workplace injuries.

Attempts have been made to address this issue. Improvements have been made to office chairs, ergonomic mice, and ergonomic keyboards. Even general awareness of the issue has increased. Additionally, sit/stand desks have been introduced. These desks allow workers to transition between sitting and standing positions at will. This change is a significant step forward in ensuring worker wellness. However, it does have a particular shortcoming.

A sit/stand desk is only useful if it is being used as intended. However, not every worker utilizes their sit/stand desks. There are many reasons for this, but a major one is that they can be inconvenient to use. The desks must be controlled manually. The more a worker utilizes the desk, the more manual raising and lowering must be done. Once the user raises or lowers the desk, they must fiddle around with it more until they feel it is at their preferred height. Of course, what they believe to be their preferred height may not be comfortable as they start to work for a while which results in further adjustments. Even if a user finds a setting that works for them and tries to stick with it, any other person who needs to use their desk may disrupt their setup. These issues may sound minor, but every little inconvenience and annoyance is something that can discourage a worker from utilizing their sit/stand desk or break their habit of using the desk before it has permanently set in. Any improvements that lower these barriers have the potential to increase sit/stand desk utilization, prevent workplace injuries, and reduce the economic consequences of these injuries.

What would an improved version of a sit/stand desk look like? Ultimately, it would be a desk that maintains user profiles for every worker that uses it. This would have the direct and immediate benefit of storing user preferences. The days of having to fiddle with the desk until it is just right would be all but eliminated. Instead, the user would only need to fiddle around at initial setup and would forever after be able to just use their desk in both modes. It would also allow multiple users to use the same desk without losing any convenience.

This proposal introduces the User Position Recognition Integrated Guiding Height Table (U.P.R.I.G.H.T.). This new generation of sit/stand desks will implement the improvements described above and many additional quality of life improvements for the user. It is a complete sit/stand desk system with a dedicated smartphone application for easy interfacing by the end user. Its goal is to affordably and conveniently improve the work environment of every office worker and prevent thousands of workplace injuries.

Chapter 2 - Project Description

This chapter will explain the overall goals and motivation for this project as well as the features planned. This chapter will be split into eight sections in total.

2.1 Background and Motivation

A study on musculoskeletal issues among office workers concluded that lower back pain is a common health problem among office workers with at least one-year experience, with an incidence rate ranging from 23% to 38% [1]. It is also the most common cause of work-related disability in people under the age of 45 [2]. This is a major concern that affects many individuals because, according to the United States Bureau Labor Statistics Occupational Requirements Survey, the average civilian worker dedicated 40.6 percent of their workday to sedentary activities. This number is even higher for certain occupations. For instance, computer programmers sat for 95.7 percent of the workday [3]. This paradigm underscores the pivotal role that the workstation plays in influencing our well-being, productivity, and overall job satisfaction.

In recognizing this connection between the nature of work and the physical environment, our senior design project seeks to address the challenges posed by static workspaces. The conventional desk, while serving as a staple in work and educational settings, may not fully align with the diverse needs of the modern workforce. The motivation to create a smarter, more adaptable workspace becomes evident in regard to the statistics on workplace musculoskeletal issues.

The conventional dichotomy of sitting and standing does not capture the nuanced requirements of today's work demands. The statistics provided by the Bureau of Labor Statistics highlight the need for a workspace that seamlessly transitions between various postures, promoting health, engagement, and performance. To address these issues, we propose a smart desk that will actively assist workers in maintaining an ergonomic work environment.

To address the ergonomic issues that plague the modern workforce, our design needs to go beyond a simple sit/stand desk. On the one hand, any effort the user needs to put into changing their desk orientation will discourage them from using the feature. Additionally, suddenly changing work styles can have adverse effects on the user [4]. To alleviate this, our design will implement smart tracking and reminders to encourage the user to switch between sitting and standing positions and thus avoid overcompensation. This smart tracking will keep track of the sitting to standing ratio and slowly increase the amount of standing so that the user is not adversely affected by the sudden increase of standing.

As we embark on the journey of designing a smart desk, our goal is to redefine the workspace paradigm by integrating intelligence, adaptability, and user-centric features. By leveraging insights into occupational dynamics, our smart desk aims to revolutionize the way individuals interact with their work environment, enhancing not only productivity but also fostering a holistic approach to well-being. The statistics serve as a compelling foundation, urging us to explore innovative solutions that go beyond the traditional confines of desk design and cater to the evolving needs of the modern workforce.

2.2 Features and Functionality

In the ever-evolving landscape of today's work environment, the combination of ergonomic design with cutting-edge technology plays a pivotal role in crafting spaces that enhance productivity while also supporting physical health. Our state-of-the-art electric smart standing desk stands as a testament to this combination, marking a major advancement in the realm of office furniture design. More than just a workstation, it embodies a holistic solution, catering to the complex requirements of modern professionals. Merging automated functionality with personalized user settings, this desk is designed to redefine ergonomic standards in the workplace by offering a transformative approach to how professionals interact with their workspaces.

The desk's defining characteristic is its automated height adjustment. This innovative functionality allows seamless transitioning between sitting and standing positions, eliminating the need for manual adjustment. At the core of this feature is a sophisticated detection system, which includes a camera and a weight-sensitive mat. These components work in unison to accurately discern the user's presence and their intent to either sit or stand. When the user stands, the desk recognizes this action and, after a brief, user-configurable delay (defaulted to 2 seconds), adjusts to a predetermined standing height. Conversely, when the user opts to sit, the desk responds by lowering to the saved sitting height, again after a short delay. For added safety measures we would include a collision detection system. This automated system is designed to prevent unintended desk movements, thus ensuring a seamless user experience.

User profile customization, facilitated through Bluetooth connectivity, adds another layer of personalization to the desk. Users can create and save individual profiles using a desktop/mobile application that communicates with the desk. The initial interaction with the desk involves a user-friendly calibration process. Here, users set their preferred sitting and standing heights. Once these preferences are saved, the desk automatically adjusts to these settings upon subsequent connections. The application is not just a tool for height adjustment; it also offers customized sit-stand reminders. These reminders are adaptable, with settings that cater to each user’s previous standing habits and ergonomic needs. Moreover, the application tracks and logs the duration of sitting and standing periods, offering valuable insights into the user’s ergonomic practices.

The desk's design incorporates a digital display, neatly mounted to the right underside of the desk which helpfully shows key information like the current desk height, the profile of the user currently utilizing the desk, and Bluetooth connectivity status. Adjacent to this display are manual controls. These controls offer users the ability to manually adjust the desk's height, pair with Bluetooth devices, and toggle the automatic desk adjustment. Such manual options are vital for users who occasionally prefer traditional operation or need to override automatic adjustments for specific tasks.

As workplaces continue to evolve, the need for furniture that adapts to the changing demands of professionals becomes increasingly evident. Our electric standing desk is a response to this need. It represents a harmonious blend of technology and ergonomics, designed to foster a healthier, more dynamic work environment. This desk is more than just a piece of furniture; it is a tool for enhancing productivity and well-being in the workplace. With its innovative features and user-centered design, it is set to redefine the standards of office ergonomics, providing a tangible solution to the challenges of modern office life.

2.3 Goals and Objectives

The objective of our senior design project is to create a standing desk that will be able to adjust its height dynamically depending on whether the user is detected to be standing up or sitting down. The overarching goals of the project are listed below:

Goals and Objectives of the Overall Project

- Develop a reliable system capable of discerning whether the user is standing or seated utilizing an integrated camera for head tracking against a pre-calibrated reference and a weight-sensitive mat for accurate weight assessment.
    - A brief delay will precede any automatic height adjustment to minimize unintended activations of the desk's automatic feature. This delay is preset to three seconds but can be customized by the user via the accompanying app.
- Develop a mobile and desktop application for communicating with the desk via Bluetooth.
- Construct a desk from the ground up, incorporating linear actuators to facilitate its movement.

Objectives for the Mat

- Develop a sensing mat placed beneath the user's chair and feet, designed to accurately measure the user's weight against a calibrated reference.
    - By employing load cells, the mat distinguishes between two distinct scenarios: a lighter weight indicating the user is seated (as the chair's presence reduces the weight applied directly on the mat) and a heavier weight suggesting the user is standing directly on the mat. The load cells will be incorporated under the mat and attached to a custom-built frame. This arrangement facilitates precise weight measurement by evenly distributing the load.

    - A calibration phase will set a baseline for the user's standing weight during the initial set up in the app. Changes from this baseline will inform the system of the user's current position.
    - The dimensions of the mat will be 4x4 feet ensuring it can comfortably accommodate a chair while the user is seated. This size was chosen to balance the need for space with functional design requirements. In selecting the mat, particular attention was paid to its thickness and firmness; it must be robust enough to support everyday office chair use without hindering functionality, yet sufficiently thick—a desired ½ inch—to house the load cells necessary for accurate weight measurement. This consideration ensures the mat remains unobtrusive in an office setting while fulfilling its critical role in our system.

Goals and Objectives for the Camera

- Develop a camera system within the desk, positioned underneath where the monitor is typically located, to provide an optimal vantage point for head tracking.
    - During the initial setup/calibration, users will define reference points for their head in both sitting and standing positions.
    - To conserve power and extend the camera's lifespan, a feature will be considered that requires a specific action (raising a flag) to activate the camera. This ensures the camera is only operational when necessary, reducing energy consumption.
    - The camera system will employ head tracking, outlined by a predetermined border based on the user's calibration, to ascertain changes in the user's position. If the user's face dips above or below a certain threshold relative to the reference line, the system interprets this as the user sitting down or standing up.

If the parameters for a change in position are met for both the mat and the camera, the desk will then change its position to the height set by the user during the initial calibration.

Additional Goals and Objectives

- Integrate an LCD screen to display information to the user. The screen will be positioned at the edge of the desk, specifically under the bottom right side, and angled upward for optimal visibility to the user.
    - Screen will display critical information, including the desk's current height, the user's posture (sitting or standing), the profile currently in use, and the status of the Bluetooth connection to the app.
- Incorporate a row of buttons in an enclosure positioned adjacent to the LCD screen for easy access.
    - There will be 4 distinct buttons, each assigned a specific function: manually raising or lowering the desk height, toggling the desk's automatic

adjustment feature on or off, and initiating pairing with a Bluetooth-enabled device.

- Include collision avoidance system to enhance safety measures.
    - Hoping to include a pre-existing “plug and play” solution for collision detection used in current electric standing desks on the market. Further research is needed.

Mobile/Desktop application Objectives

- Develop applications for both mobile and desktop platforms to enable Bluetooth connectivity with the desk. These applications will enhance user interaction by providing a suit of customizable features and settings.
    - Users can save their profile settings, including preferences for sitting and standing positions.
    - Allows transmission of information to the desk’s LCD screen, facilitating real-time updates and notifications.
    - Features an intuitive graphical user interface, which simplifies the calibration process, making it accessible for users to accurately set up their desk preferences.
    - Includes customizable reminders prompting users to alternate between sitting and standing. Users can adjust the frequency and duration of these reminders, tailoring them to fit personal health goals and daily routines.
    - Monitors and tracks the duration of time users spend in seated and standing positions. Will enable users to access and review their usage statistics, offering insights into both current and historical patterns.
    - Feature predefined settings categorized into beginner, intermediate, and advanced levels, tailored to guide users in gradually adapting to standing while working.

Stretch Goals for Desk Operation

- A directional pad, integrated into the mat, offers users an innovative method to engage in physical activity while standing. This feature, coupled with app integration, leverages the mat's sensors to guide users through various activities. Inspired by exercises recommended for seated airplane passengers to enhance circulation, this functionality encourages movements that promote health and energy. To implement this, force sensing resistors will be placed within the mat to accurately track the user’s foot positions, enabling precise activity tracking and feedback. **(Credit to Dr. Zakhia Abichar)**
- An optional automatic monitor arm accessory can be added to the desk, leveraging the object detection technology utilized for head position tracking. This monitor arm is designed to pan and tilt, adjusting in real-time to maintain the user's optimal viewing angle of their computer screen. This feature ensures ergonomic viewing positions are maintained, enhancing user comfort and reducing strain during both

standing and seated sessions.

2.4 Existing product

In the evolving market of ergonomic office solutions, our team initially conceived the idea of a Bluetooth-connected standing desk, believing it to be a novel concept. However, upon further research, we discovered the existence of similar products such as the UPLIFT Desk App combined with the separately sold UPLIFT Bluetooth Adapter [5] and the Autonomous SmartDesk Connect [6]. These products offer functionalities akin to our envisioned design, including movement reminders, daily standing goals, progress tracking, app-controlled height adjustment, and customizable memory settings for desk heights. The Autonomous SmartDesk Connect goes a step further by recommending various standing exercises like lunges and squats, enhancing the user's physical engagement.

Despite these similarities, our product distinguishes itself in several key areas. One of the most notable features setting our desk apart is the automatic transition between standing and sitting positions. This transition is seamless and intuitive, occurring automatically as the user stands or sits, without the need for manual interaction with a smartphone app. This feature is a significant advancement over the existing products, which require manual adjustments through an app for changing desk settings.

Moreover, our standing desk employs a sophisticated system comprising a built-in camera and a weight-sensing mat to accurately track actual usage times. This system is more precise in determining whether the user is actively standing or sitting at the desk, as opposed to the basic session tracking offered by other products, which may not accurately reflect real-time usage.

In addition, as a stretch goal, we aim to integrate sensors into the mat. These sensors would guide users through simple, low-profile exercises designed to promote blood circulation, such as calf raises, foot pumps, and knee lifts. This feature is particularly suited for office environments where more conspicuous activities like pushups or squats might be less appropriate. Our focus is on subtlety and discretion, ensuring that users can maintain a professional demeanor while still benefiting from physical activity.

Our standing desk is specifically tailored for office settings, balancing ergonomic benefits with the practicalities and decorum of a professional workplace. By combining advanced technology with user-friendly features, our product not only aligns with the current market trends but also introduces unique elements that enhance the overall experience of the user in an office environment.

2.5 Requirements and Specifications

Table 1 below illustrates key engineering specifications with quantitative measures for parts that will be used to construct the desk. A more detailed breakdown is shown in Table

2. In addition to the desired values, certain specifications have been highlighted in yellow to denote demonstrable specifications that will be demoed in a prototype at the end of the semester for Senior Design I.

Table 1 – Featured Design Specifications

System(s)	Parameter	Specification
Vertical Adjustability System	Controllable Up/Down Action for Legs on the Desk	Travel Speed of 25mm/sec
Weight Sensing Functionality	Used to Detect Whether User is Standing Up or Sitting Down	Able to Detect/Withstand Within 10% Accuracy Between 500 – 1,000 Newtons (Approximately 110 – 220 Pounds)
Face Tracking	Used for Tracking of the User's Face to Determine if the User is Sitting or Standing	Accuracy of Tracking Between 80 – 90%
Motor Speed Variation	Allows to Adjust the Speed of Up/Down Action of Legs of the Desk	Adjust Speed from 22.5 mm/sec to 27.5 mm/sec
System Controller	Will Control the Different Points of Operation Excluding the Camera	32 KB Flash Memory 4x Analog/GPIO Pins 10x Digital/GPIO Pins 6 PWM Pins

Table 2 - Overall Design Specifications

System(s)	Parameter	Specification
Vertical Adjustability System	Controllable Up/Down Action for Legs on the Desk	Travel Speed of 25mm/sec Maximum Load of 120 pounds (600N) Input Voltage of 12 VDC 18-inch stroke length
Motor Connection	Allows to Reverse Direction for Up/Down Action of Desk	Input Voltage of 5V 4 Channel
Secondary System Controller	Enables for communication between the system and camera Will be used for object detection to determine user's position	Baud Rate of 9600 2x USB 2.0 SDRAM 2GB
System Controller	Will control the different points of operation excluding the camera Linear actuator/motor controller, LCD, load cell, push buttons, and Raspberry Pi communication	32 KB flash memory 1x UART 1x I2C 1x SPI 4x Analog/GPIO pins 10x Digital/GPIO pins 6 PWM pins
Motor Speed Variation	Allows to Adjust the Speed of Up/Down Action of Legs of the Desk	Adjust Speed by a factor of 10% from the Base Speed From 22.5 mm/sec to 27.5 mm/sec
Weight Sensing Functionality	Used to Detect Whether User is Standing Up or Sitting Down	Able to Detect/Withstand within 10% accuracy between 500 – 1,000 Newtons (approximately 110 – 220 pounds)
Graphical Interface to User	Implemented to Provide User Interface	Able to Display Between 5 – 10 frames per second Resolution of 854x480 pixels
System for OTA Communication	Allows for Remote Communication with Wireless Enabled Devices	Up to 3 Mbps in Enhanced Data Rate Mode Up to 1 Mbps in Low Energy Mode
Peripheral for Face Tracking	Will be used for Object Detection in Conjunction With Pressure Sensing Resistors to Determine Whether User is Standing or Sitting Down	Resolution of 1920x1080 pixels Capable of Displaying 30 frames per second 180 degree viewing angle
Face Tracking	Used for tracking of the user's face to determine if the user is sitting or standing	Accuracy of tracking between 80-90%
User Standing Platform	Sensors Will be Incorporated Inside the Mat	½ inch thickness 4-foot x 4-foot

2.6 Hardware Block Diagram

The hardware block diagram can be seen in Figure 1 below. It details the overall design implementing various features discussed in Section 2.2. A responsibility matrix is also provided that notes the obligation of each team member using color coordination with the individual blocks. Power will be supplied through any generic wall duplex outlet and converted down to 12V DC using a 10A power supply AC to DC power adapter. The 10A power supply is necessary to accommodate at least two linear actuators powerful enough to meet load requirements (Insert requirements). Voltage regulators will be installed to drop voltage to the correct input for the microcontroller unit or any other components.

The central processing needed for the PCB will be handled by the microcontroller unit (MCU), however, further research is still underway to determine the specific MCU to be utilized. Web cameras and load cells within the designed mat will send data to the MCU to determine whether the user is sitting or standing and when they make a transition to the other position. A Bluetooth module will be incorporated to send/receive data from the MCU to a user connected device utilizing a customizable app. The MCU will use the data collected to determine the desired position of the desk and implement that location using a motor control module and the linear actuators. While the desk is moving, infrared sensors (IR sensors) are a possible solution to track any obstacles impeding movement to avoid collisions. Further research is necessary to implement the optimal system for collision avoidance. The relative position of the desk and the duration at the position will be tracked and shown with a built-in LCD display. Override buttons will be installed conveniently next to the LCD to enable manual control for the user and shut off automation.

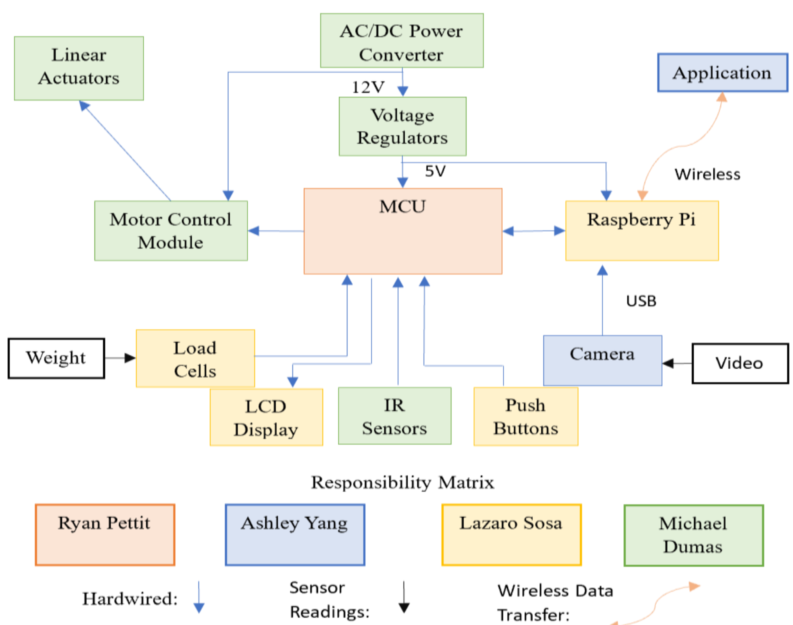

Figure 1- Hardware Block Diagram

2.7 Software Block Diagram

Figure 2 below details the software decision tree that will be implemented by the system. Flutter will be used to create the application for windows and android devices. The application will be used to save the user preferences and will provide instructions for the user during first time setup. This application will also be used for sending reminders to the user to either sit or stand-up. If the user is a returning user, it will send the saved profile settings to the embedded system through Bluetooth. Once it is determined that the user is at the desk, active tracking will be activated depending on the user's saved preferences. Then, if the user position changes, the desk will go through two checks before toggling between sitting and standing mode.

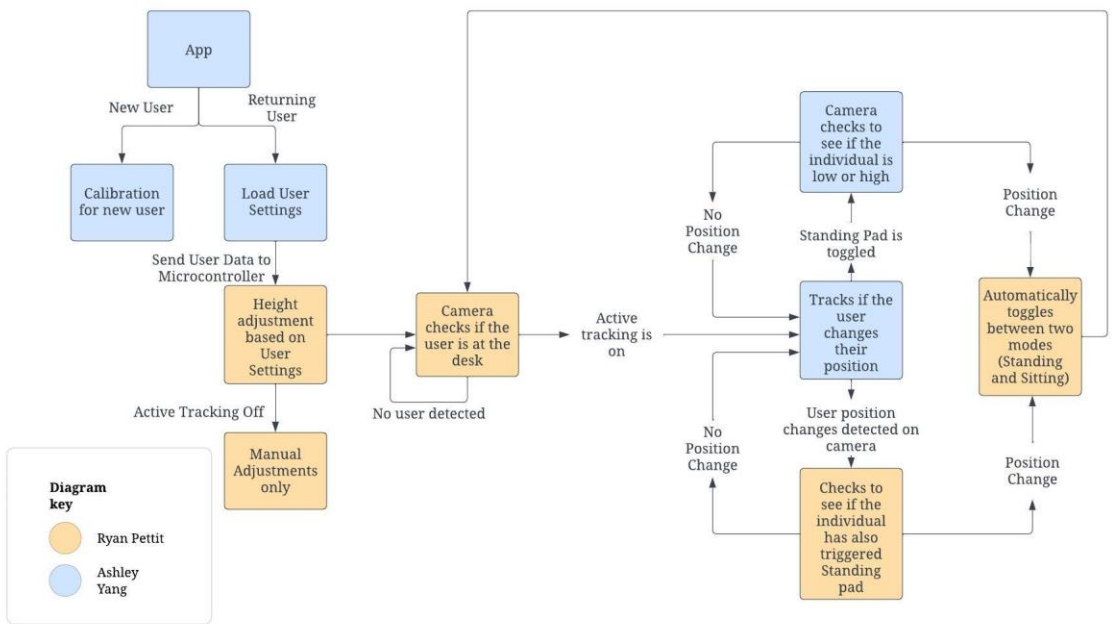

Figure 2 - Software Block Diagram

2.8 House of Quality

Figure 3 below shows the House of Quality diagram for our project for Senior Design. On the right side are the customer specifications. These are the aspects of the desk that a user would value when deciding whether to buy the product. On the top row are the engineering specifications. These are the relevant values and measurements required to get the desk to function. By plotting the desk characteristics in this way, it allows us to evaluate the relationships between the different components. For example, if we wanted to know what effect the build quality of the desk would have on the cost of the product, we could consult the House of Quality diagram to determine that they have an inverse relationship. This means that as the build quality of the desk goes up, the cost of the product goes up even though we desire to minimize the final price.

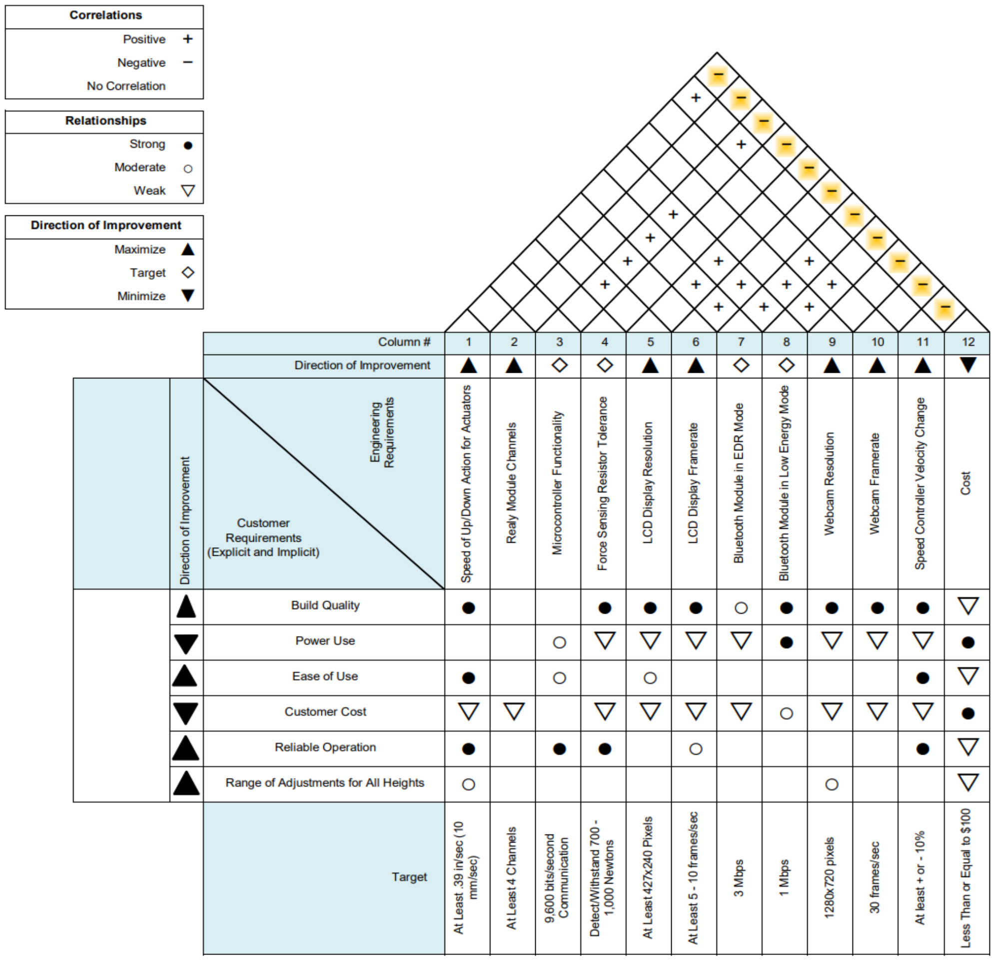

Figure 3 - House of Quality Diagram

Chapter 3 - Research and Investigation

This chapter is split up into two sections. The first section of this chapter is concerned with comparisons between the various technologies utilized in the project and the selection process that was employed to find the most cost-effective parts that would also be able the meet the defined specifications in Chapter 2 -. This includes a summarization of each comparison using a table and explaining the selection, using one table for each individual comparison of both the software and hardware technologies present in our project.

The second section of Chapter 3 - is concerned with the part comparison and selection for the project. Inside this section, summarization of each comparison using a table and explanation of our decisions can be found. In addition to this, Section 3.2 will include an individual table for each hardware and software part, providing at least three options that were considered for each selection.

Within each section, headers have been included to divide each part and technology into its own subcategory. This has been done to enable easy navigation to find specific parts and technologies used.

3.1 Technology Comparison and Selection

This section is concerned with the technology comparison and selection part of research for our project. Specifically, this section will have more of a focus on how the functionalities of our project require certain technologies in order to meet the goals and objectives present in Chapter 2 of this design document.

This section is distinct from Section 3.2 in that it will not focus on the specific parts used to meet our design requirements. Instead, it will go into explanations on why certain technologies were used over others. For example, as mentioned in Chapter 2, the desk will require a way to measure pressure so that it can determine whether the user is sitting or standing. In this example, Section 1 would be concerned with the different pressure sensing technologies, while Section 3.2 would focus on the different parts available once a selection between the various technologies available in made.

3.1.1 Pressure Sensing Technology

This section will be focused on finding the best solutions to sense the pressure of the user that will be sitting or standing on the mat. The pressure sensing technology must be capable of detecting the weight of the user accurately, with a maximum percent error of 10 percent. Anything more than this will impede the operation of the desk and result in the desk changing position even though the user has not actually changed from sitting to standing or vice versa.

These are the technologies available to us that will enable us to sense the weight of the person while they are either sitting or standing on the mat:

- Resistive Pressure Sensors (Force-Sensitive Resistors – FSRs)
- Capacitive Pressure Sensors
- Piezoelectric Sensors
- Load Cells

The first technology discussed will be the resistive pressure sensors. These are a type of sensor that changes their resistance in response to an applied force or pressure. They are constructed from a material whose resistance decreases as pressure is applied to its surface. This characteristic allows them to convert the force exerted on them into an electrical signal, which can be measured and interpreted by the system for our project.

FSRs typically consist of a conductive polymer, which changes resistance under pressure, sandwiched between two conductive electrodes. When pressure is applied to the sensor, the conductive particles within the polymer are forced closer together, reducing the resistance across the sensor. The change in resistance is measured by an electrical circuit, often a simple voltage divider, and converted into a digital signal that indicates the amount of pressure applied.

In the context of our project, FSRs have various advantages and disadvantages. FSRs are relatively straightforward to integrate into electronic systems, requiring minimal additional components to read the pressure values. They can be made thin and flexible, which makes them suitable for placement under a mat without discomfort or obstruction. Generally, FSRs are less expensive than some other types of pressure sensors, which can help keep the overall project costs down. They come in various sizes and shapes, offering flexibility in design depending on the specific needs of our project.

However, FSRs may not offer the same level of precision as some other pressure sensors, which is a drawback because highly accurate pressure measurements are crucial for determining the user’s position. Repeated and prolonged use can affect their accuracy over time, as the conductive polymer may degrade or the sensor’s sensitivity might change. They have a limited range of sensitivity, which means they might not be able to detect very low pressures or distinguish between very high pressures effectively. Also, the relationship between pressure and resistance change in non-linear, which may require additional calibration and software processing to obtain accurate measurements.

The second technology discussed will be capacitive pressure sensors. Capacitive pressure sensors measure pressure changes through the variation in capacitance, which is the ability of a system to store an electric charge. These sensors are made up of two conductive plates separated by a dielectric material (which does not conduct electricity but can store electrical energy). When pressure is applied, it alters the physical distance between the plates or the dielectric constant of the material between them, leading to a change in capacitance. This change can be measured and converted into an electrical signal to determine the amount of pressure applied.

Capacitive pressure sensors consist of two conductive plates separated by a non-conductive material. One plate is connected to an oscillating circuit that generates a charge, while the other plate measures the charge passing through the dielectric. When pressure is applied to the sensor, it either compresses the dielectric or changes it's area, affecting the capacitance, This change in capacitance is proportional to the pressure applied and is measured by the sensor's circuitry, converting it into a usable electrical signal.

In the context of our project, they are advantageous because they are very sensitive to even slight changes in pressure, making them suitable for accurate pressure measurements. They can provide high-resolution measurements, which can be crucial for detecting subtle changes in the user's position. These sensors tend to have good long-term stability and reliability, with minimal drift over time, which is advantageous for applications requiring consistent performance. They can be designed to be thin and flexible, allowing them to be integrated into the mat, without significant intrusion or discomfort.

However, they can be more complex to design and implement than resistive pressure sensors, potentially increasing our project's cost and complexity. They can be sensitive to environmental factors such as temperature and humidity, which might affect accuracy if not properly compensated for. They may also require more sophisticated calibration and signal processing to achieve accurate measurements, especially given the potential for environmental interference.

The third technology discussed in this section will be the piezoelectric sensors. Piezoelectric sensors consist of a piezoelectric material sandwiched between two electrodes. The material is typically a crystal (like quartz) or a ceramic that exhibits piezoelectric properties. When pressure is applied to the piezoelectric material, it generates a voltage proportional to the pressure. This voltage can be measured, amplified, and converted into a signal that reflects the magnitude of the applied force or pressure.

In the context of our project, they are beneficial because they are extremely sensitive, capable of detecting minute pressure changes. This makes them suitable for applications requiring precise detection of force or pressure. They can measure a broad range of pressures, from very light touched to significant forces, offering flexibility in monitoring different types of interactions with the desk. These sensors respond quickly to changes in pressure, enabling real-time monitoring and adjustments. They also generate their own voltage in response to pressure, so they do not require an external power source for the sensing operation, which can simplify circuit design.

Their disadvantages are that they are most effective for dynamic or changing pressures, For static pressure (where the force remains constant over time), the electrical signal can decrease, making it difficult to measure steady states accurately. Over time, the signal from a piezoelectric sensor under constant pressure can "drift", leading to inaccuracies. The generated signals can be small and require amplification and conditioning, adding complexity to the electronics involved. In addition to this, they can be sensitive to temperature and humidity, which might affect their performance and the accuracy of measurements.

The final technology that was investigated for integration into our project was load cells. A typical load cell consists of a metal body (steel or aluminum) designed to bend under load. Strain gauges are attached to the load cell in locations where the deformation is expected to occur. The arrangement of these gauges can vary depending on the type of load cell and the specific application. When a force is applied to the load cell, it causes the metal body to deform slightly. This deformation changes the length and diameter of the strain gauges, altering their resistance. These changes in resistance are measured through a Wheatstone bridge circuit and converted into an electrical signal that is proportional to the applied force.

Load cells have the most advantages in the context of our project. They can provide very accurate measurements of force or weight, making them suitable for applications where precise force detection is needed. They are available in a wide range of load capacities, from very small to very large forces, allowing for versatility in application. They are designed for industrial use, which means they are generally robust and durable, capable of withstanding harsh conditions and repeated use without significant degradation in performance. Finally, they can maintain their accuracy over time, making them reliable for long-term applications.

Load cells do come with some disadvantages though. These include the fact that they can be more complex and expensive than other types of sensors, such as resistive pressure sensors or capacitive sensors, due to the precision engineering involved. They also are typically more rigid and can be bulkier than other types of pressure sensors, which might limit their placement or integration under the mat. To ensure accuracy, they need to be properly calibrated, which can add to the setup time and complexity. Finally, while robust, they can still be affected by environmental factors such as temperature variations, which can influence their accuracy and require compensation.

This summarizes the pressure sensing technologies considered along with their advantages and disadvantages. A summary of these findings can be found in Table 3 below:

Table 3 - Comparison Between Relevant Pressure Sensing Technologies

Feature and Technology	Resistive Pressure Sensors (FSRs)	Capacitive Pressure Sensors	Piezoelectric Sensors	Load Cells
How They Operate	Resistance changes with applied pressure	Capacitance changes with applied pressure	Generate electrical charge in response to pressure	Convert force into an electrical signal using strain gauges
Temperature Range Comparison	-40 to +125 degrees C	-40 to +125 degrees C	-200 to +200 degrees C	-10 to +40 degrees C
Cost Comparison	Between \$3 - \$11 per unit	Between \$10 - \$50 per unit	Typically starting prices greater than \$11	Between \$1 - \$10 per unit
Sensitivity Range Comparison	Between 1 – 3 mV/V	Between 0.01 – 1 pF/kPa	Between 0.1 – 30 mV/N	Between 1 mV/V – 3 mV/V
Industry Device Application(s)	Monitoring engine oil and fuel pressure for automotive applications	Monitoring and controlling air pressure for HVAC systems	Pressure sensing for weather instrumentation	Used for products such as kitchen scales
Project Considerations	Measurement range: 0 – 10 MPa typically, Temperature range: -40 to 85 degrees C	Measurement range: 0 – 1 MPa commonly, temperature range: -40 to 125 degrees C	Temperature range: -200 degrees C to +200 degrees C, life expectancy: > 10^9 cycles	Temperature range: -10 to +40 degrees C typically, wider with special designs, life expectancy: >10^6 load cycles

Based off the research done for this section, it was determined that load cells were the most appropriate technology to use for this part of the project. This was because of the accuracy and reliability provided by the load cells as well as how robust they were made them ideal for putting underneath the mat to take the relevant measurements.

3.1.2 User Detection Technology

Detecting the user is important in determining when the desk should automatically transition between sitting and standing. In conjunction with the pressure sensing mat, three options were considered to improve user detection. A breakdown of these options is shown in Table 4 below.

The first option was using a small lidar sensor to detect when there was a user in front of the desk. This option would only determine if there was an object present in front of it. It could not tell what type of object was in front. By itself this option would not be an ideal solution to tracking the user because it could cause a false positive if there was a chair in front with no user present.

Table 4 - Comparison Between User Detection Technology

Technology	Tracking	Use case
Small lidar sensor	- Detection with 92% accuracy about 4 meters -Able to detect if user leaves desk	Detects any objects in front with no distinction.
Desk application tracking	-Automatic tracking with user login to computer. Tracking user login is 100% accurate. -Not able to detect if user leaves desk	Tracking only when user has logged in to computer. No ability to track when user has left desk
Facial tracking with camera	-Can track with up to 92-94% accuracy within view of camera -Able to detect if a user leaves desk	Tracking user face with ability to determine when there is no face present

The second option considered was using the desk application to determine if the user was present based on login to the computer. This option would work based on setting the desk application to automatically launch on start. Then when the user logins in, it can be determined that someone is present at the desk because they are logged in to the desktop. The only way for this option to determine that the user is finished is if the user logs off the computer. This method has no way of determining whether the user is continuously present. Determining whether the user is continuously present is very important for seamless transition between the two modes of the desk.

The last option considered was using a small camera to track the user. This will work by using facial tracking software in conjunction with the camera. One potential concern with this method is the placement of the camera. To get the best tracking, the camera will need to be placed directly in front of the user at a set distance. If this camera is built into the desk, then there is the potential for the camera to be accidentally blocked by common supplies that the user may put on the desk. Although this may happen, this method still is the most reliable method in determining if there is a user present at the desk since it is using facial tracking. This should allow it to distinguish between a chair and an individual. This method also continuously tracks the user so it can be used as a factor for determining when to automatically transition the desk between modes.

3.1.3 Linear Actuator Technology

Linear actuators are a key component of standing desks, and this section will take a closer look at what actuators are, the different types, and the most reasonable design to implement for U.P.R.I.G.H.T. There are many different forms of actuators across various engineering disciplines, and they make up the muscles for vast quantity of machines, however, what is it that makes some of them linear actuators? These are simply devices that take some form of input and translate it into linear motion. That input can range from electrical signals, a hydraulic system, or an actuator that utilizes rotary mechanical motion to convert to linear. A comparison of these systems is shown in Table 5.

Table 5 - Linear Actuator Technology Comparison

Feature/Technology	**Mechanical Linear Actuators**	**Hydraulic Linear Actuators**	**Electric Linear Actuators**
How They Operate	Rotary mechanical energy turned into linear motion	Linear motion of a rod occurs with pressurized fluid	Electrical energy turned into linear motion by motor, gears, screw, and nut
Use-Case Scenario	Limited Power Availability and cost sensitive projects (Low $25-$50) (High end $100-$500)	Applications requiring high load capability (10,000+ lbs) and long service life if properly maintained (10-15+ years)	Self-contained and efficient (no current generated while idle) , precise speed(driven by PWM up to 160mm/s) and position control (~0.5mm) which lends to more controlled automation
Features	Lack of automation or complex capabilities	required external components. Limited speed control, ideal temperature range 120-140 degrees F (The viscosity of hydraulic fluid is inversely related to temperature: it thickens in cold and thins in heat.)	Overheating caused by operating above rated duty cycle (typical 20% duty cycle)

One form of mechanical system is already utilized in standing desks today, the hand crank model, which requires manual operation. It would be possible to incorporate an external electric motor that would turn the hand crank, however that would add an unnecessary layer of the system. Mechanical actuator technology can be dismissed for use in the U.P.R.I.G.H.T because automation is the key functionality goal. Which leads to hydraulic linear actuators.

Fluid pressure is utilized in hydraulic linear actuators to generate linear motion and generally consists of a cylinder, piston, and hydraulic fluid. As pressure is applied to the fluid via an electrical or hand pump, the fluid pushes against the piston, causing it to move linearly. This is one possible solution for height adjustment of a standing desk. There are a few positives regarding hydraulic actuators, particularly their high force output and smooth operation. The most common applications that utilize this type of actuator are ones that include exceptionally heavy load requirements. They are generally considered the highest-powered actuator type on the market.

On the other hand, electric linear actuators rely on electrical energy utilized with a motor to produce linear motion in the form of a screw and nut mechanism. As a motor is energized, it rotates the lead screw, turning the nut along the threads, and results in linear motion. Electric actuators have many advantages including precise positioning, quiet operation, and control customization. They are commonly used in applications that require precision, speed, and minimal maintenance, such as in automated manufacturing processes or standing desks.

Having looked at both hydraulic and electrical linear actuators, it should come as no surprise that the technology most suitable for the U.P.R.I.G.H.T is electrical. Hydraulic actuators are not self-contained but require an existing plumbing infrastructure to become operational. Not only can this be expensive if that infrastructure is not in place but is also costly to keep maintained for system efficiency and to avoid any damage and leakage. The greatest advantage that hydraulic has over electric is higher load capacity, with many models able to withstand and displace thousands of pounds. However, for the purpose of a standing desk, electric actuators provide plenty of load capacity. In addition, electric powered actuators provide a plethora of easy to control capabilities. With connection to a motor control module or microcontroller, speed and position can be easily controlled and automated with precision that a hydraulic actuator cannot come close to matching. Electric actuators are also self-contained, meaning that they do not require any external system, pump, or motor to operate, only a power supply. These attributes make electric linear actuators a no-brainer for U.P.R.I.G.H.T.

There are some secondary factors that need to be considered for electric linear actuators, namely regarding the internal motor type. The factor that will be examined in this section will pertain to whether an AC or DC motor will be the driving motor within the actuator, while the voltage rating will be discussed in part comparison and selection of Section 3.2. First off, both motor types are based on the same principle, that alternating magnetic fields induced by alternating directions of current will cause a shaft to rotate. DC refers to direct current, which has a constant and continuous flow in the same direction, while alternating current, AC, alternates current direction at a certain frequency. The standard frequency for alternating current within the United States is 60 Hertz, or 60 times per second. For high powered applications, alternating current is the most common power source because it is relatively easy to change voltage and highly efficient with minimal power loss at higher voltages and longer distances travelled. Many smaller, low powered applications use DC. For instance, anything powered by a battery is using DC. The difference between AC and DC causes certain characteristics within motors that help determine each type's applicable suitability. AC motors generally have greater durability and life expectancy because they do not have any touching parts. However, DC motor speeds are far easier to control. Since a direct current motor's speed is proportional to the current that is feeding it, simply by introducing certain voltage regulation, the speed can be controlled. It is not that simple for AC motors because of the frequency, and generally a VFD, or variable frequency drive is needed to operate an AC motor. These VFDs can be quite expensive and add another layer of complexity. For this reason, and the fact that converting typical residential AC power to DC is simple, U.P.R.I.G.H.T. will utilize DC linear actuators.

3.1.4 Feedback System Technology for Electric Linear Actuators

This section will dive into the main technologies that are utilized for feedback systems in electric linear actuators. Not all actuators include a feedback system, in fact many of the base models do not. For simple applications that require an actuator to just extend and retract to one position, there is no need for feedback functionality. As projects become more complex, feedback systems were designed to help maintain real time position tracking of the stroke for accurate position control and assist with speed control. As linear actuators have continued to progress, there have been three main technologies that continue to be utilized in feedback systems listed below. The goal of this section is to determine which technology will be the best suited for utilization within the U.P.R.I.G.H.T.

- Potentiometers, also referred to as POT sensors
- Hall Sensors
- Optical Sensors

Most electric linear actuators on the market that incorporate a feedback system do so with potentiometers. Their cost effectiveness and adaptability of being utilized internally or externally are the leading factors that contribute to their wide range of use. POT sensors are especially simple in their application, as they simply output a resistance value that correlates with the position of the stroke. This is accomplished by using a thin layer of resistant material, applying a voltage, and reading the voltage at different positions of the material. The voltage readings close to a 12V voltage being supplied will be almost 12V and readings halfway along the material will be roughly half the voltage. As the readings increase in distance away from the source they will decrease in voltage until it is zero, basically providing a certain kind of position tracking. This output can be used by a MCU to scan the position of the stroke and help with synchronous positioning and speed across multiple actuators.

The next two technologies used in feedback systems, hall sensors and optical sensors, are very similar in their design, however hall sensors use magnets and optical sensors utilize optics. The main premise in hall sensors is that a thin, magnetic disk with slight ridges around the edge is installed somewhere in the gearbox of the actuator and rotates as the motor extends or retracts the stroke. As the magnetic disk spins a magnetic sensor will produce a voltage pulse each time the disk rotates 360 degrees. The greater number of rotations and pulses from the hall sensor throughout the extension of the stroke, the more precise the position control can be. For instance, U.P.R.I.G.H.T will utilize 18” strokes, and if the hall sensor sends 1000 pulses, that would be 1000/18” = 55.55 pulses per inch, in other words, 1 pulse per 0.018”. This means that this hall sensor could provide accurate position control up to about half a millimeter. This tends to be much more precise than potentiometers, however there is a drawback. Standard hall sensors are not able to track if the actuator is extending or retracting and must therefore return to a starting point (usually fully retracted) before the position of the stroke can be controlled.

Optical sensors employ the same design concept as hall sensors but utilize a disk with slots cut out around the edge. The optic sensor will read an LED that shines through the slits in the disk and will pulse an output as the disk rotates. With this design, the frequency of pulses can be much higher than the hall sensor, providing greater precision and accuracy with position control. This technology, however, also has the same drawback as hall sensors of needing a homing cycle back to a starting point before it is calibrated for position control. For an overview, see Table 6 below for the specific advantages and disadvantages attributed to these technologies. [7] [8]

Table 6 - Feedback System Technology Comparison

Feature/Technology	**Potentiometers POT sensors**	**Hall Sensors**	**Optical Sensors**
How They Operate	Resistant values are output that correspond to stroke position.	5V pulses are output as voltage is induced from a magnetic sensor reading the rotations of a magnetic disk.	5V pulses are output as an optic sensor reads flashes from a LED through the slits of a rotating disk.
Power Startup	Does not require calibration on startup.	Requires calibration on each startup or disruption of power.	Requires calibration on each startup or disruption of power.
Output	Varying resistance values as the stroke moves. Acts as a simple voltage divider when connected to a source.	Stable 5V digital pulse as stroke moves.	Stable 5V digital pulse as stroke moves.
Accuracy	Low The resistance values of different POT sensors are not universal.	High Control within 0.6mm	Very High Ten times as precise as Hall sensors with control of 0.06mm
Price	\$140.00-\$150.00 From Progressive Automations and Electric Linear Actuators	\$180.00-\$186.00 From Firgelli Automations and Progressive Automations	\$160.00-\$180.00 From Firgelli Automations

In conclusion, the best technology suitable for the U.P.R.I.G.H.T is potentiometers, with the main factor being no required calibration for power ups. POT sensors are less durable and accurate compared to optical sensors, but no need for constant calibration will help with U.P.R.I.G.H.T's goals of automation and immersion. Another tradeoff with POT sensors will be synchronous control, which is not impossible with potentiometers but will require more initial testing and prototyping, and acceptable tradeoff.

3.1.5 Power System Technology

This section will briefly discuss the options of technology that could be utilized to power the U.P.R.I.G.H.T. The power system will be integral in the overall design aspect of the desk. With key desired characteristics of seamless integration and automation, it will be imperative that the chosen method of power be able to cultivate a design that meets those features. If the desk is to be used in a business or office type environment, it will need to stay functional for the minimum of a typical workday of 8 hours. However, to accommodate the occasional long work shift, 12 hours of continuous use will be the goal.

Table 7 – Power System Technology Comparison

Technology	AC Power via AC/DC Converter	DC Batteries
Portability	Low Must have access to 120V AC device.	High Can be used anywhere
Stable output	No, for unregulated converters. Yes, for regulated converters	Yes, for fully charged No, for < 75%
Voltage flexibility	No One voltage output	Yes Multiple batteries can be run in series to change voltage output
Design Complexity	Medium Voltage regulators will need to be added for protection.	High Recommended that voltage regulators be added. Additional power supply could be added to recharge.
Cost	Low Upfront cost only ($20-90)	Low Upfront cost: roughly ($20-50) High Operation cost: due to batteries needing to be charged or replaced regularly.

Considering the power consumption of every major component, the system will need to deliver at least 60 watts of power on average, but with a max capacity of 150 watts. Ultimately there are two main technologies that will be explored for use in the

U.P.R.I.G.H.T: rechargeable batteries supplying DC power, or secondly, AC power directly from a standard 120V receptacle. There are a few pros and cons for each technology type summarized in Table 7.

Delving into batteries, the advantages of their use within U.P.R.I.G.H.T. would include stable and precise voltage output. There are three main voltages levels that different systems will utilize, those include 3.3V, 5V, and 12V. Separate batteries could be purchased for each subsystem that requires a different voltage and because the output of batteries are generally stable it will remove the need for any DC-to-DC converters. That in itself is a great advantage because there could be a decent amount of testing or prototyping needed with DC/DC converters, especially if we do custom designs.

Even with these advantages, there are numerous pitfalls with their use. As the charge within a battery decreases the voltage output will also decrease. If the battery is powering sensitive electronics where a varying input voltage can damage components, utilization of voltage regulators will still be necessary. Another obvious reason is the size of the battery needed for the linear actuators, and because the actuators could consume up to 60W each while operating under a full load, the battery would need to be able to discharge at least 10A of current at any time. Batteries of this capacity can easily weigh 10 or more pounds, creating an even greater load strain on the actuators leading to a decrease in overall efficiency and max speed. There will also be another layer of complexity needed in the design to accommodate multiple power sources. Integration of multiple batteries across the different subsystems will also require user intervention. Each battery will need to be retrieved at depletion and recharged, disrupting the desired outcome of seamless integration. Overall, the use of batteries will hinder this seamless design while also having a negative effect on constraints, even if they can provide more flexibility in power supply.

The use of a single power source will help contribute to a unified design that does not require additional attention from the user, and this can be accomplished with power supplied by a typical 120V AC receptacle. However, there will be a few drawbacks to this method. The most glaring issue is that all systems within the U.P.R.I.G.H.T require a DC power source at varying voltage levels, requiring the AC voltage to be converted. The AC/DC power adapter, a device whose input takes a typical alternating current from a wall outlet and outputs a direct current, will be the best solution. From that point, voltage regulators will need to be utilized as DC/DC converters to ensure that every voltage level is accounted for. These voltage regulators will be discussed in further detail in pert selection and hardware design.

With the linear actuators easily consuming the most energy within our system, the AC/DC adapter will need to be a 12V adapter to match the voltage rated of the actuators and also have a power rating able to accommodate the required wattage of the entire system. From there, DC/DC converters will need to drop the 12V from the adapter to 3.3V and 5V for the MCU, raspberry pi and various peripherals. There will be an additional layer of design and testing needed to incorporate the voltage regulators for the PCB (details in hardware design), however this is a necessary tradeoff in order to provide an overall seamless design. With the desire to eliminate any unnecessary attention required by the user, and the overall goal of implementing a “plug-n-play” power delivery system, it should be obvious that the U.P.R.I.G.H.T will utilize 120V alternating current for its power supply.

3.1.6 Voltage Regulator Technology

This section will dive into the two main broad topology types utilized in DC/DC voltage regulators, linear and switching, as well as the specific applications that each are best suited for, and which technology will best fit integration into U.P.R.I.G.H.T’s power distribution. A summary of these findings can be found in Table 8. The reason that the desk needs voltage regulators stem from the different voltage levels utilized by subsystems and the need for stable voltage fed to any sensitive electronic components. There will be three main voltage levels used throughout the desk: 12V for the linear actuators, 5V for the raspberry pi 4 and the web camera, and 3.3V for the MCU, motor controller and connected peripherals. As discussed in the power system technology section and the AC/DC converter section, the U.P.R.I.G.H.T will be powered directly from an AC source that is then converted into 12V direct current from an AC/DC adapter. This is where the need for the regulators arises, the 12V power source will need to be filtered down to the correct levels for the other systems to operate properly.

Table 8 – Voltage Regulator Technology Comparison

Technology	**Linear Regulators**	**Switching Regulators**
Regulator Function	Step down (buck) only	Step down (buck) Step up (boost) Inverter
Efficiency	Low to Medium Efficiency can be high if the difference between input and output voltage is very low	High Generally, between 85-95%
Heat Waste	High Especially with large input/output voltage difference.	Low Will generally run cool when dissipating less than 1W. (assuming 90% efficiency, that would be a 10W system)
Voltage Ripple	Low No ripple and low noise	Medium to High. Ripple due to switching rate
Cost	Low Small amount of need components. Generally, just a couple capacitors.	High Generally due to the need of many external components in addition to the IC

Linear regulators will be the first technology of the two explored because it is far more straightforward. Essentially linear regulators can be called variable resistance devices because their internal resistance can change in order to maintain a constant voltage output. This is accomplished using a transistor that is controlled via an amplifier feedback loop that checks the output voltage versus the reference voltage of the amplifier. These voltages will not be the same, and so a simple voltage divider is utilized to step down this output to what the reference voltage should be and then compared. Overall, the internal resistance of the linear regulator can be changed to increase or decrease the current allowed to feed the output, which will change the output voltage. If the output voltage is sensed to be less than required, additional current will be allowed to flow through the transistor to the output, increasing the voltage. The opposite is true when the voltage of the output is too high: the current will be limited, and the voltage will drop. This is the basic process of how a linear regulator can maintain a consistent, stable voltage level at the output. Generally, capacitors will then be added to the input and output terminals of the regulator to help filter the signal and stabilize the output from any sudden increase of load. [9]

Now that there is a firm grasp on how linear regulators operate, what applications are they used in? First, because of their simple design, they are only able to output a lower voltage than the input voltage, meaning that they can only be a step-down converter. However, the design allows for a noise-free, stable output build and for greater cost effectiveness vs switching regulators. Their efficiency is another important topic for this discussion as the input current is typically supposed to equal the output current in these regulators. This means that the ideal efficiency of output power divided by input power can now be simply thought of as the output voltage divided by the input voltage. The consequence of this is that linear regulators will be extremely efficient when there is only a small differential between input and output voltage. As that differential grows, however, efficiency will steadily drop. Take the necessary voltage levels of the U.P.R.I.G.H.T for instance: a 12V to 5V linear regulator will have an efficiency of 5/12 = 42%, while 12V to 3.3V will be even worse: 3.3/12 = 27.5%. Overall, linear regulators are perfect for applications that have This is the critical factor of why linear regulators will not be utilized for the U.P.R.I.G.H.T.

Transitioning to switching regulators, their basic design premise is that certain components act as a switch to control the flow of current into energy storage components (capacitors and inductors) in order to transform the input signal to a different voltage. Generally, a transistor will be the component acting as the switch, while more modern IC chips will use high frequency switching from MOSFETs (still a transistor) that helps temporarily store energy in capacitors and inductors, that will then discharge that energy at a different voltage. This method of regulating voltage is much more complex than linear regulators, but the result is a much more efficient circuit regardless of the input to output voltage difference. The downside to this design, however, is that this method will produce a voltage ripple at the output that could cause EMI (electromagnetic interference). The three main ways that the switching regulator can be designed to combat this ripple voltage is to increase inductance by making the inductors larger, increase capacitance by adding another capacitor, or by increasing the switching frequency. Ultimately, utilization of switching regulators will maximize efficiency when dropping the 12V source, even if they are more expensive and create more noise at the output. [10]

Both of these technologies have their faults and neither one makes a perfect fit for integration into the U.P.R.I.G.H.T, however, switching regulators are clearly the topology that will work best. If upon further testing and prototyping, it is found that the ripple voltage from switching is too much for certain systems, there are a few solutions to keep in mind. The easiest to implement might be the inclusion of a linear regulator after the switching in order to smooth out that ripple and provide a stable and precise voltage output. Ultimately the design of the power distribution system and PCB is fully explored in chapter 6.

3.1.7 Motor Control Technology

Motor Control of the linear actuators utilized for U.P.R.I.G.H.T will play a critical role in the functionality of the desk. There are a multitude of avenues to control motors that include relays, voltage regulation, motor drivers and full-blown motor controllers. The selection of motor control technology will derive from critical factors of motor type being used and the desired project functionality. The U.P.R.I.G.H.T will be designed to include many automated features, which the control method of the motors will need to take that into account, eliminating the need for further conversation on relays or voltage regulation. As discussed in linear actuator technology and linear actuator selection, specifically 12V brushed DC motors will be used for the desk. This type of motor is almost exclusively controlled by H-Bridge motor drivers.

H-Bridge motor drivers utilize H-bridge circuits and PWM (pulse width modulation) to flip the direction and speed of the motor respectively. The conceptual design of H-Bridge circuits is actually fairly simple, by using four “switches” in an H pattern with the motor sitting on the bridge or horizontal line of the H, different configuration of switches can change the voltage polarity on the motor causing it to reverse direction. Generally speaking, if all switches are open there will be no voltage across the motor, but closing the top left and bottom right switch will cause the motor to spin. By opening those switches and closing the other two, the polarity on the motor will shift and the motor will rotate in the other direction. Any other switch configuration can cause a short in the circuit. The actual components utilized in H-Bridge circuits are not switches, otherwise a simple relay or double pole, double throw (DPDT) switch could be used just as effectively. These circuits are actually realized using bipolar transistors or MOSFETs. Many of the older models use bipolar transistors, while new designs utilize MOSFETs because they are significantly more energy efficient. The main reason for this characteristic is the amount of voltage drop created by the components. When bipolar transistors are turned on, there is about a 0.7V drop across the transistor, whereas there is only about a 0.1V drop across a MOSFET. The drop in voltage is usually dissipated as heat and depending on the amount of current necessary to drive the motor(s), this heat can exceed the thermal ratings of electric components used in the driver, damaging it beyond repair. This is the reason why many drivers include heat sinks that can account for the wasted energy, especially ones that utilize bipolar transistors. When selecting the driver for this project, it will be important to keep in mind its power efficiency ratings and how well it can handle any wasted heat. Ultimately, these H-Bridge circuits will help with directional control of our motors; however, speed control will be handled using pulse width modulation. [11]

PWM is the most common speed control method of motor drivers used within the industry for smaller DC motors, and it employs a fairly simple premise. A motor's speed will be at full capacity when being supplied with its particular voltage rating (12V for our DC motors) and will lessen the speed as the supplied voltage is decreased. The problem with this method is that the motor's torque will also decrease along with the speed. PWM solves this issue by sending pulses at the rated voltage to drive the motor. The pulse width will determine the speed of the motor, with the motor spinning faster with wider pulses, while the available torque will not drop because the voltage has not changed. It is important to note that PWM can cause certain negative characteristics if its frequency is too low: they include a jerky, inefficient, or noisy motor, but parts with low PWM frequency ratings are less expensive. As the frequency is increased the supplied power acts proportionally more like a continuous supplied DC voltage. It will be essential that the U.P.R.I.G.H.T include the capability for higher PWM frequency, to ensure that noise or jerky movement when the actuators are activated are not noticeable to the user. It is recommended that the frequency range be between 16-20 kHz. [12] Generally PWM is communicated with the motor controller through a microcontroller, utilizing various PWM and standard I/O pin configurations. These will be explored during selection. Both PWM and H-Bridge circuits will be utilized within the motor driver chosen for the U.P.R.I.G.H.T, which is explored more in the Motor Controller Selection section.

3.1.8 Display Panel Technology

This section will be focused on finding the best solution for displaying information to the user using a display panel technology. In our quest to enhance the interactive experience of our automatic standing desk, we will delve into a comparative analysis of various display panel technologies, aiming to identify the most suitable option for integration with our chosen microcontroller. This exploration will cover a range of technologies, each offering unique advantages in terms of visibility, power consumption, and interface compatibility. The contenders in this comparison are as follows:

- LCD (Liquid Crystal Display)
- OLED (Organic Light Emitting Diode)
- TFT (Thin Film Transistor) displays
- E-Paper displays

Our objective is to assess these technologies comprehensively, determining which aligns best with our project's requirements for an optimal user interface solution.

In the realm of display technologies suitable for integration with our chosen microcontroller, Liquid Crystal Display (LCD) panels stand out as a versatile and energy-efficient option. LCDs, characterized by their low power consumption and cost-effectiveness, offer a practical solution for projects that require text and basic graphical output. Their simplicity in interfacing with microcontrollers, through either parallel or serial (I2C/SPI) communication, makes them particularly appealing for embedded applications. The ease of integration is complemented by the availability of a wide range of sizes and configurations, from simple character displays to more complex graphical modules, allowing for flexibility in design according to our project's display requirements.

However, the utility of LCD technology comes with its limitations. The primary drawbacks include relatively low contrast ratios and limited viewing angles compared to more advanced display technologies like OLEDs or TFT LCDs. Additionally, LCDs typically require a backlight for visibility in low-light conditions, which can increase power consumption and affect the overall design compactness. The performance of LCDs under direct sunlight is also a concern, as readability can significantly diminish in bright environments. Despite these challenges, LCDs are still viable for our project because of their proven reliability, ease of use, and the ability to efficiently convey information without draining the power resources of the low-power microcontrollers available to us.

The next technology that will be discussed are OLED panels. OLED (Organic Light Emitting Diode) displays, with their self-illuminating pixels, offer unmatched contrast and color vibrancy, enhancing the visual appeal of any application. This technology allows for thinner, more flexible display options, making it an excellent choice for our project to implement an aesthetically pleasing design. The absence of a backlight not only contributed to energy efficiency but also enables true blacks, providing a significant boost to the display's dynamic range and overall image quality.

Despite these advantages, OLED displays have their drawbacks. They are typically more costly then LCDs, which may impact budget considerations for our project. Additionally, OLED screens can suffer from burn-in, where static images persist on the display over time, posing a challenge for interface with fixed elements. Their longevity is also a concern, as the organic materials used in OLEDs degrade faster than the inorganic materials of LCDs, potentially leading to dimming and color shifts. These factors necessitate a careful evaluation of the application's requirements and usage patterns to ensure that the benefits of OLED technology align with our standing desk's long-term needs and objectives.

The next technology that will be discussed are TFT displays. TFT (Thin Film Transistor) displays bring a significant enhancement in visual quality to the table, characterized by their high resolution and vibrant color depth. This leap in display technology ensures that applications requiring detailed graphics and accurate color representation are well-served, making TFT displays particularly suitable for applications where visual fidelity is paramount. The individual control over each pixel allows for sharp images and swift refresh rates, critical for rendering dynamic content and smooth video playback.

However, the benefits of TFT technology come with their set of challenges. The complexity of these displays leads to greater power consumption, which could be a limiting factor for portable devices powered by a variety of microcontrollers. Furthermore, the increased cost and technical demands for interfacing with TFT displays might pose budgetary and developmental hurdles. These factors necessitate a careful evaluation of project requirements against the backdrop of TFT technology's advantages and limitations, ensuring that the choice of display aligns with our project's goals and resource constraints.

The last technology to be discussed will be E-Paper displays. E-Paper displays, with their distinctive low-power consumption and paper-like readability, offer a unique advantage for devices prioritizing energy efficiency and legibility in various lighting conditions. This technology is particularly suited for applications where the display content changes infrequently, such as e-readers or digital signage, due to its ability to maintain an image without power.

However, the limitations of E-Paper, including slower refresh rates and predominantly grayscale output, make it less ideal for dynamic content or applications requiring vibrant color displays. While these displays excel in visibility and energy conservation, their application is best suited to specific use cases where these advantages align with our project's primary goals, highlighting a trade-off between display dynamics and power efficiency.

Taking into account all of the choices available to us for our project, it was decided that an LCD display will be chosen as the display panel technology to be used in our project. The decision to utilize an LCD for our desk project is driven by its optimal balance between performance, power efficiency, and cost. LCDs offer clear visibility and sufficient resolution for displaying user interface elements and information, which is essential for enhancing user interaction. Their low power consumption aligns with our goal of creating an energy-efficient device, ensuring prolonged use without frequent power needs. Additionally, the widespread availability and affordability of LCD technology facilitates ease of integration and maintenance, making it an ideal choice for our project's display requirements. Table 9 summarizes the display panel technologies considered along with their advantages and disadvantages. A summary of these findings can be found below:

Table 9 - Relevant Display Panel Technologies Comparison

Technology	Pros	Cons
LCD	Energy efficiency – 1-2 mA without backlight and up to 20 mA with LED backlight at 5V, cost-effective - $3-$5, longevity: lifespan of 50,000 to 100,000 hours	Limited viewing angles: typically around 60 degrees horizontally and vertically, slower refresh rates: typical refresh rates might range from 60 to 75 Hz
OLED	High contrast and color depth: often around 1,000,000:1, viewing angles: near-perfect angles close to 180 degrees, response time: typically around 0.1 milliseconds	Higher cost, susceptible to burn-in, shorter lifespan: typical lifespan is around 14,000 to 20,000 hours
TFT	Brightness: typically around 250 to 500 nits, cost: can be as low as $10 to $20 for small sizes	Viewing angles: usually around 70 degrees from the center, power consumption: typically ranging from 100 mA to 500 mA, contrast ratio: typically around 600:1 to 1,000:1, response time: generally around 5 to 16 milliseconds
E-Paper	Visibility: viewing angles close to 180 degrees	Slow refresh rates: typically several seconds, limited color capabilities: black and white color palette

3.2 Part Comparison and Selection

This section of Chapter 3 is mainly concerned with comparing the specific parts available for integration into the project. Since Section 3.1 dealt with technology selection and comparison, the parts in this section must fall within the category chosen for the specific technology outlined in Section 3.1. For example, because load cells were chosen as the appropriate pressure sensing technology to include in the mat, all of the parts mentioned in this section concerned with pressure sensing must be load cells.

This section has been divided into relevant subcategories to ease in navigation of this design document. The specific part selection and comparisons for the relevant technologies continue below.

3.2.1 Load Cell Selection

Since it was decided that load cells were the most appropriate technology to use for the pressure sensors under the mat, various considerations must be made the ensure that they will be effective in the overall operation of the system. The relevant considerations are outlined below:

- Capacity and Range
- Accuracy
- Sensitivity
- Environmental Conditions
- Physical Size and Shape
- Material Output Signal Type
- Calibration
- Compatibility with Electronics
- Cost and Availability

The first relevant consideration was capacity and range. It is important that the load cells have a maximum capacity that exceeds the highest expected force (including the weight of the user and any additional load they might place on the mat, such as their chair) to avoid overloading and damaging the sensor. The range should be appropriate for the smallest and largest force we anticipate measuring. A too high capacity might reduce sensitivity for detecting small weight changes. The main value that was taken into account here was 200 kg. It was determined that this was the maximum mass our load cells should be able to accommodate.

The next consideration was accuracy. We wanted to ensure the load cells could provide the resolution needed for our system. Higher resolution allows for more precise weight measurements. When taking this into consideration, it was important to look at the accuracy specifications, including non-linearity, hysteresis, and repeatability. These factors affect how closely the load cell’s measurements match the actual applied force.

The third consideration was sensitivity. The sensitivity of a load cell indicates how much electrical output (in millivolts per volt of excitation) changes for a given change in force. This is crucial for detecting subtle changes in weight distribution when determining if a user is sitting or standing.

The fourth consideration was environmental conditions. It is important to consider the environmental conditions where the desk will be used. Temperature, humidity, and the presence of any corrosive materials can affect the performance and lifespan of load cells. Some load cells come with environmental protection (e.g., waterproof or dustproof ratings).

The next factor to take into account was the physical size and shape of the load cells. The physical dimensions of the load cells must fit within the design constraints of our mat. Additionally, we needed to consider the mounting requirements and whether the load cells’ shape and size would facilitate easy integration.

The next step was looking at the material of the load cells. Load cells are typically made from aluminum, stainless steel, or allow steel. The choice of material impacts the load cells' durability, cost, and suitability for different environments (e.g., stainless steel is preferred for corrosive environments).

The seventh aspect that was taken into account when choosing appropriate load cells was the output signal type that was supported. Load cells can provide analog or digital outputs. Analog load cells typically output a millivolt signal proportional to the load, requiring additional signal conditioning. Digital load cells offer a direct digital output, simplifying data acquisition but potentially increasing cost.

The eighth consideration for our load cells was how they would be calibrated. Before choosing, we needed to determine how the load cells would be calibrated with the system. Calibration is critical for accurate measurements. Some load cells come pre-calibrated, while others may require setup with our specific hardware and software.

It was then time to check the chosen load cells' compatibility with our electronics used in the project, mainly the parts that would be included on our PCB. We needed to ensure compatibility with our planned data acquisition system. This includes matching the load cells' output signal type and voltage levels with the input requirements of our amplifiers, ADCs (Analog-to-Digital Converters), and microcontroller(s).

The final and one of the most important considerations that was taken into account was the cost and availability of the specific load cells chosen. We needed to consider the load cells in the context of our project's relatively limited budget. Also, we needed to assess the availability of the load cells, including lead times for delivery, which would impact our project timeline.

Finally, after taking all of these aspects into account, three load cells were chosen that fulfilled the requirements stated in this section. When the research was conducted into what parts were appropriate, it was determined that there was a cost/benefit analysis that needed to be done for the final parts. This was because there was no single load cell that could satisfy all of the requirements. For example, there were load cells that were looked at that fulfilled every requirement other than the physical size and shape constraints. Because of this, they had to be removed from consideration for that fact alone because they were too big to be integrated underneath/into the mat.

With the context provided in this section and the information included in Section 3.1, we finalized the potential load cells down to three potential candidates. Table 10 below is included to demonstrate the advantages and disadvantages of each, in order to justify the final choice selected for this section:

Table 10 - Part Comparison for Load Cell Selection

Feature/Specification	Load Cell 1	Load Cell 2	Load Cell 3
Capacity	3 – 200 kg (aluminum); 80 – 200 kg (alloy steel)	10 – 200 lb-f (50 – 1,000 N)	40 – 50 kg
Rated Output	1.0 ± 0.15 mV/V	Unamplified span sensitivity of 20 mV/V	1.0 ± 0.1 mV/V
Safe Overload	120% FS	2.5X rated	150% FS
Excitation Voltage	5 ~ 10 Vdc	1.00 – 6.0 V (Analog), 2.7 – 5.5 V (Digital)	≤ 10 V
Operating Temperature Range	-10 ≤ + 55 °C	-40 ~ + 85 °C	0 - + 50 °C

It was determined due to the specification and considerations made for how our system will function, that the load cells in column 4 would be the most effective for our system. The specifications above played a part in this selection as well as the price. They were by far the cheapest parts in terms of cost that made it to the final selection. Prices for load cells 1, 2, and 3 were $9.69 per unit, $34.68 per unit, and $4.50 per unit, respectively. The name for load cell 3 was the SEN-10245, manufactured by SparkFun Electronics.

3.2.2 Electric Linear Actuator Selection

This section will detail the various criteria needed of the DC linear actuators for the U.P.R.I.G.H.T desk, while exploring specific actuators and how they meet each of the criteria listed below. After careful consideration and a cost benefit analysis, a linear actuator type will be chosen for purchase. Further testing and implementation with the desk will be carried out to ensure that all specifications are met and detailed in chapter 9. Listed below are the criteria and specifications that each actuator will be checked for:

- Voltage Rating
- Max Current/Continuous current ratings
- Load Capacity
- Pushing/Retracting Force
- Stroke Length
- Speed
- Feedback Capability

There are two standard voltage ratings for DC linear actuators, 12V and 24V, both possessing unique properties and advantages. 24V actuators are characterized as having slightly better specs than their counterpart, because the 24V internal motor is able to generate greater torque with a higher voltage. This leads to greater possible speed, improved efficiency, and better load capability in relation to the 12V actuator. With enhanced specifications, higher voltage actuators are usually seen in industrial applications, not however without some tradeoffs. The major drawback is monetary, simply put 24V actuators require both better infrastructure and more specialized components to operate. This can be seen in the motors themselves, as the voltage increases more windings around the motor coils are needed to accommodate for the rise of voltage. Ultimately, 24V linear actuators cost more for their increase of efficiency.

These factors are why 12V DC linear actuators are mainly seen in less demanding applications, where they are more cost effective. If the specifications of 12V actuator meet the criteria of an application, not only will it save money for that project, but will also be more energy efficient than going overboard with a higher voltage rated actuator. This is one of the reasons that 12V linear actuators will be used in U.P.R.I.G.H.T., along with the cost saving for both the power supply and voltage regulators discussed in section 3.1.

The next criteria that must be considered is the max current and continuous current ratings of the actuator. These ratings will heavily influence the type of power supply and motor controllers compatible with U.P.R.I.G.H.T. Most 12V actuators on the market that meet our specifications fall somewhere in between 1-3 Amps for continuous use and 3-10A max rating. Generally, as the amperage rating increases so does the cost of power converters, motor controllers, and the actuator itself, however load capacity and speed will also increase. There is not a specific max current rating that is required for this project, and this is why it is important to cross-reference cost, ampere rating, and specifications for the specific actuators in question.

The third decisive factor necessary for U.P.R.I.G.H.T is load capacity, or how much static force the actuator can handle. For clarification, load capacity generally details the force an actuator can withstand while at rest, or when the locking mechanism is engaged. Max dynamic load capacity is the terminology for max applied force the actuator can generate while in motion. It is very important to read through the manufacturing specifications for each actuator because some utilize these two terms interchangeably while others do not. Some of the guides will say load capacity but mean thrust or the force the actuator can generate while in motion, whereas others will clarify load capacity as static and have a different value for max dynamic load. For the U.P.R.I.G.H.T, the required spec for load capacity will be a total of 600N dynamic load capacity with a load capacity that meets are exceeds that value.

Pushing and retractive force specifications are closely tied to dynamic load capacity, in that it specifies how much force an actuator can generate while extending the stroke or the amount of force it can pull a load while retracting the stroke. Generally, the value of these two are not the same, with pushing force capability ranging from slightly to extensively greater than the pulling capability. Some actuators do not include the ability for pulling a load at all. The U.P.R.I.G.H.T will not be used for the pulling functionality in an actuator because it will rely on gravity when retracting. The pushing capability, however, will need to match the load capacity spec of 600N, or slightly above 120 lbs.

The fifth specification is the stroke length, which will determine the possible positions that are feasible for the U.P.R.I.G.H.T. The general standards for standing desks are given by a sub-organization of ANSI (American National Standards Institute): the BIFMA (Business + Institutional Furniture Manufacturer’s Association). Please see chapter 4 for further details regarding standards. BIFMA writes a myriad of standards for standing desks, however, they only provide guidelines for typical heights. [13] Their recommendation is that standing desks be adjustable from a minimum of 22” to a maximum of 46.5”. However, the typical non standing desk on the market ranges commonly sits between 28”-30”. With these values in mind, the U.P.R.I.G.H.T will have an adjustable range from around 26”-28” to a max height between 44”-46”. A stroke length of 18” or 450mm on the linear actuators guarantees that our desk can meet this specification.

The next criterion of speed has many tradeoffs with the other required specifications. In order to meet our goal of 25mm/second velocity, these tradeoffs will have to be cross-examined to ensure that U.P.R.I.G.H.T will maximize power efficiency and cost savings. To fully understand this objective, further definition is required. Linear actuators max speed refers to when no load is present and while straining under load, velocity is inversely proportional to load force. Voltage rating has a direct impact on the speed capability of the actuator, as voltage increases so does its load capacity, max speed, and speed under load. However, there are still 12V models that can achieve the velocity goal, but they will draw more current, increasing the actuator current rating. This is important to take note of when researching specific linear actuators and keep in mind how the increase of current will affect other systems, as in power supply and motor control.

The last specification required for the U.P.R.I.G.H.T is whether the actuator has a feedback system, and what the type of feedback is. One of the most common feedback devices for linear actuators are potentiometers, or POT sensors. These utilize resistance, and the resistance will change as the stroke extends or retracts. The resistant value sent back as an output corresponds with the stroke’s position. The other typical feedback system utilizes hall sensors, which in simplistic terms is a magnetic sensor that outputs a voltage pulse every time a disk-shaped magnet spins a full 360 degrees. The magnetic disk is usually located in the gear box and its rotation is caused by the stroke moving. A feedback system is necessary in linear actuators for applications that require position tracking or synchronous utilization between multiple actuators. U.P.R.I.G.H.T will use two linear actuators, one for each leg of the desk, making feedback functionality a required specification.

Please see table 11 below for details regarding each linear actuator in question and how they perform for each criteria listed below:

Table 11 - Electric Linear Actuator Comparison

Linear Actuator	Progressive Automations Model: PA-14P-18-xx	Firgelli Automations Model: FA-OS-xx-12-18	Electric Linear Actuators Model: 0041670
Voltage Rating	12V DC	12V DC	12V DC or 24V DC
Max Current/ Continuous Current	Max Current: 5A No load current: 1A	Max currant: 5A	Max load current: 3-6A No load current: 1.5-3A
Load Capacity	Dynamic load is equal to static load. Load options (lbs): 35/50/75/110/150	Load capacity options: (lbs) 200/500/800	Dynamic Load capacity options: (lbs) 60/110/160
Pushing Force	Same as load capacity: (lbs) 35/50/75/110/150	Pushing force: (lbs) 35/200/400	Pushing force: (lbs) 60/110/160
Price	$150.00	$159.99	$145.00
Speed	Non-Load speeds (in/sec): 2.0/1.14/0.95/0.79/0.37 Full-load speeds (in/sec): 1.38/0.83/0.70/0.59/0.28	Non-load speeds: (in/sec) 2.0/0.3/0.3	Non-load speeds: (mm/sec) 50/30/20
Feedback System	Yes, Potentiometer system	Yes, Optical sensor system	Yes, Potentiometer system. Also include internal limit switches

In conclusion, the U.P.R.I.G.H.T will utilize the linear actuators from Electric Linear Actuators, specifically model 0041670. There were a few reasons for this, but the main one came down to the load capacity vs stroke speed constraint and the ability to create seamless transitions of the desk via speed of the actuators. This model was able to deliver a greater ratio between speed and load capacity, and still achieve the desired speed spec of 25mm/s while maintaining 60 or 110 pounds of load depending on the make. The actuator from Progressive was able to meet the speed specification with a load capacity of 50 pounds, while the model from Firgelli could only guarantee 35 pounds. The ratings given are also only from non-load speeds, and when any of these actuators are operating under a load, their speed capability will drop. For this reason, the Electric Linear Actuators with the non-load speed rating of 50mm/s and dynamic load capacity rating of 60lbs will be purchased for the desk, ensuring that both specifications for load (600N/120lbs) and speed (25mm/s) will be met.

3.2.3 Motor Controller Selection

This section will focus on the parameters that went into determining the particular motor controller to be utilized for the U.P.R.I.G.H.T, and why those specific parameters were important to the selection process. Now that the linear actuators have been researched and purchased, their electrical specifications will be the base line for determining factors. Also, as discussed in the Motor Control Technology section, the MCU will need to control the linear actuators speed and direction of movement through the motor driver, and this is accomplished with varied pin configurations between the two. There are not standard pin configurations for every motor controller, making this a factor that must be explored as well. Ultimately, the critical factors that will be discussed in this section are listed below.

- Motor Supply Voltage
- Continuous Current Rating
- Peak Current Rating
- Number of Channels
- Input Logic Voltage
- Pin Requirements
- PWM Frequency

It is absolutely essential that the first three factors for the motor controller accept the ratings of the actual motors, otherwise the PCB or motor controller will be damaged beyond repair. The linear actuators that were purchased for the U.P.R.I.G.H.T are utilizing 12V brushed DC motors that operate at a continuous current rating of one to five amps and a peak current rating of three to six amps. The reason that there is a wide range of current limits can be explained from the difference in current draw when there is no load or full load on the actuators. It is vital that the motor controller has bounds that exceed the upper limits of the DC motors, in both continuous and peak current. This will ensure smooth operation and mitigate any chance of damage to the controller or motors. Generally, there is a wide voltage range that the controller will accept making it less of a constraint when selecting the specific one, however it must still be verified that 12 volts falls within that range.

The number of channels ties directly into how many motors the driver can control, which this desk utilizes two DC motors, making it essential that the driver includes at least two channels. The input logic voltage should be similar to standard microcontroller voltages of 3.3V or 5V. It is important to verify that this voltage range is included in the specific driver that is selected. Another factor that must be considered is whether the voltage and current ratings are for the entire driver or just a single channel, in which case would need to be multiplied by two. The power efficiency of the motor controller is a factor not listed, but still important to investigate for each model. How efficiently the controller can convert the input logic PWM signals into the higher voltage supplying the motor, will determine the overall effectiveness of the DC motors. If any heat dissipation is required, from a lack of efficiency, the controller must be able to handle it through the use of heat sinks.

The MCU will need to communicate with the driver utilizing a certain configuration of PWM capable pins and standard I/O pins. This configuration of pins is different among various motor controllers. A general setup includes a PWM capable pin to send the pulse width modulation signal, and a couple I/O pins that will help communicate the desired H-bridge circuit for directional control of the motor. The employment of a MCU and its software for instructional communication to the driver is imperative to realize the quick, precise speed and directional instructions needed for automated functionality.

The final key factor that must be analyzed is the PWM frequency capability of each motor controller. The higher the rating, the more functional the motors will be in their operation, however at a high enough frequency the MOSFETs utilized in most designs will not keep up and start to miss pulses. [14] At high PWM frequencies, but at a lower frequency which this event occurs, motors tend to run smoother with less generated noise. There is not an optimal frequency however, and it will be important that the motors are tested at varying frequency to determine the ideal functionality of U.P.R.I.G.H.T. See Table 12 below for a table of the motor controllers in question.

Table 12 - Motor Controller Selection Comparison

Motor Controller	**Elecrow** **Model #ACS70028DH**	**DFRobot** **Model #DRI0041**	**Cytron** **Model # MDD10A**
Motor Supply Voltage	6-22V	Input: 6.5-27V Output: 7-24V	5-30V
Continuous Current Rating	8A per motor	7A per motor	10A per motor
Peak Current Rating	15A	50A	30A per motor
Logic Input Voltage	4.5-5.5V	3-6.5V	3.3-5V
Pin Requirements	(1) PWM and (2) I/O pins per motor channel	(1) PWM and (2) I/O pins per motor channel	(1) PWM and (1) I/O direction pin per motor channel
Cost and Availability	$16.00 In stock at elecrow.com	$21.59 @ RobotShop (1 stock)	$23.50 @ Cytron Marketplace (682 in stock)
PWM Frequency	Not listed	Minimum pulse width length of 5 microseconds	20kHz

All of the motor controllers in question were dual channel that utilized MOSFETs in their design, while those that used transistors were not included in the final consideration because of the large, blocky design necessary to incorporate heat sinks. The Elecrow driver was the most cost efficient, however it also did not specify PWM frequency rating and had the lowest peak current rating. When considering the peak current, or stall current, we wanted the driver in question to have about 30% greater rating than the motors. This puts the ACS70028DH right on the edge. Overall, the DFRobot DRI0041 and Cytron MDD10A met all the critical factors we were looking at, including a very high PWM frequency capability and plenty of current carrying capacity. The model from DFRobot however, had a 4-week lead time while the Cytron was in stock at multiple locations. This led us to choose the Cytron MDD10A and capitalize on the shorter ship duration with additional time for testing and prototyping.

3.2.4 AC/DC Power Converter

This section will explore the available options for AC/DC converters and the one that best fits for incorporation within the U.P.R.I.G.H.T. There will be several key criteria that the adapter must meet including voltage and wattage ratings, in order to provide proficient power for the system. Other considerations will include whether the voltage is regulated to provide a consistent voltage, connection types, and the type of converter: switching or linear. Ultimately, these criteria will be considered for each converter:

- Voltage Rating
- Wattage/Current Rating
- Efficiency
- Converter Type (Switching/Linear)
- Regulated/Nonregulated
- Temperature Rating
- Connection types/Rating

The electrical ratings of the converters are the most critical consideration because they must be able to sufficiently handle any power requirements for the desk. When it comes to voltage rating, the converter will have two separate ratings, one for the input voltage and the other as the output. The output is the crucial rating, as there are numerous different ratings across models of converters. As previously discussed in sections of 3.1, the linear actuators have the highest voltage rating and will consume the most power of any components within the U.P.R.I.G.H.T, and so the distribution of power throughout the system will need to start at 12V. This is the output voltage level that the AC/DC converter must be rated at for incorporation into the overall system.

In terms of the input voltage, most converters that we will be considering, are generally rated between 100V to 250V. There should not be an issue with the input rating of any of the converters because most of the device locations within electrical systems across the US are rated at 110V to 120V along a single phase. It should still be verified that this voltage falls within the converter’s input voltage rating, but ultimately the output must be 12V DC.

In regard to the wattage or current rating of the converter, it will be crucial that the rating not just meets the overall consumption of our system but exceeds it as well. It should be obvious that the converter be able to handle our system’s power specifications, if it is not the desk will try to pull more current than the converter can handle causing it to overheat and most likely destroy itself in the process. However, there are a few excellent reasons for utilizing a converter that not just meets the necessary specs, but also surpasses them. Most importantly, it all comes down to safety, because a converter not rated properly can easily become a fire hazard. According to Richard Campbell in an article for the NFPA (National Fire Protection Association) of the estimated 47,600 electrical home fires every year, approximately 8 percent are caused by transformers and power supply. [15] That would be just under 4000 every year, and it is vital that the U.P.R.I.G.H.T be designed with this in mind.

The issue with using a converter that just meets the power consumption exactly, it will heat up over time from continuous use. The reason for this occurrence stems from the fact that no converter is 100 percent efficient, and the wasted power is generally released as heat. As a converter heats up, it can easily damage its internal electronics, and depending on where it is located within the U.P.R.I.G.H.T, it could also cause damage to those parts located near it as well. This is reason enough to have increased current capacity rating with the desired converter.

Another significant reason to upsize the converter's current capability is to increase the overall design flexibility. In other words, it would make it feasible in terms of power consumption, to add other components and subsystems to the U.P.R.I.G.H.T, if necessary, at a future date. Ultimately, we will shoot to have a converter with a rating that can fully power the desk at peak consumption while only using 80 percent of the rated current. The linear actuators have a nameplate rating at 20W for normal usage but can spike up to 72W (6A*12V) when under a full load. Looking at Table 25 from section 6.3, we can see that the rest of the components incorporated within the design will consume far less than 0.1W. With linear actuators greatly exceeding 99 percent of power consumption, we can take the sum of their power ratings, round up and assume this rating for the entire system in the calculations: 72W + 72W = 144W, 145W / 0.80 = 181.25W. Therefore, the minimum power rating for the prospective converter will be 180W, or 15A current capacity at 12V.

Efficiency will be the next criterion that needs consideration for each AC/DC converter, which relates to how well the 120V AC is converted to 12V DC. This is an exceptionally important metric when designing a system that requires a high percentage of continuous operation. Most components of the U.P.R.I.G.H.T will be operated continuously; however, the linear actuators will not be. The motors within the actuators are actually rated for only 20 percent usage frequency. With the desk's automated features, a user would have to change positions nearly every minute while they worked to approach this kind of usage. This is a very unlikely scenario, and even if it were to occur, the power consumption of the entire system is still only under full load 20 percent of the time. This means that efficiency is not a critical factor when exploring options for converter. It is still important, because it will affect overall energy use and operation cost, but it should not have too much of an effect on safety: over 80 percent of the time less than a single watt will be consumed, leading to very minimal heat dissipated. Ultimately, greater efficiency is better, but if a converter model with greater efficiency has a negative tradeoff of significant cost or complexity to the design, it might not be worth it.

The converter type will be given greater consideration to the specific converter chosen, and there are two main types explored: linear and switching. These types are also discussed in greater detail within the voltage regulator selection section, though they are not exactly the same thing even though they share names. In terms of AC/DC voltage converters, the main difference between the two are that in linear ones the AC input is directly connected to a transformer before being filtered to a DC output, while in a switching converter the AC input is first rectified and filtered to a DC signal before connecting to a transformer to convert to the desired voltage level. There are a few pros and cons for both methods.

Starting with linear converters, because the input signal is directly connected to a transformer, these types of converters are generally less complex than switching types. As the name suggests, the electrical signal follows a linear progression as it is converted from AC to DC. After reducing the voltage level of the AC input with the transformer, rectifiers and filters are used to smooth out the sinusoidal signal to one that approximates a single line direct current. This is accomplished by rectifiers that shift up the sine curve that is alternating between positive and negative values, until it is alternating from a certain voltage level and zero. It then utilizes capacitor filters that smooth that line down by charging and discharging as the sine wave alternates, which outputs a mostly straight DC line that includes small voltage ripples caused by the charge/discharge of the capacitor. Very cheap converters will output this signal that was produced, but it is considered an unregulated converter at this point. (The effects from this will be discussed shortly with regulated versus unregulated converters) From this point, voltage regulators will be utilized to continue the process of smoothing out the signal and in order to supply a stable DC output. This type of converter is usually more cost effective because of its simple design, and does not produce noise, however it tends to be significantly less efficient than switching converters. [16]

Again, with this next type of converter, as the name suggests, it utilizes a switching mechanism, PWM (pulse width modulation), in its design. The AC input signal is first converted into a square wave using rectifiers and PWM before it is run through the transformer to the desired voltage level. Then additional rectifiers and filters are used to convert the square wave into a DC signals, while voltage regulators finish the process of creating a stable output. The reason that switching converters can achieve greater efficiency is tied directly to the complexity of its design. With the front-loaded processes before the use of a transformer, it allows for the use of smaller transformers and capacitors in comparison with linear converters. This is the key aspect of a more efficient design, however with the added complexity it increases overall cost. Not only that, but switching converters will also make noise, a distinct disadvantage, especially for applications that are sensitive to any kind of noise. With the U.P.R.I.G.H.T designed as user friendly as possible, this could be a dealbreaker, as it will detract from overall immersion and could easily distract the user.

The next factor discussed, regulated versus unregulated converters, will be considered in much the same way as efficiency was. Regulated converters will be preferred, however, the design for U.P.R.I.G.H.T will include additional voltage regulators regardless of the AC/DC converter chosen to be utilized. As previously discussed, unregulated converters output a signal that has not been filtered through voltage regulators, causing the output to have a greater voltage ripple and to be easily corrupted with heavy loads. With unregulated signals, there is nothing to stabilize an output if the input current increases, and because power is voltage times current, the power output might be stable but if additional current is drawn there will be a decrease in voltage, or voltage-drop. A varying voltage will be acceptable in some applications, for instance motors, but it can wreck sensitive electronics. This is one of the reasons that additional voltage regulators will be used in between the power source and MCU. If an unregulated converter seems to be the best choice, it is imperative that testing be completed to verify the range of output voltage of the converter before the voltage regulators are designed. This would be accomplished to match the variable output of the converter with the input rating of the regulator. [17]

In terms of temperature rating, most converters have a maximum temperature which they can function. This will not be a critical factor in determining the converter for a couple of different reasons. The main one being that this converter will be an external unit and will be placed far enough from the U.P.R.I.G.H.T's electronics so that any dissipated heat from the converter will not interfere with the MCU processes. With the desired rating of the converter being significantly higher than max power of the system and the infrequency of peak power usage, there should not be too much heat even generated, regardless of the efficiency of the converter. Overall, temperature should not be considered too heavily, except if a converter with efficiency of 60%-65% or lower is chosen.

Lastly, there are a multitude of different connection types with regard to AC/DC converters. As far as input is concerned, there is really only one type used in a few different ways. There will be a typical wall outlet plug (specific for whichever region you occupy, US, Europe, etc.) that will need to be plugged into a receptacle for AC power that is one of the following: already integrated within the converter, that has a specific connector that plugs directly into the corresponding connection, or has a wired lead that will need to be terminated into the screw terminals on the converter dedicated for the supply source. The output connections are a different story, because there are a multitude of different connection types from cigarette lighters, USBs, barrel connectors, screw terminals for individual physical wires, and more. Many of these connectors are specifically designed for certain products. When considering a connection type, it will be important to choose a model that uses a common connector that will be easy to integrate with the desk's system and has the necessary voltage and current ratings to match the converter.

Now that the critical factors have been discussed for choosing the AC/DC converter that best suits integration into U.P.R.I.G.H.T, see Table 13 below for specific models.

Table 13 – AC/DC Converter Selection

AC/DC Converter	LEDWholesalers Product 3262-12V	Linear Electric Actuators: Model 0010128	Mean Well USA Inc. GSM220A12-R7B
Watt/Current Rating	240 Watts 20 Amps	240 Watts 20 Amps	180 Watts 15 Amps
Efficiency	Not listed	Not listed	90%
Converter type	Linear Converter	Switching Converter	Linear Converter
Connection types	Barrel type 5.5x2.1mm DC Connector. With a 2.5mm adapter.	Screw type, Input and Output leads are sold separately	Power DIN 4Pin connector, Input lead sold separately
Pricing and Availability	$45.00-$47.00 458 available from LEDWholesalers	$40.00 Available at Linear Electric Actuators	$85.37 145 available at Digikey
Misc. Features	Short circuit protection Automatic thermal and overload cut-off	Short circuit protection Overload and over voltage protection. Built in cooling fan	Overload, over temperature, and over voltage protection.

There are three converters that were seriously considered for integration into the power system of the U.P.R.I.G.H.T. Quickly running through the specs of each one, starting with the 3262-12V from LEDWholesalers, it is an AC adapter that is rated for 240W/20A which greatly outpaces the 180W/15A specification goal. It is a linear converter with a common barrel type connection that should be easy to integrate and is marked at a reasonable price. All three of these converters are regulated and have built-in safety features, specifically included in the 3262-12V is short circuit, thermal and overload protection. The adapter from Mean Well USA is also a linear adapter that meets the required 180W rating at an impressive 90% efficiency. Neither of the other two converters listed their efficiency rating, but still claimed that their models had “high efficiency”. The GSM220A12-R7B is outfitted with a common DIN 4Pin connector, but lacks the lead to plug into a AC device. However, it does boast temperature, overload, and over voltage protection, but at a high price of $85. The model 0010128 from Linear Electric Actuators (their linear actuators were selected for the U.P.R.I.G.H.T) is the only switching converter under consideration. Its connections are screw type, allowing flexibility in design for power interconnections, and is reasonably priced. After consideration, the converter that will be used is the 3262-12V from LEDWholesalers. The main justification for this choice includes competitive pricing and a higher rating when compared to the GSM220A12-R7B. The rationale for this converter over the model 0010128 comes down to noise level. Not only will noise be generated from the switching aspect of the converter, but there is also a built-in cooling fan that will generate noise. As both the 3262-12V and the model 0010128 have the same power ratings, similar price point, and comparable protections, the fact that the 3262-12V should run quietly is the key factor for integration into the U.P.R.I.G.H.T.

3.2.5 Microcontroller Selection

At the outset of our senior design project, the selection of the microcontroller (MCU) quickly emerged as a pivotal decision, foundational to the project's success. This choice was critical, as the MCU not only dictates the operational speed and efficiency of our system but also establishes the compatibility and integration capability with peripheral devices and sensors, thereby defining the range and complexity of functions that can be implemented in the project. Moreover, the selected MCU's memory capacity would directly impact our ability to develop and store complex software solutions, making the availability of robust documentation, a supportive Integrated Development Environment (IDE), and comprehensive libraries indispensable for efficient troubleshooting and development. Aware of the potential pitfalls of an ill-suited MCU, ranging from hardware incompatibilities to software limitations, our team prioritized this decision. We embarked on a thorough evaluation of MCUs, considering not only their technical specifications but also the ecosystem surrounding them, including development tools, community support, and scalability for future enhancements. This comprehensive strategy ensured our choice would facilitate a seamless integration of components, establishing a solid foundation for a system that operates in harmony and meets our project's ambitious goals.

Our microcontroller will be in charge of communicating/receiving inputs from a variety of peripherals including push buttons, a DC motor controller which is attached to two linear actuators, receiving feedback from the onboard potentiometers aboard the actuators, sending and receiving data from a raspberry pi, controlling a display panel, receiving input from our load cell sensors, and possibly several others. Thus, the communication protocols and features of our MCU are very important in order to host such a variety of peripherals. We plan on using all of the three major communication protocols in our project which our Serial Peripheral Interface(SPI), Universal Asynchronous Receiver Transmitter (UART) and Inter-Integrated Circuit (I2C). Based on the requirements of our project these three protocols should serve us well in terms of interfacing with the majority of peripherals we plan to include. However, each of the protocols have their own strengths and weaknesses, so we also would like to maintain flexibility in our design and give ourselves room to add extra peripherals or adapt if one communication protocol turns out not to be best suited. So, it would be ideal if the MCU we choose would have multiple options for each of these protocols. Another consideration is the possible need to employ an Analog to Digital Converter in our design. There is a chance the DC motor controller might have this included but we would once again, like to give ourselves room to learn and experiment. Another consideration for the motor controller is the likely need to employ Pulse Width Modulation (PWM) in order to control our linear actuators at precise speeds of our choosing at a constant and steady rate. Thus, we would like to have multiple options for PWM channels as well.

In our project, the chosen microcontroller will manage communications and inputs from a diverse array of peripherals, including push buttons, a DC motor controller connected to two linear actuators, potentiometers on the actuators for feedback, a Raspberry Pi for data exchange, a display panel for user interaction, and load cell sensors for weight measurements, among potential others. Consequently, the microcontroller's support for various communication protocols is crucial to accommodate this wide range of peripherals. We intend to utilize the three primary communication protocols: Serial Peripheral Interface (SPI), Universal Asynchronous Receiver Transmitter (UART), and Inter-Integrated Circuit (I2C), which are anticipated to meet most of our interfacing needs with the planned peripherals. Nevertheless, recognizing the inherent strengths and limitations of each protocol, we aim to incorporate design flexibility to easily integrate additional peripherals or switch protocols if necessary. Therefore, selecting a microcontroller that offers multiple channels or options for SPI, UART, and I2C is a priority. Additionally, we are considering the inclusion of an Analog to Digital Converter (ADC) in our design, to accommodate sensors that provide analog outputs, noting that the DC motor controller might already feature this capability. Additionally, precise speed control of the linear actuators, achievable through Pulse Width Modulation (PWM), necessitates a microcontroller with ample PWM channels. This will allow us to adjust the actuators' speeds accurately and maintain a consistent rate.

Another similar, but equally important aspect to consider when choosing our MCU are the availability of general-purpose input/output (GPIO) pins. Most MCU’s we have been researching have at least 20 GPIO pins which would likely accommodate our needs; however, we recognize things could change at any time during our prototyping phase. We also recognize that the total number of GPIO pins listed on an MCU’s specifications sheet could be deceiving at first glance. For example, many of the pins that are labeled as GPIO have multiple functionalities and are tied to important functions such as PWM or ADC. So we have decided to aim for a board with more than enough GPIO pins.

Another similar, but equally important aspect to consider when choosing our MCU are the availability and versatility of general-purpose input/output (GPIO) pins. While most MCUs we've evaluated include a baseline of around 20 GPIO pins, likely sufficient for our initial design, we're mindful that project requirements could shift unpredictably during the prototyping phase. It's important to recognize that the total GPIO count provided in an MCU's spec sheet might not offer a complete picture; many GPIO pins are multifunctional, serving essential roles in specialized tasks such as Pulse Width Modulation (PWM) or Analog to Digital Conversion (ADC), which could limit their availability for generic I/O purposes. Therefore, we're inclined to select an MCU offering an ample number of GPIO pins, surpassing our present needs. This strategy aims to afford us the flexibility to accommodate unforeseen changes and additions to our project, ensuring we're not restricted by hardware limitations.

Memory considerations play a pivotal role in ensuring our design remains flexible and scalable without being constrained by codebase size or the inclusion of various libraries. Our investigation into memory requirements revealed the challenge of estimating the precise memory footprint for our microcontroller (MCU), as it's influenced by both our code and the libraries we incorporate. Given that modern compilers optimize through link time optimization (LTO) by only including necessary library components, memory management becomes more efficient. However, we're planning to choose an MCU with ample memory to ensure we have the freedom to use any libraries we find useful without memory constraints. This decision, aimed at future-proofing our project, allows us to focus on developing logical and efficient solutions within our time constraints, rather than rewriting code or eliminating libraries due to memory limitations as our Senior Design project progresses. Small projects might suffice with 32KB to 64KB of flash memory but considering our need for a range of functionalities and the inclusion of various libraries, opting for an MCU with at least 128KB to 256KB of flash and 16KB to 64KB of RAM would provide a comfortable buffer. This generous memory allocation ensures our project remains robust and adaptable, supporting our evolving requirements and facilitating innovation and growth without hardware restrictions.

In selecting the clock speed for our microcontroller (MCU), 16MHz emerged as a well-considered baseline, informed by an evaluation of low to medium-end MCUs used in various home-based and educational projects, including notable development boards like the Arduino Uno Rev3 and the MSP430FR6989 LaunchPad, both of which operate at this speed. This choice was reinforced by our firsthand experience with the MSP430 in an embedded systems course, where it proved adept at handling a wide range of tasks, from interfacing with sensors to managing communication protocols, suggesting that 16MHz is sufficiently robust for diverse applications. While the adage 'more is almost always better' often holds in the context of MCU specifications like clock speed and memory—especially when considering budgetary allowances and desired functionalities—this principle is counterbalanced by considerations of energy consumption. Higher clock speeds, while potentially enhancing performance, significantly increase power demand. Therefore, if opting for an MCU with a clock speed substantially above 16MHz, careful attention to power management strategies, such as utilizing clock dividers and low-power operational modes, becomes crucial to maintain efficiency and reliability. Consequently, 16MHz stands as our preferred minimum, guiding us toward selecting the highest feasible clock speed within our project’s specifications and budget constraints, aiming for a balance between performance, cost, and energy efficiency, and ensuring our system is both adaptable and capable of scaling with project demands.

As we delve into our system’s design, a pivotal aspect we’re evaluating is the need for multiple cores or the integration of a real-time operating system (RTOS) functionality. Opting for FreeRTOS, a lightweight, open-source RTOS, could afford us granular control over task management and the ability to employ multithreading, ensuring seamless task execution without interference. However, the necessity of implementing an RTOS like FreeRTOS in our project warrants further exploration. Effective task scheduling and resource management might also be attainable through a meticulously structured software approach, utilizing timers and interrupts for efficient task switching. This consideration necessitates additional research to fully understand our project's requirements. Ideally, we aim to choose a microcontroller (MCU) that keeps our options open, allowing us the flexibility to incorporate an RTOS, should our project's complexity and performance criteria demand it.

Additionally, deciding on the microcontroller unit for our project, a pivotal consideration for our group was the richness of learning resources, community support, and the extent of documentation available. Given the venture into largely uncharted territories for our team members, the accessibility to resources that facilitate self-education on necessary technologies and features is paramount. We are inclined towards selecting a board that not only is compatible with comprehensive integrated development environments (IDEs) but also boasts a substantial library ecosystem to mitigate our learning curve amidst the tight deadlines of our senior design project. Achieving a balance between user-friendliness and complexity to deliver a sophisticated, fully functional project within our time constraints is critical. This balance is also vital for arming us with the knowledge and practical experience necessary for a smooth transition into the professional realm post-graduation. The temptation to default to components with extensive Arduino library support for their simplicity is considerable. Nonetheless, opting for the path of least resistance without due forward-thinking introduces inherent risks, including limited portability, scalability challenges, potential negative perceptions among industry professionals, and compromised real-time performance. That said, outright dismissal of the Arduino platform may be premature. Investigating ways to harness Arduino libraries within a more advanced IDE could present a balanced solution, though this avenue demands further exploration to ensure seamless code compilation. On the other hand, choosing an MCU with lacking community support, sparse documentation, or a limited selection of libraries could severely hamper our project's progress, potentially derailing our timeline over trivial issues. Thus, our search is for a professionally challenging yet accessible MCU option that doesn't necessitate reinventing the wheel for each aspect of our implementation. This strategy aims to not only meet our project's immediate needs but also ensure we're well-prepared for future professional challenges, combining the drive to push our technical boundaries with the practical necessity of timely project completion.

One of the final, yet crucial, considerations for selecting our microcontroller unit hinges on the availability of a consistent and reliable inventory. The ideal MCU for our project becomes meaningless if we're unable to procure it in time for the prototyping phase and subsequent construction of our printed circuit board (PCB). Therefore, our strategy involves shortlisting several viable MCU options and researching both their market availability and cost per unit. Price, of course, plays a pivotal role in a project like ours. While individual components priced at ten or twenty dollars might seem economical at a glance, the cumulative cost can escalate rapidly, significantly impacting the overall budget by the project's end. This consideration is especially poignant for us as students operating without substantial financial resources, emphasizing the necessity of frugality in our project management. Moreover, this practice mirrors a critical aspect of project planning in the professional realm; the industry constantly grapples with the delicate balance between cost and performance. Optimal component selection goes well beyond mere technical suitability, entailing a careful evaluation of financial implications. Indeed, superior performance is always within reach with a higher expenditure, yet adhering to a predefined budget is paramount. Overspending can jeopardize the project's viability, rendering it unattractive or impractical from a commercial standpoint. Consequently, our decision-making process not only reflects our immediate academic objectives but also instills a foundational principle of project management in the industry: the imperative to balance technical requirements with economic constraints, ensuring the deliverable remains within budgetary bounds while meeting or exceeding performance expectations. Table 14 below summarizes our considerations.

Table 14 – Comparison of Acceptable Microcontroller Options

Microcontroller	**ATmega328P (PDIP)**	**MSP-430FR6989**	**ESP32-WROOM-32E-N8**
Clock Speed	16 *MHz*	16 *MHz*	240 *MHz*
Communication Protocols	6 PWM 1 USART 1 SPI	14 PWM 2 UART 4 SPI	16 PWM 3 UART 4 SPI
GPIO	23 GPIOs	83 GPIO	26 GPIO
Memory	32KB Flash 2KB SRAM	127KB FRAM 2KB RAM	8MB Flash 520KB SRAM
Operating Voltage	1.8 - 5.5 V	1.8 - 3.6V	3 – 3.6V
Availability	49,053 in stock on Mouser $2.65 each	990 In stock on Mouser $8.70 each	1,270 in stock on Mouser $2.80 each

After careful consideration, our group has selected the MSP430FR6989 as our MCU of choice, over the ATmega328P and ESP32-WROOM-32E-N8. The ATmega328P was not selected primarily due to its lack of memory compared to the other two options. Despite its higher cost, the MSP430FR6989's extensive GPIO capabilities, with 83 pins, and its diverse communication protocols (SPI, UART, I2C) afford us the desired flexibility. It should be noted that although the MSP430-FR6989 MCU is more expensive, we will be saving money in the development phase due to one of our team members already owning a development board with this MCU incorporated. While its 16MHz clock speed is slower than the ESP32's 240MHz, we deem it sufficient for our project's needs, particularly given our group's prior experience with this MCU and Dr. Abichar's expert guidance. Although the RTOS support for the MSP-430fr69 is less robust than the ESP32's, we are exploring workarounds for efficient task management if needed. This decision, summarized in Table 15, balances our technical requirements, project familiarity, and expert support, positioning us for successful project execution.

Table 15 – Overall Comparison of Acceptable Microcontroller Options

Microcontroller	ATmega328P (PDIP)	MSP-430FR6989	ESP32-WROOM-32E-N8
Clock Speed	16 *MHz*	16 *MHz*	240 *MHz*
Communication Protocols	6 PWM 6 10-bit ADC 1 USART 1 SPI 1 I2C	14 PWM 16 12-bit ADC 2 UART 4 SPI 2 I2C	16 PWM 18 2*12-bit ADC 3 UART 4 SPI 2 I2C
GPIO	23 GPIOs	83 GPIO	26 GPIO
Memory	32KB Flash 1KB EEPROM 2KB SRAM	127KB FRAM 2KB RAM 256B ROM	8MB Flash 520KB SRAM 448KB ROM 16KB SRAM in RTC
Power Consumption	Operating Voltage: 1.8 - 5.5 V Operating Current: 0.2mA Active Mode 0.1uA Power-down Mode 0.75 uA Power-save Mode	Operating Voltage: 1.8 - 3.6V Operating Current: 100uA/MHz Active Mode 0.4uA (typical) Standby 0.2uA (typical) Shutdown	Operating Voltage: 3 – 3.6V Operating Current: 5uA Hibernation Mode
Availability	49,053 in stock on Mouser $2.65 each	990 In stock on Mouser $8.70 each	1,270 in stock on Mouser $2.80 each
IDE	Arduino, Atmel Studios	CCS	VSC with ESP32-IDF ESP32-IDF Arduino
Additional Features	Arduino Libraries are built with this chip in mind Mounting style: through hole	Experience with via coursework, Dr. Abichar's recommended choice Mounting Style: SMD/SMT	FreeRTOS support, Dr. Weeks's recommended choice Mounting Style: SMD

3.2.6 Button Switch Selection

For the purpose of manual desk control and Bluetooth connectivity initiation, we determined the necessity for at least three buttons. Although the selection process appeared straightforward due to the fundamental nature of this component, the extensive variety of available button and switch options necessitated careful consideration to identify the most suitable choice. The primary factors in our decision-making process included:

- Category
- Termination Style
- Circuit
- Switch Function
- Mounting Type
- Dimensions/Aesthetics

- Price/Availability

In the initial phase of selecting suitable buttons for our design, we focused on two primary categories: tactile switches and pushbutton switches. Tactile switches are distinct for their feedback mechanism, which provides users with a noticeable response through either an audible sound or a physical click sensation upon activation. These switches tend to be smaller and more cost-effective compared to their counterparts. On the other hand, pushbutton switches constitute a broader category, offering a wide array of options. While some pushbutton switches incorporate tactile feedback, integrating this feature significantly increases their cost, rendering them impractical within the constraints of our budget. Therefore, pushbutton switches with tactile feedback were excluded from further consideration. It became clear that pushbutton switches were available in a wider array of sizes and features, potentially simplifying the project's development. The specifics of these features will be elaborated on in the following sections.

The next considerations were termination style and mounting type. Termination style refers to how the switches are attached to a circuit board. Envisioning our buttons as non-soldered to the PCB provided the desired flexibility for housing design and seeing many push buttons with "wire leads" termination style confirmed their suitability for our project, promising ease of assembly and design adaptability. The choice of mounting type was directly influenced by our connection strategy for the switches to the PCB and their placement on the desk for user convenience. Opting for a 3D printed mount/cover for the button installation, we found the "panel mount, front" type to be especially fitting, designed specifically for accessible and straightforward integration, aligning perfectly with our project's requirements.

Next, we considered the switch circuit and function. The switch circuit refers to the electrical layout, detailing the connections and their operational dynamics. We selected the "SPST-NO" (Single Pole Single Throw - Normally Open) configuration for its simplicity and directness, offering a single pathway for current that is either made or broken upon activation, aligning perfectly with our design goals. For switch function, "Off-Mom" (Off-Momentary) was identified as the ideal choice, maintaining the switch in an 'off' state by default and temporarily switching to 'on' when pressed. This functionality suited our requirement for momentary user interaction, such as adjusting desk height or initiating Bluetooth pairing.

The aesthetic and functional aspects of the buttons, including their dimensions, were pivotal in our decision-making process. Figure 4 visually depicts each option side-by-side. Aiming for a blend of professionalism and user-friendliness in our desk design, we opted for buttons that were not only large enough for easy operation but also complemented the desk's aesthetics. A circular, possibly domed design, with dimensions of at least 10mm, was chosen to meet these criteria. Additionally, we explored potential for illuminated buttons, recognizing the possible utility of such a feature in low-light conditions.

Figure 4 - Side by side Visual Comparison of Buttons [18] [19] [20]

Concluding our selection process shown in Table 16, availability and cost became our final considerations. While tactile switches emerged as the most economical option, their limited features made us explore other avenues to ensure a quality user experience, given that these buttons are the primary interface for users interacting with the desk. We set a budget threshold of less than $10.00 per button, balancing cost-efficiency with the necessity for durable and reliable components. Additionally, ensuring a sufficient supply was crucial; we required the availability of at least a hundred units to proceed confidently, securing our project's timeline and feasibility.

Table 16 - Button Comparisons

Feature	PB6B2RS2M1CAL00Y500	RP8100B2W1CEBLKBLK BLU	320.02E11.09BLK
Category	Pushbutton Switch	Pushbutton Switch	Tactile Switch
Termination Style	Wire Leads	Wire Leads	PC Pin
Illumination	N/A	LED, Blue	N/A
Circuit	SPST-NO	SPST-NO	SPST-NO
Mounting Type	Panel Mount, Front	Panel Mount, Front	Through Hole
Dimensions	Panel Cutout Circular – 13.60mm Dia	Panel Cutout Circular – 13.60mm Dia	12.40mm x 12.40mm
Price/ Availability	>1000 in stock from Digikey $8.73 each	449 in stock from Digikey $8.22 each	886 in stock from Digikey $2.63 each

After thorough consideration, we chose the PB6B2RS2M1CAL00Y500 pushbutton switch. The pushbutton switch offered the necessary features and flexibility, significantly more so than the tactile option. Its wire leads termination style provides the added benefit of allowing for easy adjustments during the design and assembly process. We ultimately determined that the illumination feature of the RP8100B2W1CEBLKBLKBLU was superfluous, considering the minimal quantity of three buttons and their installation in positions that are readily visible and accessible to the user. While the tactile button was a viable, cost-effective choice, it did not meet our user experience and design feature criteria, leading us to favor the pushbutton that best matched our envisioned look and functionality.

3.2.7 Raspberry Pi

The project goal is to create a smart ergonomic tracking desk. One such feature discussed was to determine if a user is present using facial tracking. The software and library selected was decided in Section 3.2.11 and Section 3.2.10. To run the facial tracking software, Raspberry Pi was selected because of the wide capabilities and community support of the device. Raspberry Pi Foundation in the United Kingdom created a series of single-board computers called Raspberry Pi. The goal of this foundation was to make computing education more accessible by creating an affordable computer. The basis of Raspberry Pi runs Linux and typically consists of general-purpose input/output pins that allow the user to control a multitude of electronic components for physical computing. There are five main Raspberry Pi models currently but only the latest 3 models will be compared and selected for this project. [21]

3.2.7.1 Raspberry Pi 3 Model B

Raspberry Pi 3 was released in 2016 and is the third-generation model in the series. This series features a Quad Core 1.2GHz Broadcom BCM2837 64bit CPU. A bonus of this system is the affordability of the system. This allows individuals around the world to learn to build hardware and programming projects. With this wide range of affordability there is a lot of user support. Since this is a few generations old that means this version is very stable since there are a few firmware updates that address some of the concerns with new models. One downside to this model is the limited amount of memory it comes with. This is due to keeping the model affordable, but this may make it not suitable for some projects. The main communication between the mobile and desktop application with the desk tracking features is going to be through Bluetooth. So, it is important that the Raspberry Pi model used can use Bluetooth. This model does come with a Bluetooth Low Energy (BLE) which is a lower power consumption Bluetooth that is also referred to as Bluetooth 4.0. [22]

3.2.7.2 Raspberry Pi 4 Model B

Raspberry Pi 4 is the fourth-generation model in the series that was released in 2019. This model comes with Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz. This model is sold with different sizes of RAM such as 1GB, 2GB, 4GB or 8GB. It also has 2 USB 3.0 ports that allow for faster data transfer. Another bonus feature of this model is that there are two power sources via USB-C and GPIO header. This model also comes with both Bluetooth 5.0 and Bluetooth Low Energy (BLE) [22].

3.2.7.3 Raspberry Pi 5

Raspberry Pi 5 was the most recent model that was released in October 2023. This latest generation features a Broadcom BCM2712 quad-core Arm Cortex A76 processor @ 2.4GHz. A few notable new features of Raspberry Pi 5 are that it comes with a power button, Real-time clock (RTC), and UART debug port. This model was also built with what is known as the RP1 I/O controller. The package also has silicon that was designed by Raspberry Pi. [22]

3.2.7.4 Comparison & Selection between the Models

The main functionality of the Raspberry Pi in this project is to run the facial tracking software and to relay information between the MCU and the mobile application. The main requirement for this is Bluetooth communication and the ability to run the face tracking software that was selected in Facial Tracking Software Selection. One requirement to download the library selected is at least 4GB of RAM. This automatically eliminates the Raspberry Pi 3 B because it only comes with 1GB of RAM. The last two models are very similar with the CPU of Pi 5 being much faster. Although the Pi 5 has a fast-processing speed, this is not needed to run the facial tracking software. The next consideration was cost. In this category, Raspberry Pi 4 B was cheaper compared to Pi 5. With the rest of the capabilities being similar the Raspberry Pi 4 B was chosen due to the cheaper price. A summary of this selection process is shown in Table 17. [23]

Table 17 - Raspberry Pi Comparisons

Model	CPU	RAM	Wi-fi	Bluetooth	Cost
Raspberry Pi 3 B	Quad Core 1.2GHz Broadcom BCM2837 64bit CPU	1GB	802.11n	4.1 Bluetooth Low Energy (BLE)	$41.09
Raspberry Pi 4 B	Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.8GHz	1GB, 2GB, 4GB, 8GB	2.4GHz / 5GHz 802.11ac	Bluetooth Low Energy (BLE) / Bluetooth 5.0	$55.00
Raspberry Pi 5	Broadcom BCM2712 quad-core Arm Cortex A76 processor @ 2.4GHz	4GB, 8GB	2.4GHz / 5GHz 802.11ac	Bluetooth Low Energy (BLE) / Bluetooth 5.0	$60.00

3.2.8 Display Panel Selection

This section will focus on the parameters that went into determining the display panel selection for the project. The relevant considerations are outlined below:

- Technology
- Supported Interface(s)
- Physical Size
- Power Characteristics
- Ease of use
- Graphical Flexibility
- Controller used for programming
- Availability/Price

The initial factor in our display selection process is the underlying technology, which directly affects performance attributes including response time, color representation, and viewing angles. Our project intends to employ an LCD display, but we're expanding our scope to include TFT LCD displays as potential options. A TFT LCD can provide a vivid, high-resolution image, perfect for intricate graphics such as project logos and personalized welcome messages. This capability could significantly elevate the user interface and branding experience. On the other hand, a standard character LCD, with its more basic output, aligns well with the fundamental requirement of showing the desk's height setting. While a character LCD would adequately fulfill our primary need, opting for a TFT display could afford us additional creative latitude to offer users an aesthetically richer interaction, should we choose to prioritize an enhanced visual engagement over simplicity.

The interface of the display panel plays a pivotal role in determining the ease of integration with our desk's control system. To conserve GPIO pins on our microcontroller unit (MCU), we have prioritized displays compatible with either SPI or I2C protocols—both of which are efficient in terms of pin usage. The choice between these communication protocols will also influence the intricacy of coding required for interaction between the MCU and the display. Opting for a TFT display necessitates more sophisticated programming to handle its rich graphical output, while a 16x2 character LCD, with its straightforward character-based output, promises a less complex implementation. Our decision will hinge on finding a balance between the desired functionality and the development resources available, ensuring streamlined communication within the device's architecture without overcomplicating the system.

The dimensions of the display panel are a key factor, as they need to complement the desk's design both functionally and visually. An optimally sized TFT display can offer enriched content and interactive opportunities, albeit at the expense of increased power usage and the necessity for more installation space. In contrast, the more compact character LCD, with its lower power requirement, offers a subtler presence. The display will be positioned under the desk surface, ensuring that the information is easily viewable without requiring users to adjust their posture. It's essential that the display is neither too small, which would make it difficult to read, nor excessively large, which could become obtrusive and not economical given the limited amount of information it needs to convey. A visual comparison of the displays is shown in Figure 5. The goal is to strike a balance that maximizes visibility and utility while minimizing distractions, power consumption, and costs.

Figure 5 - Side by side Visual Comparison of Displays [24] [25] [26]

Power consumption is a critical factor in our choice of display panel, especially considering our requirement for a backlight to ensure visibility regardless of ambient lighting. TFT displays generally have higher power needs, not just for the display itself but also for the backlighting that enhances visibility. Character LCDs, while more modest in power demand, also are available with backlighting for clear readability in any lighting condition. Although our standing desk will be powered via a wall outlet, which eases concerns about power limitations, energy efficiency remains a priority. Therefore, the decision between a power-intensive TFT and a more energy-efficient character LCD will also factor in the potential impact on overall energy consumption of the desk.

When considering ease of use, we are focusing on the programming aspect for our development team. Character LCDs typically offer a straightforward programming interface, which could accelerate development and simplify troubleshooting. Their simplicity would allow us to efficiently program the functionality needed to display the desk height setting. On the other hand, programming a full-color TFT display would be more complex due to its rich graphical capabilities. While this complexity could enhance the end-user experience with visually appealing interfaces, it requires more time and expertise to implement. Since our standing desk project demands a balance between functionality and development efficiency, we must weigh the benefits of a TFT's advanced features against the simplicity and quicker implementation time of a character LCD.

The selection of the display panel's controller is a significant consideration, as it directly influences our programming approach and the development timeline. A controller that has widely available drivers and libraries can greatly enhance our productivity, reducing both the learning curve and the time spent on development. For instance, a controller with substantial community support and pre-existing code examples would allow us to quickly integrate the display with our standing desk's system, streamline the coding process, and focus on refining user features. Therefore, while evaluating our display options, we are giving preference to those with controllers backed by robust support and resources, ensuring we can leverage these advantages to expedite our project's progress.

For the final consideration, availability and cost are of paramount importance. Ensuring that our chosen display is in stock avoids delays in development and keeps our project timeline on schedule. Equally critical is adhering to our budget, particularly during the prototyping stage and subsequent production of our final design. We seek a display panel that is both economically priced and readily available, allowing us to manage our resources effectively and avoid costly hold-ups. This pragmatic approach will facilitate a seamless development process and contribute to the overall financial feasibility of project. Table 18 and Table 19 summarize this decision process.

Table 18 –Display Panels Comparisons

Feature	**CFAF128128B1-0145T**	**CFAF80160A0-0096TN**	**NHD-C0216CZ-NSW-BBW-3V3**
Technology	Full Color TFT, 128 x 128 Dot Matrix	Full Color TFT, 80 x 160 Dot Matrix	COG (Chip-on-Glass) 16 x 2 Character LCD
Interface	SPI	SPI	SPI or I2C
Size (W x H x D) (mm)	Module Dimension: 33.3 x 38.2 x 2.3 Active Area: 25.498 x 26.496	Module Dimensions: 13.5 x 27.95 x 1.54 Active Area: 10.8 x 21.696	Module Dimension: 41.4 x 24.3 x 4 Active Area: 37.6 x 12.8
Controller (integrated)	Sitronix ST7735S	Sitronix ST7735S	Sitronix ST7032
Availability/ Price	>1000 in stock from Crystalfontz $9.21 each	>1000 in stock from Crystalfontz $12.58 each	>1000 in stock from Mouser $12.75 each

After careful consideration of the factors most relevant to our project's needs, we have decided to select the CFAF128B1-0145T display panel. This decision was influenced primarily by its cost-effectiveness, as it was the most affordable option among the three considered. Additionally, the CFAF128B1-0145T is a full-color TFT LCD display, which offers greater flexibility and customization than the alternatives. While the NHD-C0216CZ-NSW-BBW-3V3 16x2 character LCD would have presented a simpler software integration, its limited functionality and higher cost compared to the other options made it less desirable. Among the remaining TFT LCD displays, which shared the same integrated controller, we preferred the dimensions of the CFAF128B1-0145T for aesthetic reasons, leading to its selection for our project.

Table 19 – Detailed Display Panels Comparisons

Feature	CFAF128128B1-0145T	CFAF80160A0-0096TN	NHD-C0216CZ-NSW-BBW-3V3
Technology	Full Color TFT, 128 x 128 Dot Matrix	Full Color TFT, 80 x 160 Dot Matrix	COG (Chip-on-Glass) 16 x 2 Character LCD, White Backlight
Interface	SPI	SPI	SPI or I2C
Size (W x H x D) (mm)	-Module Dimension: 33.3 x 38.2 x 2.3, -Active Area: 25.498 x 26.496	-Module Dimensions: 13.5 x 27.95 x 1.54 -Active Area: 10.8 x 21.696	-Module Dimension: 41.4 x 24.3 x 4 -Active Area: 37.6 x 12.8
Power Characteristics	-Supply Current for LCM (3.3V): 1.7 Typ, 2.55 Max mA, -Input High Voltage: 0.7 * VDD Min, VDD Max V, -Backlight Supply Current (3.2V): 20 mA Typ, -Backlight Supply Voltage: 2.7 Min, 3.0 Typ, 3.3 Max V	-Supply Current for LCM (3.3V): 2.0 Max mA, -Backlight Supply Current (3.2V): 20 mA Typ, -Backlight Supply Voltage: 2.8 Min, 3.0 Typ, 3.3 Max V	-Supply Current (3.3V): 40 Min, 170 Typ, 300 Max uA, -Supply for LCD (contrast): 5.2 Min, 5.5 Typ, 5.8 Max V, -Backlight Supply Voltage: 3.0 Min, 3.1 Typ, 3.2 Max V, -Backlight Supply Current (VLED = 3.1V): 10 min, 30 Typ, 36 Max mA
Optimal Viewing Angle	Top 35 degrees, Bottom: 15 degrees, Left/Right: 45 degrees, Viewing Direction: 6 o'clock	Top/Bottom/Left/Right: 80 degrees, Condition: Contrast Ratio >= 10	Top: 20 degrees, Bottom/Left/Right: 40 deg Viewing Direction: 6 o'clock
Controller (integrated)	Sitronix ST7735S	Sitronix ST7735S	Sitronix ST7032
Availability/ Price	>1000 in stock from Crystalfontz $9.21 each	>1000 in stock from Crystalfontz $12.58 each	>1000 in stock from Mouser $12.75 each

3.2.9 Programming Language for Embedded System Selection

C is renowned for its exceptional performance and direct hardware manipulation capabilities, vital in embedded systems where resource optimization is paramount. Its efficient memory management promotes compact code essential for the limited memory space in microcontrollers. This performance and memory efficiency make C highly suitable for real-time capabilities required in embedded systems. Despite these advantages, C's manual memory management and the absence of object-oriented programming necessitate more groundwork for developing complex applications, potentially slowing down development. This situation underscores the language's extensive use in environments where system-level control and efficiency outweigh the drawbacks of increased complexity and lower code reusability.

C++, by extending C with object-oriented features like classes, inheritance, and polymorphism, facilitates structured and maintainable code. It inherits C's performance and control while introducing abstractions that simplify complex system management. C++ enhances code reusability and modularity, crucial for scalable embedded systems development. However, the intricacies of its features may elevate the learning curve and risk of bugs. Despite these challenges, C++'s rich standard library and template support expedite development, demonstrating its capacity to balance performance with developer productivity, even in constrained environments. The advanced concurrency support in C++ further underscores its suitability for sophisticated embedded projects that demand both efficiency and advanced programming paradigms.

Python stands out for its simplicity and rapid development features, attributed to its high-level syntax and comprehensive standard library. Ideal for scripting and developing high-level applications, Python's ease of programming significantly accelerates the development process. Yet, its interpreted nature and resultant runtime overhead render it less fitting for the core, performance-critical tasks of microcontroller-based embedded systems. Although MicroPython attempts to bridge Python to embedded contexts, performance and memory limitations may still present challenges. Despite these concerns, Python's extensive ecosystem and support for embedded development through interfaces like MicroPython highlight its potential for certain aspects of embedded projects, particularly those not constrained by real-time performance or severe resource limitations. A comparison of the three languages discussed above is shown in Table 20.

Table 20 – Summary of Embedded Software Language

Feature	**C**	**C++**	**Python**
Performance	High (close to hardware, low level of abstraction)	High (close to hardware, slightly higher abstraction but still minimal)	Low (interpreted nature and dynamic typing)
Memory Efficiency	Excellent (manual memory management)	Good (higher level abstraction compared to C, controlled automatic management)	Moderate (much higher level of abstraction, garbage collector)
Object-Oriented	No	Yes	Yes
Embedded Ecosystem	Extensive, almost all MCU's support C, Countless libraries, few examples are IwIP, FreeRTOS, CMSIS	Extensive, Many ARM Cortex-M MCUS and Arduino use C++. Many libraries available, few examples are Boost, uSTL, ETL	Limited, Some ESP or SAMD MCUs and Raspberry Pi Pico.
Integration with Embedded Hardware and Sensors	Direct and extensive (default choice for nearly every peripheral)	Direct and extensive (used in most Arduino libraries)	Via interfaces like MicroPython and CircuitPython

For our envisioned project, C surfaces as the primary choice for microcontroller programming due to its superior performance, efficiency, and precision in hardware control—qualities essential for the MSP430FR6989 microcontroller's real-time operation and sensor interaction. These advantages, coupled with the extensive development tools, IDE support, and the robust embedded development ecosystem, ensure that C provides a solid foundation for achieving the project's objectives while navigating the complexities of embedded system programming. [27]

3.2.10 Programming Language for Facial Tracking

Python is a high-level programming language with dynamic typing and binding. It is a popular object-oriented and interpreted language. A benefit to using this programming language is the user-friendly syntax. There is also no compilation step which can speed up the overall development cycle. Another benefit is that the Python interpreter is extremely efficient and when it discovers an issue it will raise an exception. This is an excellent feature because bad input or bugs in some other programming languages would cause segmentation faults. Whereas the Python interpreter will catch this error as either an exception or print a stack trace. Python is often compared to other programming languages such as JavaScript and Java.

JavaScript and Java are also another interpreted language like Python. The programs written in Java are usually expected to run faster than Python programs. However, python programs usually take less time to create, and the actual programs are usually shorter in comparison to the same Java program. Python also has an advantage over Java in that it uses variables and simple functions without the need for a class definition. JavaScript also has this advantage over Java in being object-based but that is all it has. While for Python it supports code reuse and large programs in a true object-oriented style. This is where inheritance and class can play a useful role. [28]

This project is using facial tracking to help determine if the user is present at the desk. In doing so, it is important to decide on the programming language that will be used for this task. Python is a possible choice for this portion of the project because it has powerful computer vision libraries such as NumPy, OpenCV and SciKit-image. Since Python has these libraries, this makes Python an ideal choice for the project. [29]

3.2.11 Facial Tracking Software Selection

Using a camera in conjunction with face tracking software was determined to be the best method out of the three options mentioned. For the facial tracking software there are various options available. A few considerations before picking the software are determining the device compatibility and ease of use. As a result of this consideration Raspberry Pi was selected due to the capabilities of the device and the wide community support. After determining the device that the potential software would be running on, five potential face tracking software were selected for comparison. An overview of this comparison is shown in Table 21.

Table 21 - Facial Tracking Software Comparison

Software	Interfaces	Accuracy	Use case
OpenCV	Python	Depends on the data on which the model was trained	Camera, video manipulation, object tracking, computer vision libraries
Dlib	C++, Python	Accuracy of 99.38%	Camera, video manipulation, object tracking, computer vision libraries
Face_recognition	Python	Accuracy of 99.38%	Facial tracking
OpenFace	Python	Accuracy of 97.38%	Facial tracking and Pose tracking

OpenCV is an open-source machine learning and computer vision software library. The library includes a comprehensive set with more than 2500 optimized algorithms and can be used for more than just facial tracking such as classify human actions, extract 3D models, follow eye movement and much more [30]. One of the main advantages of using OpenCV is the potential to further expand the capabilities of the software because of the wide support this library has in terms of other algorithms. For example, classification of human action may become useful if this project wants to further improve the tracking on user movement to provide useful feedback. Another advantage to using this library is the vast amount of support. This includes C++, Python, Java, MATLAB for programming languages and Windows, Linux, Android, Mac OS for operating systems. Lastly the library is used by many well-established companies and individuals. This can make it easier to use because there may already be multiple answers to common problems since there is a wide usage of the library.

Dlib is a C++ machine learning and computer vision library that is also open-source and free. A few machine learning algorithms this library include are structural SVM for object detection, deep learning and general-purpose multiclass classification tools [31]. One main benefit of using Dlib is that the documentation of this library is known for being very complete and precise. Another advantage of using the Dlib library is the high-quality portable code that also has a good ratio of unit test lines. The reason having great portable code is important is because of ease of use in a project. This library also has image processing and tools needed for frontal face detection and pose estimation that is needed for this part of the project.

Face_recognition library is a simple face recognition library that can be used for facial tracking. This library was built using Dlib library’s face recognition algorithm that was created with deep learning. The main advantage of this is the ease of use of this library and its high accuracy. This tool allows for simple face recognition through the command line on a folder of images and has an accuracy of 99.38% [32]. One disadvantage of this library is that it is only designed for face recognition and cannot be used for further expansion if more capabilities are desired in the future such as pose classification.

OpenFace is another free and open-source face recognition library using deep learning. It is a face recognition implementation that uses Torch and Python with deep learning techniques. Specifically, it uses FaceNet and Torch allows it to be used with either CUDA or CPU [33].

This this portion of the project is going to be running on Raspberry pi so it is important to choose the software that will work well on this device. With these considerations, Face recognition library was chosen as the main library for facial tracking. It is simple and lightweight with an accuracy of 99.38%. The focus of this project is to provide useful ergonomic transitions and metrics through a combination of components. The main goal for facial tracking is accuracy and not of a wide range of object detections that the other libraries would be providing as the main source. OpenCV and Dlib will also be used in this project but won't be the main source of the tracking. OpenCV will be used to access the camera and Dlib library is used by Face recognition library.

3.2.12 Application Development Software

It was decided that the main application created will be for windows and android. This application will serve as an initial guide for first time users and store user preference settings for desk height. The user will have the choice to use either options of the windows or android application. To build these applications, a few options compared were react, react native and flutter. The mobile application will be the main goal currently with the windows application as a stretch goal.

3.2.12.1 React

React is a library created by Facebook that is used to build web and native interfaces [34]. React consists of building interfaces through pieces called components. Then these components are combined to create entire pages and apps. This works by using HTML inside JavaScript which makes the syntax look like HTML which makes it familiar to individuals with some web design experience. One major benefit to using React is the wide support and current usage in the community. Since React was created by Facebook, it has the support and resources from that major company. It also has been around for open-source use since 2013 which means that there is now a large community following and using React. One downside to using React is that since it was created with mainly web development in mind, it means other tools and plugins will be needed to create a desktop or phone application.

3.2.12.2 React Native

React Native is a JavaScript framework for creating mobile platforms that is based on React. Since it was created based on React, it allows those who are familiar with developing in React to easily switch over to React Native. Since React was created to be easy to use for those who already have basic web development experience, React Native by extension is intuitive to learn as well. Some call it native because it allows for design and management of code in a format that they are used to working with in web design. This makes it easier for those who are already familiar with web-based development to also write mobile applications. [35] React Native contains most JavaScript libraries with the ability to be shared between platforms. This makes development for both iOS and Android possible to simultaneously be created and worked on. React Native also uses APIs and native UI components while React uses traditional CSS, HTML and JavaScript. Both use the same syntax so users of React can easily transition to using React Native easily. A useful feature of React Native is that it can use platform features through JavaScript interfaces. Some of these platform features include visual, audio and Bluetooth. React Native also has useful capabilities for developers. One such feature is the ability to see changes without the need to rebuild the entire application. Tools that can shorten development time can save time that can be used in other areas.

3.2.12.3 Flutter

Flutter is another open-source software development platform that was created by Google in 2017. It was designed for building a multitude of applications such as android, iOS, Windows, Linux, and web browsers. Flutter works for a wide range of applications by running them through a virtual machine. Then the applications created through Flutter are compiled straight into machine code which allows for it to be cross platform compatible. [36]

Structurally Flutter works through widgets where these new widgets are used in other widgets until the desired application is created. Each widget can be specific components of the application such as button style, navigation bar, font, layout and more. Flutter also has access to the device’s tools such as Bluetooth, camera and notifications which make this an ideal tool for developers of a wide range of applications. Flutter itself runs on the Flutter engine which is written using mainly C++. While the core engine was built using C++, the applications created by Flutter is completed using the programming language Dart. This programming language was developed by Google and is object-oriented, has garbage collection and is class-based. [37]

3.2.12.4 Comparison between the mobile development platforms

Each of the previously mentioned development platforms has its strengths and weaknesses. To select the best development platform for this project, the three platforms mentioned will be compared in this section. In the current project the main application is going to be for

Android with a plan to also add a Window's application. React is known to be a great platform for developing web applications and can be used for making a desktop application with the use of a plugin. A reason to consider React in this project is that there is large community support for React since it has been around since 2015. React is also very user friendly and can easily be picked up if the developer has previous web programming experience. A major downside to React is that it is not really made for mobile programming so another platform would need to be used.

React Native is a tool that is mainly used with mobile programming. This application is a better fit than using React for this project because the main application is going to be an Android application. React Native also has a wide range of error reporting and debugging tools that enhances the development experience on this platform. This platform also shares the same syntax as React, so this makes it easy for developers to switch between the two platforms. However, in this project the current goal is to make a mobile application with a desktop counterpart. React Native was mainly created for mobile applications and not for applications on the desktop. As a result, React Native by itself would not serve as a good tool for this project. The platform would need to be used conjunctionally with React to be of full use to this project. Using both platforms could work as they share the same syntax. However, they are structured differently from each other, so it is not easy to share code from both applications.

Flutter is considered very new to the development world. This means there are less tutorials and community support. There is also the chance for early libraries to be quickly retired and replaced because the support is relatively new compared to React and React Native. Although it is new compared to the other platforms, it has gained a great deal of traction because it was created by Google. Another disadvantage to using flutter is that for testing android applications there is the need for using android studios for an emulator if one does not have a device available. However, this limitation can be overcome by using an actual android phone for development. Flutter uses a new programming language called Dart. This programming language was created by Google for Flutter. Through this it uses widgets, and the structure does not resemble traditional html or JavaScript like React and React Native. Even so Flutter was created to be object-oriented, so it is easy to pick up for most programmers.

Even though Flutter has a few disadvantages it still has a lot of advantages. One major advantage is the ability for hot reloading and seeing live changes without the need for a build. This speeds up development a great deal and saves countless hours. Flutter was also made for creation of applications across multiple platforms. This means that mainly only one application needs to be created and it can be complied on for different devices. This allows for easy sharing of code between applications and potentially ease the amount of code needed overall. Another benefit to Flutter is that it was created by Google which is a large company. This means that it will have support for a long time and have a better chance of being adopted into the community in the long term.

In conclusion, React and React Native by themselves would not be a good fit for the project. However, using both together would make them a good combination for this project. Flutter on the other side would be ideal for the project by itself since it would not need another platform to perform well for the project. Overall, the most influential factor in deciding between the platforms is the experience of the team in using each. This is because no matter how long one has been programming, it takes time to learn a new platform. This means that it will save time to use the platform that the team has the most experience in. Most of the members on the team do not have experience in mobile or web development. However, the main team members designing and building this portion of this project do have experience in mobile and web development, so it is important to decide on a platform to use based on their experience. The reason for this is that since they have experience in that field, they can easily share the knowledge and skills with the other members. That specific team member has experience building applications with Flutter and React. To limit the number of platform setup it would be best to only use one. With that consideration, this would mean that Flutter would be the most ideal fit and is what the team decided to use for this project. A summary of this decision is shown in Table 22 below.

Table 22 - Comparison Table of Development Platforms

Development Platforms	**Application**	**Team Experience with Platform**	**Use case**
React	Web applications	- 1 member with experience on this platform	- Only used for web development
React Native	Mobile applications	- 0 members with experience on this platform	- Only used for mobile development
Flutter	Cross platform applications	- 1 member with experience on this platform	-Used for both mobile and web development

3.2.13 Database

The mobile and desktop applications will require a database to store and interface with each user’s unique desk settings. Three options were considered for this purpose: MongoDB Atlas, Microsoft Azure, and Amazon’s DynamoDB. Table 23 compares these services and what they could contribute to U.P.R.I.G.H.T..

Table 23 – Database Comparisons

Database Service	Storage Space	Price	Team Familiarity	Max Tier Storage	Max Tier Price
MongoDB Atlas	5 GB	Free	2 members	4 TB	$ 33.26 / hour
DynamoDB	25 GB	Free	None	Unspecified	$0.25 per GB/month
Microsoft Azure	32 GB	Free	None	100 TB	$34.72 / hour

While U.P.R.I.G.H.T. requires the use of a database to track user information, the amount of storage required is relatively small. This fact coupled by the existing team familiarity make MongoDB the favorable choice. 5 GB of free storage is sufficient to get the project off the ground. While the other options may be more economical for very large databases, this project will not require that kind of size. Therefore, the team will move forward using MongoDB.

Chapter 4 - Standards and Design Constraints

This chapter will consist of three sections. The first section of this chapter will include a discussion of one to two standards in detail. The second section will be concerned mainly with discussing two to three design constraints in detail. The third section will include the remaining relevant standards and design constraints of the project that must be included but will be discussed briefly.

Within each section, headers have been included to divide each part and technology into its own subcategory. This has been done to enable easy navigation to find specific parts and technologies used.

4.1 Standards

This section will be concerned with a discussion of the main standards that will be used for our automatic desk project. Information from this section was sourced mainly from the manufacturers of the standards as well as various standards licensing committees. Information in this section was summarized from the technical documentation for the most relevant parts to be included in the project.

4.1.1 Standard for LCD Communication Through SPI

Information from this section was taken from standard document ETSI TS 103 713 V18.0.0. This was relevant for the section of our project concerned with our LCD because it leverages the SPI interface for communication between the microcontroller and display module.

The Serial Peripheral Interface (SPI) is a synchronous serial communication protocol widely used in embedded systems for connecting microcontrollers and peripheral devices. Known for its simplicity and speed, SPI facilitates full-duplex communication between a single master device and one or more slave devices. This section outlines the operational principles, signal characteristics, and implementation guidelines of SPI.

The first part to be discussed are the operational principles of SPI. SPI operates on a master-slave architecture, where the master device initiates communication and controls the clock signal. Communication occurs over four primary lines:

- Master Out Slave In (MOSI): Transfers data from the master to the slave.
- Master In Slave Out (MISO): Carries data from the slave back to the master.
- Serial Clock (SCK): Clock signal generated by the master to synchronize data transmission.
- Slave Select (SS): Active-low signal used by the master to enable individual slave devices.

Data transmission is full-duplex, allowing simultaneous data exchange between the master and the slave. Each SPI transaction begins with the master selecting a slave device by pulling its SS line low and ends with the SS line being released high.

The next part of this section will discuss the signal characteristics of the SPI protocol for data transmission. The characteristics for the signal can be broken down into the following sections:

- Clock Polarity (CPOL) and Clock Phase (CPHA): SPI communication can operate under four different clock modes determined by two parameters: CPOL (clock polarity) and CPHA (clock phase). These parameters define the idle state of the clock signal and the data capture edge, allowing for compatibility with devices having different timing requirements.
- Data Frame Format: SPI does not inherently specify a data frame size; however, 8-bit data frames are most common. Systems can configure the frame size to accommodate specific needs, ranging from a few bits to several words.
- Speed: The SPI protocol does not impose a maximum clock frequency, making the achievable speed device-dependent. Factors such as the microcontroller's capabilities, the slave device's response time, and signal integrity considerations (e.g., cable length and electromagnetic interference) influence the operational speed.

The next section discusses the best practices and implementation guidelines for incorporating SPI into a design as per the information included in the standards document.

Implementing SPI communication requires attention to hardware capabilities, software configuration, and signal integrity. Key considerations include:

- Hardware Selection: We chose specific microcontrollers and peripheral devices with SPI support that will meet the project's speed, power, and compatibility requirements. We also assessed the number of available SPI ports and slave select lines to accommodate the desired peripherals.
- Software Configuration: We will utilize our microcontroller's SPI module configuration settings to set the clock polarity and phase, data frame size, and clock frequency. This also includes implementing robust error handling and data validation mechanisms to ensure reliable communication.
- Signal Integrity: We will ensure proper PCB design practices to minimize signal degradation and electromagnetic interference. This will involve using pull-up and/or pull-down resistors on the SS lines, employing signal conditioning techniques, and implementing proper grounding and shielding methods.

SPI's versatility allows its application across various domains, from simple sensor data acquisition systems to complex multimedia interfaces. Although SPI's fundamental operation remains consistent, variants and extensions exist to cater to specific needs that may be required for the design of our project. These include quad-SPI (QSPI) for higher data throughput and multi-master SPI configurations for dynamic systems requiring multiple controlling devices.

The standard documentation concerning the SPI protocol shows that it embodies a crucial component in the design and implementation of embedded systems. It is for this reason that it is important for use in our project's design. By adhering to the operational principles, signal characteristics, and implementation guidelines outlined in ETSI TS 103 713 V18.0.0, we can leverage SPI's full potential to achieve efficient, reliable communication between a microcontroller and peripheral devices, such as our LCD. As electronic systems evolve, the foundational role of SPI facilitating device interconnectivity continues to be of paramount importance. [38]

4.1.2 Standard for Bluetooth Communication

Bluetooth will be used in our project for communication between our Raspberry Pi and application. Information for this document has been taken from the Bluetooth Core Specification document for the revision version 5.3. The revision date for this document is July 13, 2021. This document was prepared by the Core Specification Working Group which is part of the Bluetooth Special Interest Group (SIG), which oversees the development of the specification, manages the qualification programs, and protects the trademarks. The document defines the technologies required to create interoperable Bluetooth devices.

Bluetooth technology is a global wireless communication standard that enables the exchange of data between fixed and mobile devices over short distances. Utilizing UHF radio waves in the ISM band from 2.400 GHz to 2.485 GHz, Bluetooth facilitates connectivity in a wide range of products including phones, speakers, cars, and smart home devices. Governed by the Bluetooth Special Interest Group (SIG), the standard has evolved through various versions, enhancing speed, range, and security.

Conceived as a wireless alternative to RS-232 data cables, Bluetooth technology was named after Harald Bluetooth, a 10th-century king known for unifying Denmark and Norway. Introduced in the late 1990s, the standard aimed to unify different industries under one wireless protocol. The Bluetooth SIG, formed by leaders in telecommunications, computing, and consumer electronics, continues to expand and refine the specifications.

Bluetooth operates on a radio-frequency standard that allows devices to communicate in the 2.4 GHz band. It uses a spread spectrum, frequency hopping, full-duplex signal at a rate of 1,600 hops/sec. This method minimizes interference from other wireless devices and ensures secure communication. Bluetooth devices are categorized into three power classes: Class 1 (100 mW, up to 100 meters range), Class 2 (2.5 mW, up to 10 meters range), and Class 3 (1 mW, up to 1 meter range).

The Bluetooth stack is composed of a "controller" (the physical radio layer) and a "host" (handling the higher layer protocols). The core system architecture includes the Link Controller (LC), Link Manager (LM), Logical Link Control and Adaptation Protocol (L2CAP), and Host Controller Interface (HCI). The LC and LM manage physical and logical links, respectively, while L2CAP provides multiplexing and segmentation of higher layer protocols. HCI serves as the interface between the host and controller.

Bluetooth technology defines a wide range of profiles that specify the general behaviors through which Bluetooth-enabled devices communicate with other devices. Profiles such as the Advanced Audio Distribution Profile (A2DP) for audio streaming, Hands-Free Profile (HFP) for voice calling, and Human Interface Device (HID) for connecting mice, keyboards, and other input devices ensure interoperability among devices from different manufacturers. Underpinning these profiles are protocols such as the Serial Port Profile (SPP) and Generic Attribute Profile (GATT), which define the underlying data structures and communication patterns.

Security is a fundamental aspect of Bluetooth technology, incorporating features such as pairing, encryption, and authentication. The Secure Simple Pairing (SSP) process uses a shared secret technique to protect against eavesdropping and man-in-the-middle attacks. Bluetooth devices also support transport layer security and encryption based on user-configurable keys, ensuring secure communication.

Bluetooth technology has significantly evolved, with major versions introducing improvements in speed, range, and energy efficiency. Notable versions include Bluetooth 2.0 + EDR (Enhanced Data Rate), offering faster data transfer rates; Bluetooth 4.0, introducing Bluetooth Low Energy (BLE) for low-power applications; and Bluetooth 5.0, which further increases range and speed and introduces capabilities for IoT devices.

Bluetooth technology is ubiquitous in modern life, found in consumer electronics, automotive, healthcare, and smart home devices. Its applications range from wireless audio and wearable fitness trackers to industrial monitoring systems. The future of Bluetooth lies in enhancing IoT connectivity, improving security features, and further increasing energy efficiency to enable new applications in smart cities, advanced healthcare, and beyond.

As a pivotal technology in the wireless communication landscape, Bluetooth continues to adapt and expand its capabilities to meet the evolving needs of users and industries. Its ongoing development by the Bluetooth SIG ensures that it remains at the forefront of secure, reliable, and convenient wireless connectivity. [39]

4.1.3 Bluetooth Core Architecture

At the heart of the Bluetooth device is the Link Controller (LC), which operates within the physical layer. It is responsible for managing the physical channel and direct link between

Bluetooth devices. This includes tasks such as frequency hopping sequence generation, timing and synchronization, and data packet transmission and reception. The LC works closely with the baseband protocol, which defines the specifications for device discovery, connection establishment, and the types of packets exchanged between devices. The baseband protocol also manages the asynchronous and synchronous links, enabling both data and voice communication.

The Link Manager (LM) operates above the LC and is responsible for the establishment and management of the connection between Bluetooth devices. It uses the Link Manager Protocol (LMP) to communicate with the LM of other devices. LMP handles tasks such as pairing, authentication, and encryption setup. It also manages power control and ensures that communication parameters are optimized for the conditions of the link, adjusting the power and frequency of transmission as necessary to maintain a stable connection.

L2CAP provides multiplexing and segmentation of higher-layer protocols over the baseband. It abstracts the baseband and Link Manager’s functionalities to the upper layers, allowing for the simultaneous communication of multiple higher-level protocols over a single physical link. L2CAP enables the segmentation and reassembly of large packets and provides both connection-oriented and connectionless data services to upper layer protocols and applications.

4.2 Software Standards:

This section will be detailing the relevant software standard.

4.2.1 ISO/IEC 9899:2011 – Programming Languages – C

In the selection of a programming standard for our project, we have opted for the ISO/IEC 9899:2011 standard, known as C11, owing to its modern features and strong emphasis on security and concurrency. This decision was underpinned by the capabilities of Code Composer Studio (CCS), our chosen development environment, which provides comprehensive support for ANSI C89, C99, and C11 standards. The alignment with C11 allows us to leverage CCS’s features to the fullest extent, capitalizing on C11's advancements such as multi-threading, atomic operations, and improved memory alignment, which are pivotal for our project’s goals in systems programming. [40]

By choosing C11, we ensure that our software conforms to the latest C standard supported by CCS, granting us the ability to write code that is both forward compatible and optimized for performance on current and future hardware architectures.

4.3 Design Constraints

The development of an automatic standing desk requires careful consideration of various design constraints that influence both functionality and manufacturability. This section outlines the critical constraints that our design team must navigate to successfully deliver a product that is not only efficient and reliable but also user-friendly and economically viable. These constraints are derived from a combination of ergonomic standards, mechanical and electrical limitations, safety regulations, and market-driven requirements.

4.3.1 Cost and Manufacturability Constraints

The mechanisms used for height adjustment should be durable and capable of repeated use without degradation. The choice of motors, sensors, and control systems must reflect a balance between cost, reliability, performance, and ease of maintenance. Additionally, electrical components must comply with relevant safety standards to prevent hazards such as overheating or electrical shorts.

The choice of materials directly affects both the cost and the production process. Materials must be strong enough to ensure durability and stability but also cost-effective. The use of premium materials (like high-grade steel or aluminum) should be balanced with cost constraints to keep the product affordable.

The manufacturability of the desk involves selecting production methods that are efficient and economical. Techniques like stamping, molding, or laser cutting can be chosen based on their suitability for large scale production and cost-effectiveness. The design should be optimized to utilize these techniques, minimizing complex assemblies that require more labor-intensive processes.

Using standardized components can reduce costs and simplify the manufacturing process. This includes using off-the-shelf bolts, nuts, motors, and other hardware whenever possible. It reduces the need for custom parts, which are more expensive to design, test, and manufacture.

The design should facilitate quick and easy assembly to reduce labor costs. This includes designing parts that easily fit together and minimizing the number of unique fasteners required. Features like snap-fit connections or modular components can enhance assembly efficiency and reduce manufacturing time.

Design choices should consider the logistics of material supply and product distribution. Selecting materials and components from readily available, local sources can reduce shipping costs and lead times. Additionally, designing the product to be compact and easy to disassemble can lower shipping costs and improve storage efficiency.

The desk should be scalable, allowing for economical production increases without significant delays or costs. This means planning for potential demand increases and ensuring that the manufacturing process can be scaled up efficiently without compromising product quality.

Initial investments in tooling and manufacturing equipment should be justified by expected sales volumes. Designs that require expensive custom tooling or equipment might not be viable unless they can be amortized over a large number of units sold.

Ensuring compliance with various safety and quality standards can involve significant costs. The design must meet these standards while managing costs associated with certification and testing.

By addressing these specific design constraints, the project can manage costs effectively while ensuring the desk is manufacturable at scale. These considerations are crucial for aligning the product design with business objectives and market expectations.

4.3.2 Ergonomics

Taking into account ergonomics is a critical aspect when designing any product that will be used by humans, especially for our automatic standing desk, which interacts directly with the user and will affect their physical health and productivity. Making the desk ergonomic can reduce the risk of discomfort and long-term injuries, much as musculoskeletal disorders, and can improve the overall user experience. This section will focus on the different aspects taken into account to ensure the desk's design will be ergonomically sound.

The height adjustability range is pivotal in an ergonomic standing desk. It must accommodate the 5^{th} to 95^{th} percentile of user height, ensuring it can be used comfortably both while sitting and standing. Typically, this means:

- The sitting height should range from about 22 inches (for shorter users) to at least 33 inches (for taller users).
- The standing height should ideally adjust from about 35 inches to 49 inches or more, depending on the tallest expected users.

The next consideration is transition ease. The ease with which the desk transitions from sitting to standing height is also important. It should allow users to change positions effortlessly and frequently to encourage movement, which is beneficial for health. This involves smooth and easy-to-control adjustment mechanisms and user-friendly controls, possibly with programmable presets (stretch goal) for preferred heights.

In addition to these considerations, the dimensions of the desk surface should accommodate various tasks and equipment setups. This includes sufficient depth and width to comfortably to hold a computer, keyboard, mouse, and other necessary tools without causing the user to overreach or strain. Also, it should have a depth of at least 30 inches which is recommended to provide ample space for different arrangements and for resting the wrists.

The next consideration for ergonomics would be keyboard and monitor placement. Proper placement of the keyboard and monitor is essential to prevent strain on the neck, shoulders, and arms. The keyboard should be placed at a height that allows the user's arms to form a 90-degree angle at the elbows, keeping the wrists straight and relaxed. In addition to this, the monitor should be at a height where the top of the screen is at or slightly below eye level, and about 20 – 30 inches from the eyes, to prevent neck strain and reduce glare.

The next consideration to be taken into account will be the stability and movement of the desk. The stability of the desk at all heights is crucial to prevent wobbling or shaking, which can disrupt work and lead to discomfort. The desk should have a robust frame and support system to hold the necessary weight without sagging or bouncing during use. Consideration should also be taken for cable management to avoid clutter and potential hazards, which will also contribute to a clean, functional workspace.

In addition to this, the choices for material and edge design should be taken into consideration for the automatic desk. This is because the choice of materials and the design of the edges can significantly impact comfort. The surfaces should be made of durable, non-reflective, and easy-to-clean materials. Also, the desk edges should be rounded or include a soft bevel to prevent pressure points and discomfort when leaning or resting arms against them.

The final design constraint that will be taken into account for the desk will be the footrest and flooring. This is because providing support for the feet and legs can enhance comfort during long periods of standing.

- An adjustable footrest can help shorter users comfortably position their feet when the chair or desk height does not allow for optimal foot placement on the floor.
- Anti-fatigue mats can reduce strain on legs and backs, encouraging healthier standing habits.

By integrating these ergonomic principles, the design of our automatic standing desk will not only meet functional requirements but also promote health and productivity, creating a positive impact on the user's overall workplace well-being.

4.3.3 Safety

Safety is a crucial aspect of designing our automatic standing desk, as it directly impacts the user's well-being. Ensuring the desk is safe to use involves several detailed considerations that protect against potential hazards and accidents. This section includes an analysis of the safety features and consideration for our desk.

The first design constraint consideration would be the mechanical and electrical safety of the desk. The first design constraint would be anti-collision technology. This can be integrated in a variety of ways. We could implement sensors that detect objects in the desk's path when adjusting heights. This technology helps prevent damage to the desk or other items and reduces the risk of injury by stopping the movement if an obstruction is detected. An addition to this, we can take into account electrical safety standards. We can ensure all electrical components meet regulatory standards such as UL, CE, or similar certifications. This includes using components that are properly insulated, rated for the correct voltage, and have overload protection to precent electrical fires. Finally, as part of the mechanical and electrical safety, we can include an easily accessible emergency stop mechanism that immediately halts all motor functions to quickly address any unexpected situations.

The next design constraint for our desk would be child safety. Considerations to address this can include incorporating a child lock feature on the control panel or through an app to prevent unintended use by children, reducing the risk of injury. In addition to this, we could design the control panel to be out of reach of small children or require activation that is difficult for children to operate, such as requiring a long press or simultaneous button presses.

The third consideration to keep in mind concerning the safety design constraints to take into account when designing our standing desk is the stability and load handling. The desk should have a robust design that can handle the maximum expected load without tipping or collapsing. This includes a wide enough base and quality construction materials. In addition to this, we will clearly specify the weight capacity of the desk surface. Going over this value could lead to mechanical failure or tipping.

The next consideration would be to minimize the pinch points and moving parts. We will ensure that our design minimizes pinch points or areas where fingers or other body parts could get caught between moving parts or between the desk an another surface. Also, we can use guards or enclosures around moving parts to prevent contact, which can help avoid injuries relates to crushing or pinching.

The next aspect to keep in mind is the material safety. We will take extra effort to use materials that do not emit harmful substances or odors, which is especially important for indoor environments. This includes avoiding lead paint, BPA in plastics, or volatile organic compounds (VOCs) in manufacturing materials. Another step that can be taken towards meeting this goal is to design the desk with rounded corners and smooth edges to reduce the risk of cuts or scrapes.

The next part of the safety that can be taken into account is the reliability and maintenance of our project. The following considerations can be looked at to ensure that our project is reliable:

- We can design the desk for easy maintenance and include guidance on regular checks for wear and tear on mechanical parts, ensuring everything is tightly secured and functions properly.

- We can also consider implementing fail-safe mechanisms that revert the desk to a safe position or stop functioning in case of a critical failure.

The part of this section includes the ergonomic safety of the desk. Part of this section can include ensuring that controls are easy to reach and use from both sitting and standing positions to prevent ergonomic strain during operation. Also, we can provide clear, visible instruction and safety warnings about proper use and the risks of misuse, including stickers or labels on the desk itself.

In conclusion, including these safety features not only protects the users but also enhances the usability and reliability of our automatic standing desk, contributing to a safer and more productive working environment.

4.3.4 Stability

In our project, achieving high stability in the automatic standing desk is very important to ensure user safety and equipment security across all of our adjustment levels. Stability is crucial not only for maintaining a productive workspace but also for preventing potential accidents that could arise from desk wobble or tipping. Our focus is on designing a desk with a robust frame and base that can reliably support typical office loads, including multiple monitors, desktop computers, and other office essentials, without any risk of tipping or undesired movement.

To address this, our design incorporates a wide and weighted base that distributed the load evenly. This broader base increases the desk's footprint, which significantly enhances stability, especially when the desk is extended to its highest position. We will use high-quality materials for the frame – such as reinforced steel or aluminum (for the actuators) – which provide strength and durability while maintaining a sleek, modern aesthetic. The choice of material also ensures that the desk can withstand the daily schedule of office use without degradation of its structural integrity over time.

We can also consider the incorporation of adjustable feet at the bottom of the desk legs. These adjustable feet will allow for minor modifications to level the desk perfectly, even on uneven surfaces, which is a common issue in many home office settings. This feature helps to eliminate wobbling and ensures that the desk remains stable regardless of the flooring.

In terms of our mechanical design, our desk has one motor in each actuator of the legs of the desk, to have two motors overall. This will enable the desk to have proper lifting capacity and speed but also enhances the desk's stability by ensuring even lifting and lowering without it tilting. This is critical because uneven movement could destabilize the desk, particularly when it is loaded with heavy accessories on top.

The last consideration to be taken into account involves conducting testing of our design under various load conditions and at different heights to verify stability in real-world scenarios. This testing phase will help us identify any potential instability issues before finalizing the final design of the desk, ensuring that our desk meets our desired safety and functionality requirements. By prioritizing stability in our design, we aim to deliver a project that can meet the ergonomic needs of users but can also ensure their safety and the security of the stuff that they choose to put on top of it.

4.3.5 Load Capacity

For our standing desk, addressing load capacity is important to making sure the desk can handle the typical demands of a professional or home office environment without compromising the structural integrity or functionality. Our goal is to design a desk that supports a variety of devices and accessories commonly used in workspaces, such as multiple monitors, desktop computers, laptops, printers, and other widely used office supplies.

To achieve this, we first needed to have a substantial maximum load capacity that the desk can reliably support. Based on web searches on user needs for a desk, it was determined that our desk should be able to carry around 50 – 100 pounds of evenly distributed weight across its surface. This capacity is sufficient to accommodate the weight of common office equipment while also providing a buffer to prevent overloading.

To ensure our desk meets this load requirement, we are planning to use materials that are not only strong and durable but also lightweight to maintain the desk's adjustability features. The legs will be constructed of a metal alloy for the actuators, which is known for its durability. For the desktop surface, we will use a high-quality wood that combines lightness with a high strength-to-weight ratio, ensuring it can support the load without adding excessive weight to the overall structure of our desk.

The mechanical components, including the lifting mechanism, will be specifically chosen based on their load-bearing capacities. We will incorporate a dual linear actuator system that provides a stable and even lift, reducing strain on any single part of the mechanism, which can lead to premature wear or failure. The actuators will be picked to handle more than the maximum designated load to ensure reliability under continuous use.

Additionally, stability tests will be conducted not just for maximum load at the lowest height but also at various heights, particularly the maximum extension, where the risk of tipping or structural failure increases. These tests will help us refine the design to enhance safety and durability under full load conditions.

We also plan to integrate an automatic shut-off feature that activates if the load exceeds the recommended capacity, thereby preventing damage to the actuators and the structural components. This feature will include a button that will halt the desk's movement if the user decides that they do not want to take advantage of the automatic functionality.

In summary, by addressing load capacity through material selection, mechanical design, and safety features, our desk will provide users with a reliable, safe, and versatile workspace that meets the demands of modern office and home-office environments. This approach not only ensures the longevity and functionality of the desk but also enhances user trust and satisfaction with our design project.

Chapter 5 - Comparison of ChatGPT with Similar Platforms

Developed by OpenAI, ChatGPT is an advanced language model trained by hundreds of billions of words from the internet. The latest version is powered by GPT-4, which is a part of a series of generative pre-trained transformers. ChatGPT can be used to perform a lot of tasks like classification, summarizing topics, and even perform error correction of code while responding with human like replies. ChatGPT is often compared to era changing technology like the iPhone because of the huge impact this technology is currently having in the world. One such consequence of this is the streamlining productivity that is also leaving groups of individuals to feel anxious about the potential risk of becoming unemployed due to these advancements. [41] [42]

5.1 Alternatives to ChatGPT

ChatGPT is great for certain applications, but it might not be a good fit for all needs. Also, due to high traffic, it sometimes reaches capacity, and the user cannot use it until it lowers to a certain point. It was mainly designed to engage in conversations in response to user prompts, and while it can be used for a wide range of activities there are alternatives to the traditional OpenAI ChatGPT platform. Some popular AI alternatives to ChatGPT include Chatsonic, Gemini AI, Codewhisperer, DeepL Write and Elicit. Each of these has slightly different uses and can be helpful in a variety of tasks.

5.1.1 Chatsonic

Chatsonic is an AI platform powered by GPT-4 as well as containing some of its own custom models. It was created by Writesonic and the main use of it is to fill in the limitations of ChatGPT. This includes providing real-time image, data and content creation capabilities that is not currently available on the OpenAI platform. [43] It also uses persona to customize AI chat experience. This works by creating distinct personalities and vocabulary which make it seem like the user is chatting to different individuals. It is also integrated with Google Knowledge Graph which can provide relevant and trending content on topic [41]. Another useful feature that OpenAI's ChatGPT is limited by is creating art. Chatsonic can create art using two different models, the Stable diffusion and DALL-E. Another useful feature is that Chatsonic has a chrome extension that enables generative AI capabilities on many websites. This extension has been used almost like a personal secretary that summarizes documents and replies to social media posts. Chatsonic also has an AI chatbot builder extension called Botsonic. This can be used to train ChatGPT on specified data for either business or personal use. [41]

Some similarities to ChatGPT are that it can remember previous parts of conversations and use it in generating a response to future questions in the same chat. Each of these chats can then be saved and used again when the user wants to continue a conversation topic. Like ChatGPT, Chatsonic also has a mobile application that supports all its features. It also offers free generative AI prompts that can be used on ChatGPT or Chatsonic without the need of an extension.

5.1.2 Gemini AI

To keep up with the latest AI race, Google announced that it is also producing its own AI model. Bard AI (renamed to Gemini AI recently) is also a chatbot like ChatGPT. Gemini AI was developed using Google's Transformer and Mixture-of-Experts (MoE) architecture [44]. Currently it is an experimental conversational AI service that shows promising results however is not quite on par with ChatGPT yet. Gemini AI just released version 1.5 and claims that its natural language processing capabilities have improved comprehension and response to user input with greater accuracy. It also claims to have reduced the restriction of having data limited to a specific year and they aim to have it be integrated as a future personal assistant that analyses input text and provides document summaries.

5.1.3 Codewhisperer

Although OpenAI's ChatGPT can generate code, it is not known for being the most accurate or consistent platform for generating code. A few AI platforms have focused its main functionality on generating code instead of a more traditional conversational bot like ChatGPT. One such platform is Amazon's Codewhisperer. Amazon created this platform to give developers an efficient way to debug, analyze and decipher code problems. It is not meant to be a replacement for coders but is supposed to make the developer's work easier in helping to identify problems faster. It does this by utilizing natural language processing techniques to review code and uses machine learning algorithms to identify errors in the code. Often a developer may take hours to identify a single problem and this platform aims to minimize the effort needed to identify and resolve issues in the code.

The main benefit to CodeWhisper is that it was designed to be user-friendly and intuitive. This is achieved by the variety of customizations which can be adjusted for use from beginners to advanced developers. Amazon also created this with the plan to be able to handle large code bases and made it integrated with popular development tools such as GitHub. Thanks to this it can be easily and quickly integrated into current existing projects which will support faster use rates of CodeWhisper adoption. [41]

5.1.4 DeepL Write

DeepL is a firm that specializes in AI language translation and created in 2017 in Germany. With language translation as the main goal of this company, DeepL created an AI assistant called DeepL Write. Currently this is still only a beta product, but it was created with the aim of being a writing assistant. This AI is meant to be used to help refine writing accuracy and quality. It currently provides helpful suggestions and recommendations on style, quality, phrasing, and tone. It also helps with identifying grammar corrections and suggestions to word choices to improve overall writing and communication. One advantage available on this platform is that there is the read aloud functionality. Currently OpenAI's ChatGPT platform does not have a built-in functionality that will read aloud the text. [45]

5.1.5 Elicit

Elicit is another AI platform that uses language models similar to GPT-3. The difference between this platform and OpenAI's ChatGPT is that Elicit was designed for helping the research process. This works through reviewing literature that researchers need to process. After inputting an initial inquiry to Elicit, it will then go through and summarize documents that are highly rated and related to the inquiry. The idea behind this platform is to provide summaries on dependable sources which can then be used in research. While this platform could be useful for getting summaries on potential research sources, many use this to find relevant papers. Oftentimes it is difficult to track down relevant sources so students and researchers alike will use Elicit to get relevant papers and to find other potential research that could be used as potential citations relevant to their research and work. [46]

5.2 Comparison of different Platforms to ChatGPT

This section will compare similar platforms to ChatGPT and discuss the potential use case of each. A summary of this comparison is shown in Table 24.

A major benefit of using Chatsonic is that it was created to fill in the limitations of OpenAI's ChatGPT. One such limitation that Chatsonic fills in for is having access to the latest information. With Chatsonic having access to the latest information, this allows for more up to date generalization of relevant data. This feature could be useful for this project as it can be used to generalize the latest information regarding current breakthroughs. Another ChatGPT limitation that Chatsonic makes up for is being able to generate art. This feature could be useful for generating diagram layout ideas. Although it could be useful in generating diagram ideas, it does not guarantee the most efficient layout for the project needs. Hence this feature would be needless and could potentially create more problems than it is worth.

While showing promising results Gemini AI is still in its infancy stages compared to OpenAI's ChatGPT since it is not fully accessible to the public yet. Although this is the case, this platform can still potentially be of use soon as it was built by Google with plans to compete with OpenAI's ChatGPT. This brings potential usage as Google plans to integrate it with Google Nest. This in turn could potentially be integrated into this project by integrating existing google Nest into the smart desk and mobile app. However, that is beyond the scope of this project and would be more of a future expansion of this project.

Codewhisperer is a platform that aims more towards the developer community compared to ChatGPT. Although ChatGPT can generate code, it has issues with accuracy, and it doesn't always do a good job with analyzing the code. This grey area is what Codewhisperer aims to fill by providing a user-friendly platform for debugging and code analyzation. One downside to this platform is that for in-depth analysis and debugging, that means providing access to the code. This can cause potential issues with security as it has access to all the code given to it and therefore the company behind this platform would also have access to the code. There is also no guarantee that the generated code is one hundred percent correct. However, since this platform is aimed towards developers it is more correct in comparison to ChatGPT.

Table 24 - AI platform Summary

Platform	Usage	Pros	Cons
ChatGPT-3	- General conversation	- Very versatile platform that is widely used for a range of topics	- Doesn't have the latest news from the most recent years - The next tier is for paid members only
Chatsonic	- Generalization of information - Generation of art - Conversations	- Access to current events and information - Ability to generate art - Usage of Persona	- Potential ethical issues with the generation of art
Gemini AI	- General conversation - Smart home appliances integration	- Potential to increase the usability of smart home appliances with its integration into Google Nest	- Not fully accessible to the public yet - Features not fully developed yet
Codewhisperer	- Generation of code - Analysis of code	- Saves developers hours in debugging code - Can help speed up the development process by generating efficient code	- No guarantee that the generated code is 100% correct - Potential security issues
DeepL Write	- Writing assistant	- Gives useful writing suggestions and refinement - Ability to read text aloud	- Still only a beta product
Elicit	- Research assistant	- Summarizes documents from dependable sources - Can help researchers find potential sources in a shorter amount of time	- May have limited access to certain dependable sources

ChatGPT can be used as a writing assistant, but it struggles with refining and giving quality recommendations. This is what DeepL Write aims to achieve on their platform. Another useful feature of this platform is that it can read text aloud. Being able to read aloud text means that the user will be able to continue working without having to stop and read its suggested recommendations.

A major benefit to Elicit compared to the other platforms is that it was created to help with the research process. This means it can help save researchers hours by providing summaries on dependable sources. This is something that ChatGPT lacks because it doesn't have access to the latest documents and information after a certain cutoff time. While it was created with the idea of summarizing a great deal at once, it shines in helping researchers find relevant sources related to their current search. With this fast help in finding relevant sources, the researchers can focus on reading and understanding the sorted sources.

While each of these different platforms have their specializations, they are only useful in that specific context. This is where ChatGPT shines the most as it is a multipurpose platform that may one day have all these features in one area. As the popularity of AI platforms increases, it also brings with it many controversies with the increase and potential usage of it. Therefore, no matter how the platform is used, it should be used with caution and should not be something to be fully reliant on.

Chapter 6 - Hardware Design

In the realm of electrical engineering, the translation of theoretical concepts into tangible, functional systems is an exercise that bridges the gap between abstract ideas and their practical applications. The hardware design section of our senior design project document illustrates the process through which our intended solution takes physical form. This section is dedicated to presenting the foundational elements of our project's hardware aspect, designed to meet the specified requirements.

6.1 Subsystem Block Diagram

At the core of our hardware design documentation, the subsystem block diagram shown in Figure 6 serves as the initial blueprint. It provides a high-level overview of the project's architecture, illustrating the key components and their interconnections. This diagram acts as a roadmap, guiding the reader through the complex network of subsystems and highlighting how they synergize to achieve the project's objectives. It's an essential tool for understanding the overall structure and flow of data within our system.

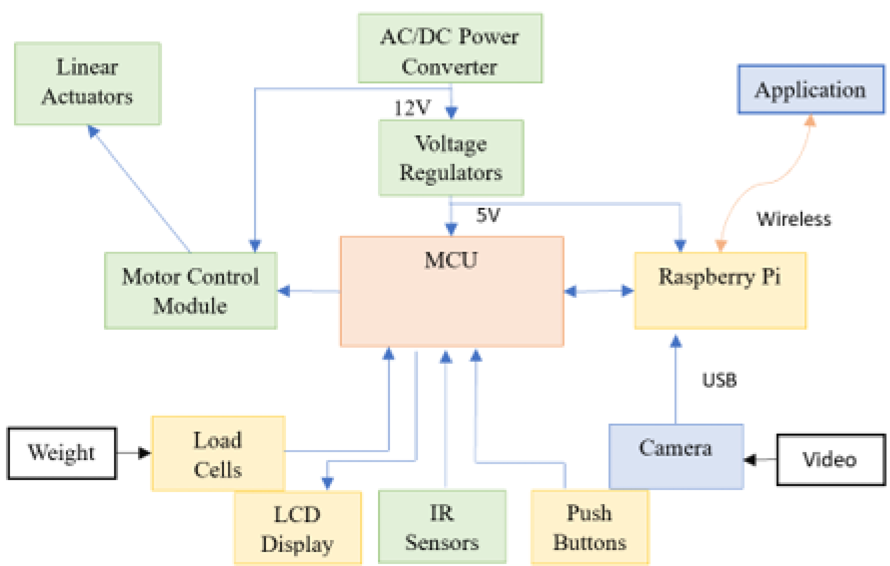

Figure 6 - Entire Subsystem Block Diagram

6.1.1 MCU

The MCU is adeptly powered by a dual-stage regulation system. Initially, the AC/DC Power Converter adjusts incoming current to a consistent 12V DC output, safeguarding against fluctuations inherent in AC sources. Subsequently, Voltage Regulators meticulously condition the power to a stable 3.3V supply, tailored to meet the MCU's operational requirements. This two-tiered power supply ensures the MCU operates within its optimal voltage parameters, maintaining the integrity and longevity of our system.

The MCU’s architecture boasts an array of input and output connections, interfacing with various components that enhance the system’s functionality.

It governs a Motor Control Module, which drives Linear Actuators, translating digital commands into precise mechanical movements. These interactions are fundamental in systems requiring motion control, such as robotic arms or automated machinery.

It is intrinsically linked to Load Cells, instruments that measure weight or force. Through the MCU’s analog-to-digital conversion capabilities, these measurements are digitized, enabling accurate monitoring and weight-dependent decision-making processes.

An LCD Display is driven by the MCU to provide a user-friendly interface, displaying vital statistics, system statuses, or user prompts, thus facilitating interaction and monitoring of system performance.

The MCU gathers environmental data via IR Sensors, which detect information to ascertain proximity and movement, feeding this information back into the system for responsive and adaptive behaviors.

User inputs are captured through Push Buttons connected to the MCU, allowing for manual control or command input, essential for user-initiated operations or emergency interventions.

To augment its capabilities, the MCU interfaces with a Raspberry Pi via a wireless connection. This symbiosis unlocks advanced computational power, enabling complex processing tasks such as image recognition or internet connectivity. The Raspberry Pi, in turn, communicates with a Camera, transferring video data through USB, which can be used for real-time monitoring, security surveillance, or image processing applications.

6.1.2 Raspberry Pi

In our sophisticated hardware ecosystem, the Raspberry Pi emerges as a critical component, serving as an intermediary between high-level application commands and the core functionalities managed by the Microcontroller Unit (MCU). This compact yet potent computing module extends the capabilities of our system beyond traditional embedded boundaries, introducing the versatility of a full-fledged computer.

The Raspberry Pi is integrated into our system to leverage its substantial processing capabilities. Equipped with a more powerful CPU and the ability to run a full operating system, the Raspberry Pi can handle complex tasks such as data analysis, image processing, and network communications which would be beyond the scope of the MCU alone.

It boasts a dedicated wireless module, which allows it to communicate with the MCU and other networked devices seamlessly. This wireless functionality is pivotal in applications where remote operation or data transmission is essential, providing the system with the ability to interface with other devices, cloud services, or Internet-based applications.

Additionally, the Raspberry Pi connects to a camera module via USB, which enables it to capture and process high-resolution video streams. The integration of video capabilities opens up avenues for advanced monitoring applications, such as security surveillance, machine vision, or real-time video analytics.

One of the key roles of the Raspberry Pi within this diagram is to act as a bridge to the application layer. It receives processed data and user inputs from the MCU and translates these into actionable insights or graphical interfaces, which can be used by the end-user or other applications to monitor, control, or further process the system's output.

The choice to include a Raspberry Pi in our design is indicative of our commitment to reliability and expandability. It allows the system to be updated with new software features over time, ensures compatibility with a wide range of peripheral devices, and offers the possibility to scale up the computational capabilities as needed.

6.1.3 Linear Actuators

In the realm of electromechanical systems, linear actuators play a pivotal role in converting electrical energy into precise linear motion. Within our project's hardware framework, the Linear Actuators represent a fundamental component, tasked with the direct implementation of physical actions dictated by the system's control logic.

The Linear Actuators are directly connected to the Motor Control Module, which in turn is governed by the Microcontroller Unit (MCU). This hierarchy ensures that the actuators receive accurate control signals, dictating their motion parameters such as position, speed, and force. These actuators are the physical embodiment of our system's outputs, making them crucial in applications ranging from automation to robotics.

They are engineered to execute commands with high precision, enabling our system to carry out intricate tasks that require delicate movement or force application. Whether it's adjusting the position of a sensor, manipulating a tool, or controlling a valve, these linear actuators transform electronic instructions into mechanical reality.

Selected for their reliability and durability, our linear actuators are designed to withstand the rigors of continuous operation under varying loads. Their robust construction ensures longevity and consistent performance, vital for maintaining the overall system's integrity over time.

Coupled with the Load Cells in our system, the linear actuators are part of a feedback loop that allows for real-time monitoring of the forces they exert or the weights they manipulate. This feedback is critical for adaptive control strategies where precise force application is necessary, ensuring that our system operates within its defined mechanical constraints.

Linear actuators are versatile elements within our design, enabling the system to interact with the external environment effectively. They are instrumental I a myriad of applications, from simple open-close operations to complex automated sequences that require sequential and coordinated movements.

6.1.4 Motor Control Module

The Motor Control Module in our system architecture is an integral component tasked with the precise management of actuation processes. It acts as the conduit between the digital commands issued by the Microcontroller Unit (MCU) and the physical movements executed by the Linear Actuators. This module is the cornerstone of our design's ability to affect the physical environment, translating electronic instructions into mechanical motion with finesse and accuracy.

Embedded within this module is the logic and power electronics necessary to interpret the PWM (Pulse Width Modulation) signals or other digital control messages from the MCU. These signals are meticulously converted into the current and voltage required to drive the actuators, modulating their extension and retraction in a controlled manner.

The Motor Control Module is not just about turning actuators on and off; it is engineered for the synchronization of multiple actuators. This ensures coordinated movements in applications where multiple degrees of freedom or simultaneous actuations are needed, a common requirement in robotic systems or automated machinery.

Furthermore, this module is designed with protective features to prevent electrical and mechanical overloads, ensuring that the Linear Actuators operate within safe parameters. These features protect the actuators from potential damage due to excessive force or overcurrent conditions, thereby enhancing the system's reliability and longevity.

Efficiency in power consumption and precision in control are key attributes of our Motor Control Module. It utilizes advanced algorithms to optimize the motor driving process, reducing energy waste and enhancing the precision of movement. This is critical in applications where battery life is limited or where meticulous actuator control is paramount.

The module is also capable of integrating feedback from the actuators and other sensors to implement closed-loop control systems. This feedback allows for real-time adjustments to the actuator movements, compensating for any discrepancies between the expected and actual positions.

Designed with versatility in mind, the Motor Control Module is compatible with various types of actuators, from simple DC motors to complex servo systems. This broad compatibility allows our design to be flexible and scalable, accommodating a wide range of applications and future enhancements.

6.1.5 AC/DC Power Converter

In our system's electrical landscape, the AC/DC Power Converter stands as a critical gateway, bridging the gap between the conventional alternating current (AC) power supply and the direct current (DC) power required by our system's components. This converter is meticulously designed to ensure a smooth transition of power from the AC mains to the precise voltage levels necessary for the electronics and actuators to function optimally.

The converter performs the vital task of converting the higher-voltage AC power, typically available from standard electrical outlets, down to a more manageable 12V DC output. This conversion is not merely a reduction in voltage; it involves rectifying the alternating nature of the input to produce a steady, direct current that our sensitive electronic components can safely use.

Beyond the initial conversion, the AC/DC Power Converter incorporates sophisticated voltage regulation capabilities, it ensures that despite any fluctuations or surges in the AC mains voltage, the output remains consistent and stable. The quality of this output power is of paramount importance, as it lays the foundation for the system's overall performance and longevity.

Once converted, this 12V DC output feeds into secondary voltage regulators, which further refine the power to suit the specific demands of the system's diverse landscape. The regulators downstream tailor the voltage to an even more precise 3.3 V level, necessary for the sensitive logic circuits and microcontrollers at the heart of our design.

Efficiency is a hallmark of our AC/DC Power Converter design, minimizing energy loss through heat during the conversion process. It employs cutting-edge components and thermal management techniques to ensure that the system operates coolly and efficiently, which is especially important for maintaining the integrity of the components and for the longevity of the system.

Safety is embedded in the converter's design through features such as overvoltage, overcurrent, and short circuit protection. These measures protect not only the power converter itself but also the downstream components from potential electrical hazards.

The converter is built to meet rigorous industry standards and certifications, ensuring that it can reliably handle the demands of continuous operation. The quality of this module directly influences the dependability of the entire system, making its design and selection a process governed by stringent criteria.

In conclusion, the AC/DC Power Converter is a vital component that embodies the robust and efficient electrical foundation upon which our system is built. It transforms and conditions the power supply, ensuring that each subsystem receives clean and stable energy to perform its functions – a testament to the thoughtful engineering and foresight applied in our design to guarantee seamless and reliable operation.

6.1.6 Voltage Regulator

The Voltage Regulator is a crucial element in the power management subsystem. Ite performs the essential task of converting and regulating the voltage level from the AC/DC Power Converter to a stable 3.3V required by the Microcontroller Unit (MCU) and potentially other 3.3V-compatible components. In the hardware subsystem diagram, it shows a clear hierarchical relationship where the 12V output from the ACDC Power Converter is stepped down to a safe, consistent 3.3V supply.

The role of the Voltage Regulator is to ensure that the downstream devices, like the MCU, receive a constant voltage, irrespective of fluctuations in the input supply or variations in load on the power system. This regulation is critical because microcontrollers and other sensitive electronic components require a precise operating voltage to function correctly without being damaged by overvoltage or underpowered by undervoltage conditions.

Voltage regulators typically incorporate features such as thermal shutdown, current limiting, and short-circuit protection, which safeguard the electronic system against common electrical issues. Moreover, the regulated output contributes to the reliability and stability of the entire system's performance, which is particularly important in applications involving data processing by the MCU or Raspberry Pi, as depicted further downstream in the diagram.

In the context of the subsystem block diagram, the Voltage Regulator is part of an interconnected architecture. Its position reflects its intermediary function, converting the power supply to appropriate levels for both processing units and peripheral devices like the Load Cells, LCD Display, and all other possible components shown in the diagram that require a 3.3V input.

6.1.7 Load Cells

The Load Cell is an integral sensory device within the diagram's data acquisition and monitoring subsystem. Its primary function is to transduce physical force into a quantifiable electrical signal that can be read and processed by the system's electronics, most notably the Microcontroller Unit (MCU).

In the given diagram, the Load Cells do not interface directly with other sensory components like the Push Buttons, instead choosing the be fed into the MCU. The positioning of the Load Cells show that the data produces by them is vital for the system's operations, which will include weight measurement for the pressure sensing system, which requires precision such as balancing, inventory management, and the automated control system.

Our Load Cells operate on the principle of strain gauge technology, where deformation caused by an applied load results in changes in electrical resistance. This change is then measured and converted into a digital signal by the MCU for further processing. In our system, the Load Cells are part of a feedback loop, informing the Motor Control Module to make adjustments based on the measured weight to maintain desired operational parameters.

Key to the function of the Load Cells are their accuracy and reliability, as they often operate in environments that require precise measurements. They must withstand the physical stress of the loads they measure while maintaining their sensitivity and linearity to provide accurate, consistent output.

Overall, the Load Cells' role in this subsystem is to deliver precise measurements of weight or force that are critical to the system's application. They are foundational sensors that contribute to the intelligence and responsiveness of the system, enabling it to act upon real-world physical changes in a controlled and measured manner.

6.1.8 LCD Display

The LCD (Liquid Crystal Display) Display within the system's block diagram serves as a user interface that presents data in a visual format. Located within the output modules of the system, it takes information processed by the Microcontroller Unit (MCU) and displays it in a human-readable form. This will include measurements such as the position of the linear actuators and other system metrics that require monitoring.

In this system, the LCD Display is a critical component for user interaction allowing for real-time monitoring and system status updates. It provides a direct line of feedback from the system's operations, which could be crucial for immediate decision-making or for understanding messages, or other information pertinent to the system's function or diagnostics.

The placement of the LCD Display in the diagram indicates that it is one of the key interfaces for users or operators to interact with the system. It is linked directly to the MCU, which means that it displays information processed or relayed by the MCU, ensuring that the displayed information is timely and accurate.

The LCD Display is also shown in conjunction with the linear actuators and Push Buttons, which shows that there is an interactive system where the display changes based on the position of the linear actuators and/or button presses. For instance, the user uses the Push Buttons for the desk to raise the legs of the linear actuators up and down, which in turn will move the countertop of the desk up and down. This is in addition to the automatic functions provided by the load cells face tracking software.

Overall, the LCD Display is an important part of our system's human-machine interface (HMI), facilitating direct communication between the system's internal operations and the user. It enhances the system's usability by displaying information in a clear, visual format, which can improve the ease of use, safety, and efficiency of the system's operations.

6.1.9 Push Buttons

Within the landscape of the subsystem block diagram, the Push Buttons are presented as an essential interface for user input. These buttons allow for manual control over certain aspects of the system, providing a simple and effective way for users to issue commands and make selections.

Positioned physically at a perpendicular fashion to the bottom of the desk, along with the LCD Display, in order to have the buttons facing the user, the Push Buttons will feed directly into the Microcontroller Unit (MCU) to provide a tactile interface for real-time system interaction. A third button will be used either to provide emergency stopping or to turn on or off the automatic capabilities. These functions will provide a responsive and immediate method for users to engage with the system.

In the system depicted in our subsystem block diagram, Push Buttons were selected for their ease of use and reliability, as well as easy integration capabilities. Each button can be programmed to correspond with a particular action or command within the system's logic. The feedback loop created between the push buttons, the MCU, and linear actuators allows for an interactive experience, where a user can see the results of their input reflected immediately by the legs of the desk.

The inclusion of the push buttons also shows that we value user control and manual override capability. In the event that the automatic functions of the desk need to be turned off, or when precise manual control is needed, these buttons offer a straightforward way to ensure continued operation.

Overall, the push buttons are a vital part of the user interface. They are instrumental in allowing users to interact with the system in a controlled and predictable manner. Their function within the system demonstrates our group's desire to have human input within our system and to provide a fail-safe for automation, ensuring that the system remains versatile and user-friendly.

6.1.10 Overall Section Conclusion

Our subsystem block diagram illustrates a well-organized architecture that integrates power management, processing units, sensory inputs, and user interfaces to create a responsive and functional system.

At the power management level, the AC/DC Power Converter and Voltage Regulators ensure that all components receive a stable and appropriate power supply, which is fundamental for maintaining the integrity and longevity of the electronic components.

The central processing units, consisting of the MCU and the Raspberry Pi, form the brain of the system. They process data from sensory inputs, such as the load cells, and execute the logic of the system, while facilitating wireless communication for remote interactions.

The sensory inputs, particularly the load cells, are critical for providing accurate real-time data that the system can act upon. They enable the system to interact with the physical world in a measurable way, which is vital for our application which depends on precise force and weight measurements.

User interfaces, namely the LCD Display and push buttons, allow for real-time user interaction with the system. The LCD display provides a visual output of system statuses and measurements, while the push buttons offer a direct method for user input, ensuring that the system is accessible, controllable, and adaptable to user needs.

Additionally, the system includes a motor control module and linear actuators, indicating a capability for mechanical control and movement, which shows that the system will interact with its environment not just in data acquisition but also in performing physical tasks.

In conclusion, the subsystem block diagram depicts our hardware subsystems which will be engineered to balance automated functions with user control. It shows our careful planning and integration of various electronic and mechanical components to serve a specialized purpose. The system's design shows that it's capable of handling complex tasks while providing users with the necessary tools to monitor and interact with the system efficiently and effectively.

6.2 Schematic Diagrams

Transitioning from a broad perspective to a more detailed view, the schematic diagrams offer a comprehensive look at the electrical connections and components that make up each subsystem. These diagrams are crucial for understanding the inner workings of our project, depicting everything from component specifications to connection types, thus ensuring clarity and precision in the assembly and testing phases.

This section will be divided into three separate parts, the first one discussing the peripheral connections to the MCU and the second part discussing the power delivery of our system. The third part will show the overall schematic with all the connections made that will be used for PCB construction.

6.2.1 Peripheral Schematic and Analysis

Figure 7 below shows the schematic for the peripheral connections to the MCU that will be used to power and control the different components. An explanation of the different connections and why they were made that way will be discussed in the following section.

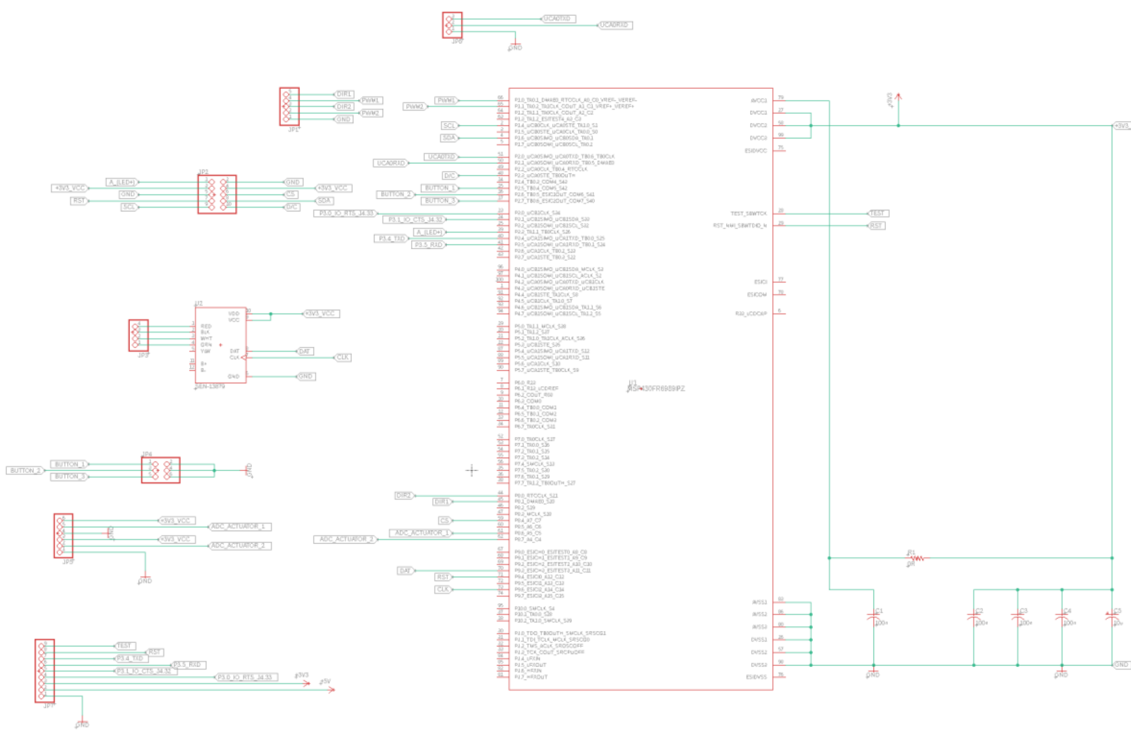

Figure 7 - Overall Peripheral Connection Schematic

Since there are many connections to our MCU and the MCU has 100 pins to connect to, the connections to our microcontroller are difficult to differentiate between without zooming in to make out the different labels to the different pin on the microcontroller. Figure 8 shown below zooms in on a specific section and will explain the different connections when they are more visible. Any connections not shown in the preliminary zoomed-in photo will also be included in separate pictures to discuss those in depth as well.

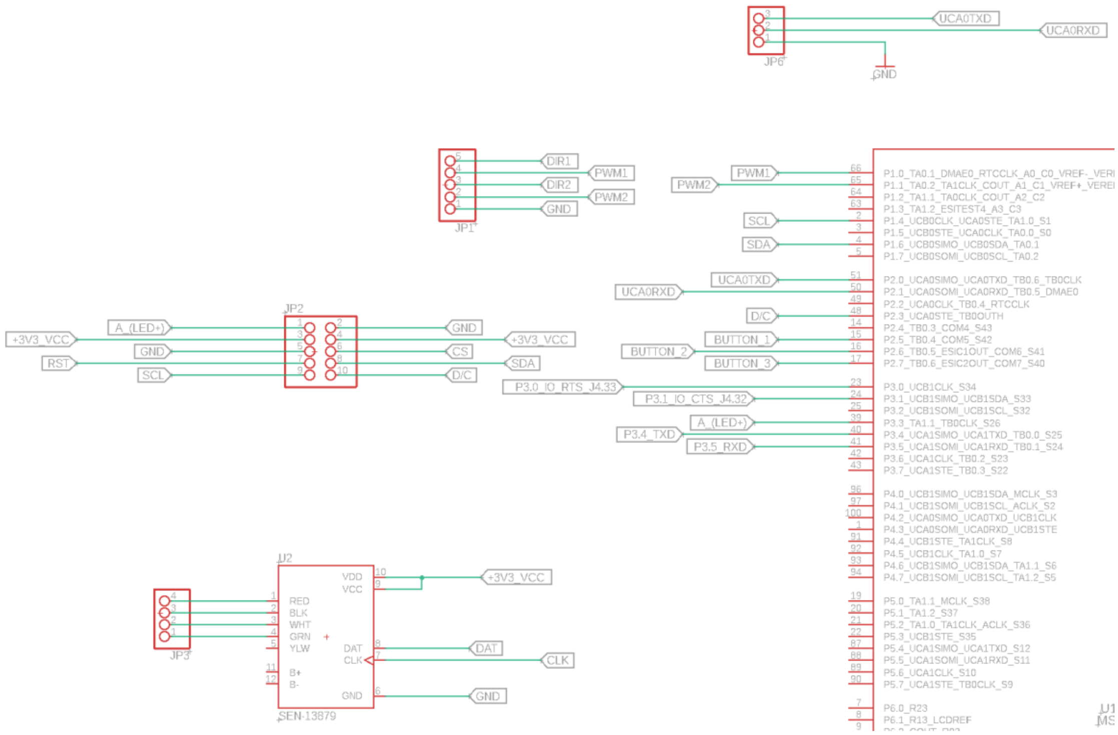

Figure 8 - Zoomed-In Peripheral Schematic 1

The first part to be focused on is component JP6. For future reference, every component denoted with the letters "JP" are pin headers. Pin headers were an important part of our design because most of the components controlled by the PCB needed to be located far away from our board. For example, the linear actuators for our desk need to be located on each of the legs of our desk and will be connected to our central board with wires since the board will be mounted underneath the desk and cannot be mounted to either leg of the desk at the same time.

To return back to component JP6, this handles the peripheral connections from the MSP430FR6989 microcontroller to our Raspberry Pi Board. Pins 1 and 2 on the header will be wired to P2.0 and P2.1 on the microcontroller which correspond to UCA0TXD and UCA0RXD. These connections are responsible for data transmission between the Raspberry Pi and MSP430. In addition to this, pin 3 on JP6 is connected to the ground since the Raspberry Pi and microcontroller will need to share a common ground to allow for the data transmission.

The next part to be discussed is the connection for the motor controller, denoted in the schematic as JP1 in the schematic. Starting from the top, pin 1 denoted as DIR1 by it's label is connected to P8.1 on the microcontroller. This is responsible for the direction input for motor 1. The second pin denoted as PWM1 on the schematic is connected to P1.0 on the microcontroller and is responsible for PWM input for speed control on motor 1. The third pin denoted as DIR2 is connected to P8.0 and is responsible for the direction input for motor 2. The fourth pin denoted as PWM2 is connected to P1.1 and is responsible for the PWM input for the speed control on motor 2. Finally, the fifth pin denoted as GND is connected to the ground.

The next component is a pin header denoted as JP2 on our schematic. This is responsible for the connection from our microcontroller to the pin extender for our LCD. Referring to the labels on the pins, A_(LED)+ is connected to P3.3, GND is connected to the ground, +3.3_VCC is connected to the supply voltage, CS is connected to P8.4, LCD_RST is connected to P9.4, SDA/SIMO is connected to P1.6, SCL is connected to P1.4, and D/C is connected to P2.3.

The next component that will be connected to our microcontroller is the amplifier which is responsible for amplifying the signals sent by the load cells so that our microcontroller can properly read the outputs. This component is denoted as U2 on the schematic. VDD and VCC are shorted and are connected to our 3.3V supply. DAT is connected to P9.3 on our microcontroller while CLK is connected to P9.6 on our microcontroller. The final connection to be made is GND which is connected to our common ground. In addition to this, the connections labeled RED, BLK, WHT, and GRN are connected to a pin header that we can connect our load cells to in order to transmit the measurements taken from underneath the mat the user will be utilizing.

Included below in Figure 9 are the next three peripherals that will be connected to our microcontroller. These connections are responsible for the buttons, linear actuators, and the connection from our microcontroller to an external MSP430 which has the eZ-FET Onboard Emulator with EnergyTrace Technology so that we can load our code onto our PCB once completed.

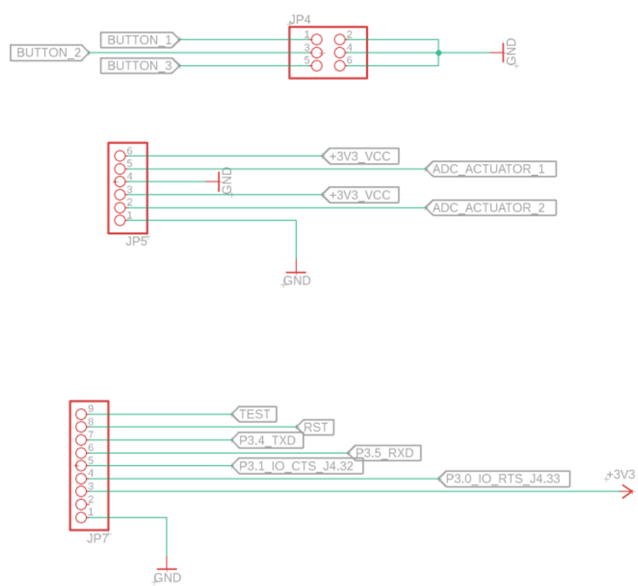

Figure 9 - Zoomed In Peripheral Schematic 2

The first peripheral to be discussed in this section is JP4. This component is responsible for connecting the three external buttons to our MCU for operation. One lead of each button will be connected on the left side of the pin header while the other lead will be plugged into the pins on the right side in order to connect them to the ground. This will ensure that the buttons will be wired in an active low configuration in order to make them easily programmable.

The next component found below JP4 is JP5 and this is responsible for the connection from each of our linear actuators to our microcontroller. Pins 6 and 3 on the header will be connected to our 3.3V supply voltage. Pins 5 and 2 on our header will be connected to separate ADC pins on our microcontroller. There are five total wires coming out of each linear actuator. Two of them, as stated earlier, will be connected via our motor controller to our microcontroller in order to control the motion of each actuator. The remaining three wires are for the potentiometer located inside each of the actuators. Each actuator has a five kiloohm potentiometer that's value changes as the actuator moves either up or down. We want this information so that we can take this value and correspond it to a certain position of each actuator so that we can save the user setting. To read the resistance values on each of these potentiometers, one connection must be made to the supply voltage, one connection to the ground, and the other connection to an ADC pin. The reason the pin must be ADC is it because it reads an analog value and those are the only pins that have that functionality on our microcontroller.

The last peripheral that will be found in this section is the pins responsible for communication between the microcontroller that will be mounted on our PCB and the microcontroller available on the ez-FET Onboard Emulator with EnergyTrace technology. This is on our PCB for convenient loading and debugging of our code from our PCB without having to include an onboard emulator. The explanation for this part will be referring to the labels on the net connections. TEST is connected to the TEST/SBWTCK pin on our microcontroller. RST is connected to the RST/NMI/SBWTDIO pin on our microcontroller. TXD is connected to P3.4 on our microcontroller. RXD is connected to P3.5 on out microcontroller. IO_CTS_J4.32 is connected to P3.1 on our microcontroller. IO_RTS__J4.33 is connected to pin 3.0 on our microcontroller. Finally, the last two pins are dedicated to connecting our supply voltage of 3.3 V and the common ground on our schematic design.

The last part to focus on for the peripheral connections can be found on the right side of our MSP430FR6989. On the right side it shows how our supply voltage connections are connected to each other. The pins responsible for DVCC1, DVCC2, DVCC3, and AVCC1 are connected to the 3.3V supply voltage while AVSS1, AVSS2, AVSS3, DVSS1, DVSS2, and DVSS3 are connected to the ground. They will be separated with decoupling capacitors C1, C2, C3, C4, and C5. A special note to make here is that C5 is an electrolytic polarized capacitor that differs from the other ones.

In summary, the meticulous planning and implementation of connections between the microcontroller and its various peripherals are fundamental to the robustness and efficiency of the standing desk as a whole. By carefully considering the nature of each peripheral, the communication protocols involved, and the specific requirements of our application, we have established a harmonious and scalable interaction framework. This not only ensures optimal performance and reliability but also provides a solid foundation for future enhancements and integration of new technologies. Moving forward, this groundwork will serve as a critical component in our pursuit in Senior Design II to realize and fully build our project.

6.3 Architecture

The architecture section delves deeper into the conceptual and physical layout of our system. It discusses the rationale behind architectural decisions, the choice of components, and how these elements come together to form a cohesive system. This part of the document addresses both the challenges and solutions encountered in designing a robust and efficient architecture. Providing insights into the thought processes and technical considerations that shaped our project.

6.3.1 Power Distribution

This section will discuss the overall design of power distribution for the U.P.R.I.G.H.T, detail where each system will be located within the desk and explain why certain chose were made. There are some critical factors that went into how the design was approached. Those factors included a desire that the power system require little to no interaction from the user, that each subsystem be powered in a safe and secure manner, that there would be minimal visionary cues of any hardware for aesthetic purposes, and that the desk could be used basically anywhere. As the topic of conversation is progressed throughout each component of the system, keep these critical factors in mind.

The first important issue that faced the design was the primary source of power that the desk would utilize. For a workable solution, all of the major components planned for subsystems within the desk had to be researched and chosen. From there, the overall power requirements could be realized. See Table 25 below for each component design parameters that were used for the overall power requirement.

Table 25 - Detailed Component Power Design Parameters

Design Parameters	Rated Voltage	Rated Current
Raspberry Pi 4B	5 V	2.5 – 3 A Minimum
Web camera Microsoft LifeCam HD-3000	5 V	0.5 A
Linear Actuator #1	12V	Max load current: 3-6 A No load current: 1.5-3 A
Linear Actuator #2	12V	Max load current: 3-6 A No load current: 1.5-3 A
Motor controller Cytron Model # MDD10A	Motor Supply: 5 – 30 V Logic Input Voltage: 3.3 – 5 V	Max Continuous: 10 A Max Peak: 30 A
MCU MSP-430fr6989	1.8 – 3.6 V	100uA/MHz Active Mode 0.4uA (typical) Standby 0.2uA (typical) Shutdown
LCD Display CFAF128128B1-0145T	2.7 – 3.3 V	-Supply Current for LCM (3.3V): 1.7 Typ, 2.55 Max mA,

Looking through the table above, it can be observed that there are three main voltage levels that need to be supplied for full power distribution throughout U.P.R.I.G.H.T, which include 12V for the linear actuators, 5V for the raspberry pi and webcam, and lastly 3.3V for the MCU and LCD display. Other peripherals that will be controlled by the MCU, namely the buttons, load cells, and linear actuator potentiometers require minimal additional power or will be fed directly from another component. With the actual parameters set, the particular primary source decided upon also needed to consider how it would affect any user interaction. Taking these facts into account it was determined that batteries would not be recommended because of the additional requirement from the user to charge the batteries as they died. Instead, the desk would be fed from a 120V AC source that would then be converted down to 12V by an AC/DC adapter. This adapter would need to be sufficiently rated for the entire system, the reason why a 20A/240W model was chosen.

From this point, the most optimal way to transform the voltage down to 5V and 3.3V was the next design step to be considered. The initial rationale was to feed the Raspberry Pi directly from the custom PCB utilizing two different voltage regulators to convert the primary signal, separately, to each necessary voltage level. This would have no doubt worked with one regulator feeding the MCU and the other, the Raspberry Pi, however this approach added some unneeded complexity. Additionally, the thinking behind not utilizing the 5.1V/3A USB-C power supply that came with the Raspberry Pi was to limit the number of plugs to just the one from the main adapter. If this concept was followed through, the Raspberry pi would have had to be fed directly to its GPIO (general purpose input output) pins (which is possible, but the user manual warned against the practice) or the PCB would have needed to add the capability to connect with a USB. Instead of accepting this added layer of complexity to the PCB design, an alternative solution was devised.

First, utilizing the standard USB-C power supply would eliminate the need to for either the Raspberry Pi to be powered through the GPIO or the PCB to add USB connection capability. This would still leave two plugs instead of one that would need to be powered before the U.P.R.I.G.H.T was operational. The decided upon solution included the integration of a 120V/20A NEMA 5-20R duplex receptacle to be mounted underneath the desk where both the USB-C power supply and AC/DC adapter could be plugged into and mounted under the desk as well. Then, a 120V, 3-#12-gauge wire cable could be connected with the receptacle and integrated with a NEMA 5-20P plug to be inserted into a standard electric outlet. Not only does this solution solve all the various problems, but it also eliminates the need for a 12V to 5V voltage regulator within the PCB, further simplifying that design aspect. The rest of the components can be powered via the 3.3V rail from the PCB. Those include the MCU, motor controller, and all various peripherals.

It is also important to note that not only does each component need to be supplied with correct specifications due to their ratings, but every connection, cable, and wire must also be able rated to handle the necessary voltage and current. Figure 10 below can be used as a reference for the main components and systems, where they are located within the U.P.R.I.G.H.T, and the method by which power will be distributed among them. The desk will be plugged into a standard wall outlet and whether that is located within a residential or commercial building, that device will either be rated as 15A or 20A respectively. In order to accommodate either location, the receptacle installed under the desk, the plug to insert into the wall, and the cable in between will all be rated for 20A. The cable will be mounted in such a way that there will be plenty of slack when the desk is in a sitting position for it to extend the full 18” up without the power cable impeding any movement.

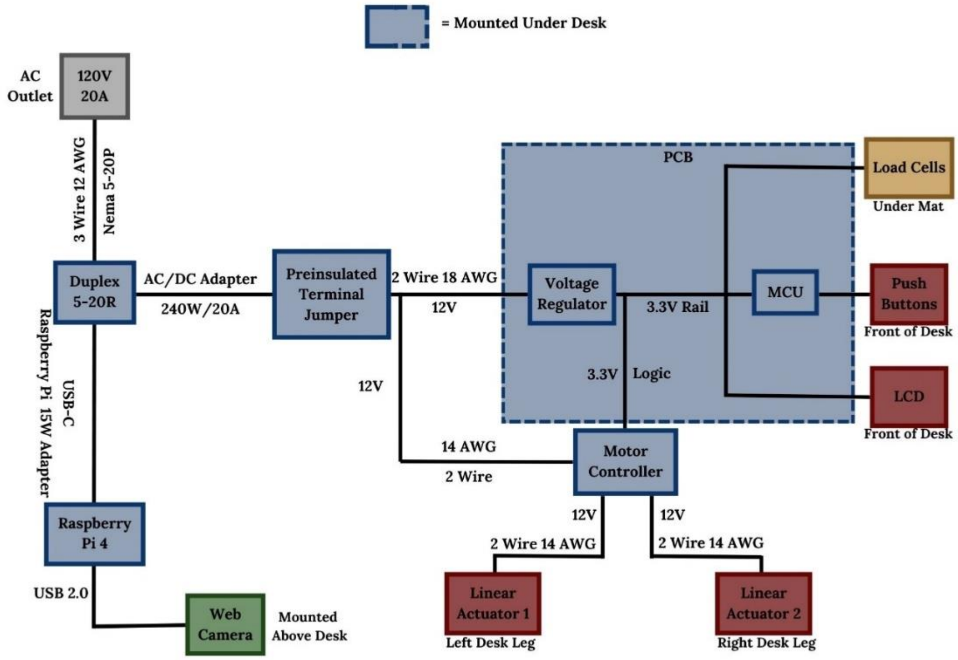

Figure 10 - Main Power Distribution

From the installed device, both power adapters will be plugged in and securely fastened to the underside of the desk to ensure that neither will lose connectivity and be squarely out of the way. The USB-C adapter is rated for Raspberry Pi's power requirements, and the webcam will be connected to the Pi via a USB 2.0 cord. Holes in the back corner of the desk will be drilled out and insulated to allow easy wire management for both the USB cable we install, as well as any misc. user cables. The wire leads from the main adapter will power a couple of screw type pre-insulated terminal jumpers that can be mounted under the desk. The terminals will be protected from any accidental electrical point of contact and any surrounding hardware will be insulated from the power on the terminal. There are many various models with different ratings, but they max out around 40A and 600V, meaning that they can easily handle U.P.R.I.G.H.T's power consumption. This will allow the wire leads from the PCB and motor controller supply pins to easily connect to the main power source with the fear of overheating any subpar connections. For instance, the cable lead that the AC/DC adapter came with matches the 20A rating of the adapter itself but the DC barrel connector that was included is only rated 5A. By bypassing that connector and connecting straight to an insulated terminal, it will eliminate any overheating risk.

Within the PCB, the designed voltage regulator will step down the voltage to feed (The next section discusses this in more detail) the MCU, logic input for motor controller, load cells, push buttons, and LCD display. The wires feeding the motor controller supply and then each actuator individually will also be rated for 20A. By no means will the motors ever pull anywhere close to that current, but it ensures a safe design with no possible overheating, even at full load. Take note that the above figure only shows the hardware connections that are tied to power distribution, not the connections related to communication and control of peripherals, which were discussed in the Section 6.1 and Section 6.2.

6.3.2 Voltage Regulator

This section will take a look into the design aspect and selection of components of the 12V to 3.3V DC/DC voltage regulator. As discussed in the previous section this will be the only regulator required because the systems demanding a 5V input will be fed from the official Raspberry Pi 15W USB-C adapter. The design of the 3.3V will constitute the power management side of U.P.R.I.G.H.T's custom PCB. Looking through the component power design parameter table in Section 6.2.1, will help clarify certain design criteria when deciding on a regulator. First off, it is obvious that every component that needs power at 3.3V is not going to be pulling very much current, and so it will be crucial that the chosen regulator be able to sufficiently convert power even at a very light load. For instance, the main components of the PCB, the MCU and LED will only pull a few milliamps together. The other major component, the motor controller is actually powered by the 12V supply feeding the motors, while only requiring 3.3V for logic communication with the MCU.

Ultimately, three regulators were chosen for closer inspection, and Table 26 below lists some of the parameters from each one. The data inserted into this table was found in the corresponding datasheets of each component from Texas Instruments' website. (These references are cited in the Reference page of the Appendices). [47] [48] [49] They were chosen to begin with, because they are all switching type regulators (as discussed in chapter 3 voltage regulator technology) and their respective components were in stock and available for purchase. The WEBENCH power design tool from TI was instrumental in designing voltage regulator circuits that were rated for the U.P.R.I.G.H.T's power requirements, namely that they can operate at very light loads. [50] As the table shows, the quiescent current for each regulator is quite low. This current is referring to the amount that the regulator will pull when in stand-by mode and not currently operating. Generally, the amount of quiescent current is tied directly into how much power the regulator is using, even while off, thus leading to how quickly a battery is drained. That will not be an issue with this design because of the main power supply being derived from an AC source, however it is always good practice to aim at not wasting any kind of power consumption. Another thing to watch out for, is if the quiescent current is too high, it could lead to difficulty with converting voltages at a very light load. The rule of thumb is to ensure that the output current never drops below the quiescent one, which should not be an issue with the components in question. Ultimately, the LMQ66410MC3RXBRQ1 regulator has the least amount of quiescent current.

Table 26 - Voltage Regulator Parameters

Design Parameters	LMQ66410MC3RXBRQ1	TPSM365R3RDNR	TPSM265R1V3SILR
Input Voltage Range	4 – 36 V	4 – 65 V	3 – 65 V
Max Output Current	1 A	0.3 A	0.1 A
Quiescent Current	1.5 Micro Amps	6.5 Micro Amps	10.5 Micro Amps
Voltage Ripple	50 mV	49.5 – 82.5 mV (1.5 – 2.5% of Vout)	50 – 70 mV
Switching Frequency Range	400 – 2200 kHz	200 – 2200 kHz	unknown
Operating Temperature	-40 – 150 ^{o}C/W	-40 – 125 ^{o}C/W	-40 – 125 ^{o}C/W
Theta-JA	45 ^{o}C/W	56.3 ^{o}C/W	49.7 ^{o}C/W

The rated input voltage is the next important factor in this design, namely because the output voltage of the AC/DC adapter might drop when power consumption from the linear actuators spike from the motor startup or straining under full load. It is vital that the regulators be able to handle any variations of voltage input. Seen from the table above, both of the TPSMs have a huge voltage range up to 65V, while the LMQ66410 rating comes up a little short of that, at 36V. Either way, both of these voltage inputs will work with plenty of room to spare. In regard to the switching frequency range, the higher the frequency the smaller the internal or external inductors and capacitors will have to be. Both the LMQ66410 and TPSM365 have a great range of switching frequency and have a fixed rate of 2.2MHz at 3.3V output, which can also help lead to a smaller output voltage ripple. The output current rating is also an important aspect of the design, and each of these regulators' max current capacity is greater than the required specs. It should be noted that the LMQ66410 also has the greatest current capacity of the three and choosing it will lead to better flexibility if any future components want to be added to the design. Efficiency will be the next key factor discussed as it will be important how each regulator performs when under light loads. This is the reason that the table below has efficiencies listed at low current output ranging from 0.001A up to 0.1 A, the max capacity of the TPSM265 regulator.

Table 27 below shows that LMQ66410 regulator easily has the other two beaten when it comes to efficiency ratings, especially for light loads of under 5 milliamps, which will be the typical current draw from the components at this voltage level. Now since the load will generally be small, efficiency does not matter as much as it could, mainly because there will not be as much wasted energy dissipated as heat. This ties directly into theta-ja, which is a number that corresponds to the increase of temperature of the device in conjuncture with ambient temp as each watt of power is dissipated as heat. Once again LMQ66410 has the best theta-ja rating of 45 ^{o}C/W, which means each wasted watt of energy will raise the temperature 45 degrees Celsius above the ambient temp. Here in Florida, that would equate to around 25-35 ^{o}C, meaning at least 2 watts of energy would have to be lost to approach the upper end of the operating temperature range of most electronics, 125 ^{o}C. To provide as much design flexibility as possible, however, efficiency and temperature ratings should not be ignored. This is the reason why the LMQ66410 was selected as the best regulator for utilization within the PCB.

Table 27 – Voltage Regulator Efficiency

Output Current	LMQ66410MC3RXBRQ1	TPSM365R3RDNR	TPSM265R1V3SILR
0.001 A	87%	70%	72%
0.005 A	90%	80%	76%
0.02 A	92%	83%	78%
0.1 A	91.5%	86%	78%

Figure 11 below details the overall schematic design for the LMQ66410MC3RXBRQ1 integrated circuit. Each individual component had to be verified for availability to be purchased. With the typical electronic suppliers Digikey, Mouser, and Texas Instruments, each component was found in stock at a minimum of one supplier. Ultra Librarian free PCB libraries were utilized to find footprints and symbols of each component that was compatible with the PCB design software being used for U.P.R.I.G.H.T, Eagle. [51] The parts have been ordered, and testing will be required within the first couple weeks of SD2 to ensure that the regulator operates as designed before PCB fabrication.

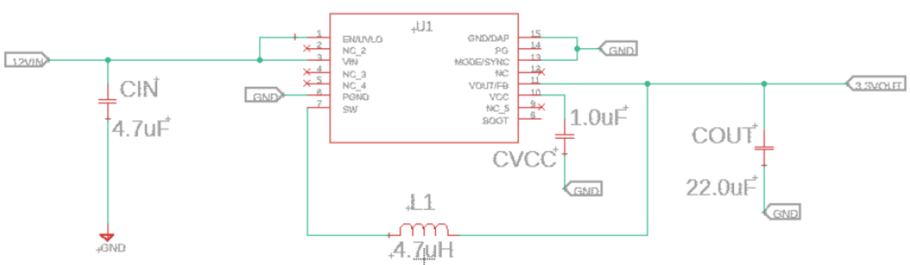

Figure 11 – 12V to 3.3V Voltage Regulator Schematic

In terms of the main IC for the voltage regulator circuit, the main 12V supply will be connected to the Vin pin along with a capacitor connected to ground. This input capacitor is required to be at a minimum 4.7 micro farads, but it can be increased to help with any input ripple voltage or varying voltage input. The minimum value should be sufficient in this case because it is being fed from a linear voltage converter that should have minimal voltage ripple. The enable pin (EN/UVLO) enables input into the IC and can be directly tied into the Vin pin, which is does as seen in the schematic. None of the NC pins require any kind of connection and the PGND pin should be connected to ground. The SW pin is the switching pin that should be connected to the external power inductor whose value is found through equations in the user manual. The most important aspect of the inductor is that it does not ever become saturated, which could lead to a rapid spike of current damaging the regulator. The inductor should be connected to the Vout/FB pin that will constitute the node for output, in this case 3.3V. A capacitor will then be connected between the output node and ground in order to help with transient response of the output. In this design, the capacitor will not affect or improve the voltage ripple and the desired value can be found in data tables of the user manual. The Vcc pin is used to supply internal circuits and the datasheet requires a 1 micro farad capacitor to be connected between the pin and ground. The GND and MODE/SYNC pins are required to be connected to ground because the SYNC pin will not be connected to an external clock. The rest of the pins are not needed for this design. [47]

6.3.3 Overall Schematic

This section will showcase the overall design schematic that will be incorporated into the PCB for the U.P.R.I.G.H.T. Most of the individual systems for each peripheral and how they communicate with the MCU was discussed in detail within section 6.2, however there were a few added features that were incorporated into the overall schematic shown in Figure 12 below.

The first additional component is a 2-pin header for wired leads to connect with the pre-insulated terminal that is being utilized for the 12V main power source connections. This pin header will only have traces that connect to the voltage regulator Vin pin and the PCB ground. When designing the PCB layout in the first couple weeks of senior design two, it will be imperative that any power components be grouped away from the rest of the board to ensure that there is minimal overheating or EMI (electromagnetic interference). It will also be important to refer back to the LMQ66410 voltage regulator datasheet for any guidelines regarding PCB layout design to guarantee that there will be no issues after fabrication. Taking another look at the schematic, it can be seen that all of the various external components for the voltage regulator circuit have been added and that the output node was connected to the 3.3Vcc net. All of the peripherals will need to be supplied with 3.3V as well as connections to the various MCU pins. Lastly, it will be important to design it in such a way that all the pin headers designated for components not located within the PCB be placed around the edges of the PCB for any screw type connections. [47]

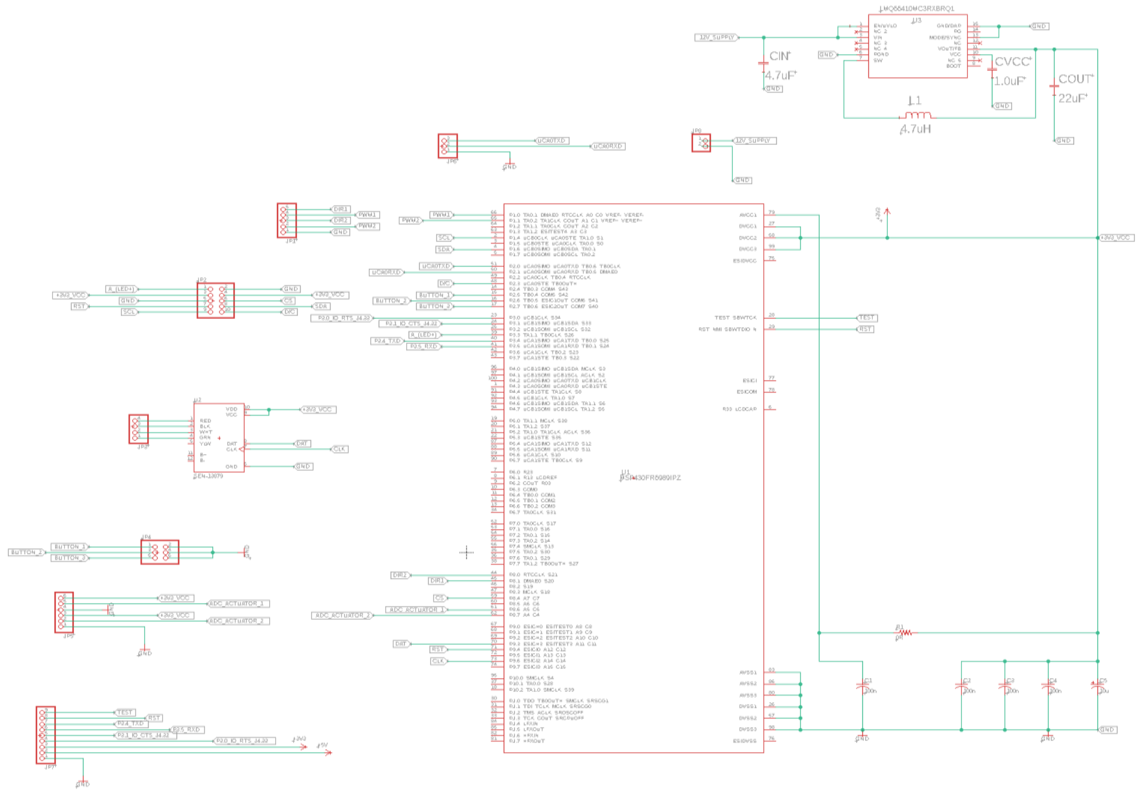

Figure 12 – 12V to 3.3V Voltage Regulator Schematic

This chapter has gone into detail of the overall hardware design, why certain decisions were made with hardware selection, and the general location of every part within the U.P.R.I.G.H.T. The next chapter will rationalize and walk the reader through similar design aspects related to the software, and how it will be implemented with the hardware to provide a seamless and automated design.

Chapter 7 - Software Design

This chapter outlines the comprehensive software design framework for our project, organized into three distinct sections. The first section focuses on programming the MSP430FR6989 microcontroller, which serves as the core of our hardware control system, handling inputs and outputs from various peripherals. The second section details the software architecture of the Raspberry Pi 4, which acts as an intermediary, facilitating communication between the microcontroller and the mobile application while managing high-level data processing tasks. The final section describes the design and functionality of our mobile application, which not only enables users to interface with the system via Bluetooth but also handles data storage and retrieval from a centralized database.

7.1 MSP430FR6989 Software and Components

In the development of our software for the MSP430FR6989 MCU, we opted for Code Composer Studio (CCS) as our primary IDE. CCS, a robust environment engineered by Texas Instruments, is tailored for their microprocessors, offering an array of libraries and built-in functions that streamlined our development process. Our programming was carried out in the C language, chosen for its efficiency and control when interfacing with hardware components. Our project required the MCU to communicate with various peripherals, including load cells via the hx711 for weight measurement, motor controllers for desk adjustment, potentiometers within linear actuators for positional feedback, a TFT LCD display for user interaction, push buttons for manual control, and a Raspberry Pi 4 for managing user settings and processing vision-based feedback. The following sections will delve into the specifics of software development pertaining to each of these components.

7.1.1 MSP430FR6989 Development

For the development of our software for our MSP430FR6989 MCU we used its corresponding development board known as the MSP430FR6989 LaunchPad development kit shown in Figure 13. This development kit proved an easy way to develop, troubleshoot, prototype our design before committing to a final PCB design. Equipped with 40 pin headers, the LaunchPad provided convenient access to the MCU's full range of functions necessary for our application. Although the actual MCU boasts a much larger pin count, we strategically chose pins available on the development board, when possible, to ease the transition to our final software, which will be implemented on the MCU mounted to our custom PCB design in Senior Design 2.

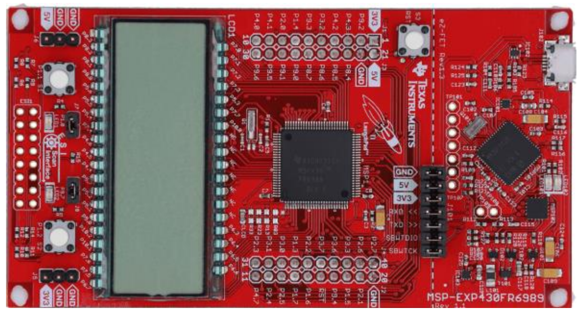

Figure 13 - MSP430FR6989 LaunchPad Development Kit [52]

A critical feature of our chosen development kit is the integration of Texas Instruments' eZ-FET onboard emulator, which can be seen on the right of the development board in Figure 13 separated by a row of removable jumpers. This feature offers two significant advantages for our project. Firstly, it facilitates a “backchannel” UART-over-USB connection through a simple two-wire interface, streamlining the debugging process and enabling straightforward communication with a PC. Secondly, the eZ-FET's “Spy-Bi Wire” emulation capability allows us to connect our PCB directly to the development kit with just two wires. This grants us the use of Code Composer Studio's debugging tools and the ability to program our PCB’s MCU.

7.1.2 Load Cells

This section will detail the critical role of the load cells in our design and how they contribute to the software logic involved in accurately determining if a user is sitting or standing at the desk. We will also describe how the system interfaces with the load cells via the MCU, utilizing the HX711 24-bit Analog-to-Digital Converter (ADC)

Load cells are vital to our design, providing essential data that allows our software to accurately identify not only if a user is present at the desk, but also if they are in a seated or standing position. This capability is crucial for minimizing false positives that could arise from relying solely on facial tracking technology which has limitations in distinguishing between a user stepping out of frame or choosing to stand while working from a seated position. By integrating load cells, we offer an elegant solution to this challenge.

Facial tracking, implemented via a webcam connected to a Raspberry Pi, delineates a user's presence by monitoring their face within a predefined boundary. However, this method falls short in scenarios where the user's face moves outside the camera's view, leaving the system to guess between absence or a shift in working posture. The load cells, strategically positioned within a standing mat, fill this gap by providing tangible evidence of the user's presence and posture. They do so by measuring the weight exerted on the mat, which varies significantly between sitting and standing positions.

Upon initial setup through our app, users are prompted to calibrate the system by recording their weight under two distinct conditions: sitting, where a portion of their weight is supported by an office chair, and standing, where their full weight is centered on the mat. This calibration process establishes a baseline weight range for sitting and a minimum threshold for standing, incorporating a buffer zone to account for minor weight fluctuations. These calibrated values enable the software to dynamically toggle flags, signaling whether the user is sitting or standing based on the current weight reading from the load cells.

Below in Figure 14 is a simplified flowchart of the software showing how flags will be set based on weight readings from the load cells and the pre calibrated weight data loaded in from the raspberry pi interfacing with the app. The calculations for the sitting and standing ranges will need to be formulated based on thorough testing once we have a working prototype.

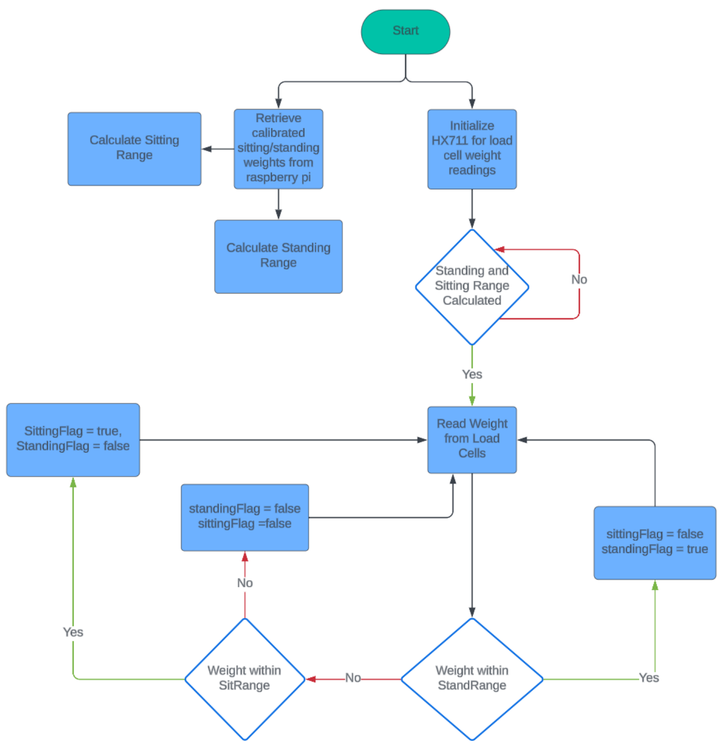

Figure 14 - Load Cell Logic Overview

To facilitate data acquisition from the load cells in our system, the MSP430 microcontroller interfaces with the HX711 24-bit Analog-to-Digital Converter (ADC) via two General-Purpose Input/Output (GPIO) pins. Specifically, the HX711's DOUT (Data Out) and PD_SCK (Power Down and Serial Clock) pins are connected to GPIO pins P9.6 and P9.3 on the MSP430, respectively. These pins were selected after confirming that they are not utilized by other critical functions within the project's scope. Detailed wiring information and considerations for the HX711 and the load cells are provided in the Section 3.2.

The DOUT pin functions as the digital data output from the HX711, conveying the ADC's conversion results that correspond to the load cell's detected weight. The PD_SCK pin, however, serves a dual role. Primarily, it delivers clock pulses required for data transfer, allowing the microcontroller to clock out bits of data from DOUT. Additionally, sustaining PD_SCK in a high state for longer than 60us triggers the HX711's power-down mode, thus reducing power consumption when measurements are not needed.

Gain setting and input channel selection are determined by the count of PD_SCK pulses issued by the MSP430. Issuing 25 pulses will select Channel A with a gain of 128, whereas 26 pulses will opt for Channel B with a gain of 32, and 27 pulses will revert to Channel A with a reduced gain of 64. For our application, we select the default configuration, which is Channel A at a gain of 128, to maximize sensitivity and resolution.

Within the main operational loop, the MSP430 monitors the DOUT pin in a non-blocking manner, waiting for it to go LOW. This indicates the HX711 has completed the ADC process, and the measurement data is ready for retrieval. Upon this signal, the microcontroller issues 24 PD_SCK pulses to read the 24-bit data from the HX711. Each pulse corresponds to one bit of data, starting with the most significant bit (MSB). After the 24th bit is read, an additional pulse (the 25th) is applied to the PD_SCK pin. This 25th pulse is crucial as it not only finalizes the data retrieval process but also sets the HX711 for the next measurement with Channel A at a gain of 128, maintaining this configuration as needed for our application. If the automatic feature of the desk is disabled, then the MCU will pull the PD_SCK pin high for a minimum of 60us in order to signal the HX711 to power-down. Once the automatic feature is turned back on, or the desk power cycles, or a new user connects, the HX711 will be awoken again by pulling the PD_SCK to low and the process will repeat.

7.1.3 Motor Controller

In our design, the MSP430 microcontroller plays a crucial role in managing the desk's height adjustments through the motor controller, which drives a pair of linear actuators. These adjustments are made smoothly and synchronously, thanks to the implementation of Pulse Width Modulation (PWM). PWM allows us to fine-tune actuator speeds, ensuring that the movement of the desk meets our design specifications for noise levels and operational speed.

The desk height can be modified in two ways. Users can manually adjust the desk height by pressing buttons affixed to the underside of the desk. These buttons are programmed to raise or lower the desk through interrupt-driven signals that temporarily suspend other processes to prioritize immediate user input. Alternatively, automatic adjustments are made in response to the combined input from the weight-sensing mat and facial tracking webcam. This intelligent logic enables the system to deduce the user's intended posture—standing or sitting—and adjusts the desk height to the customized preferences set during the initial app calibration.

Figure 15 depicts the logic flowchart, illustrating the coordination between the facial detection flag from the Raspberry Pi and the weight-based flags from the load cells. We've incorporated additional checks to account for scenarios where a user's face remains visible to the webcam even when transitioning from standing to sitting, which could occur with varying chair heights. The specific values for "Sitting Weight on Pad" and "Standing Weight on Pad" are retrieved from the app following user calibration. Subsequent logins to the app prompt the system to load the user's reference weights for sitting and standing, along with the preferred desk heights for each posture.

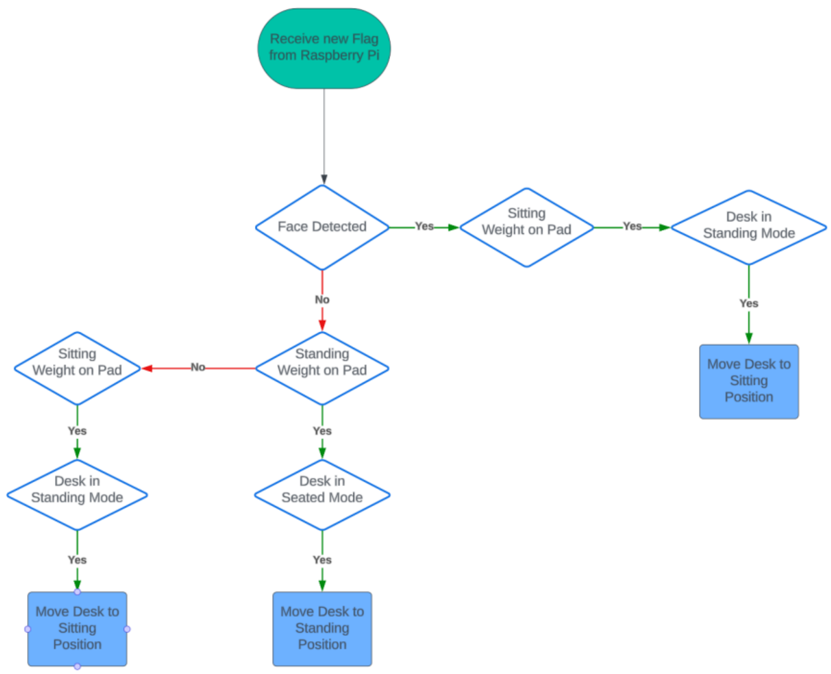

Figure 15 - Flowchart of Desk Position Change Logic

In terms of the physical connections to the MCU The Pin numbers for the input to the Motor controller is shown in Figure 16. The connections for DIR1 and DIR2 can be connected to any GPIO pin on the MSP430 MCU. No added special functionality needs to be available on these pins because they simply need to be set to high or low in order to signal the direction of the motor. We chose P8.1 for the DIR1 pin and P8.0 for DIR2. The pins that are connected to PWM1 and PWM2, however, require PWM functionality which requires the use of one of the MSP430's Timer Module. Our MCU has several options when it comes to Timer Modules. The MSP430FR6989 comes with 5 available timer modules and each module has multiple channels that allow timing independent intervals. They are split up into Timer_A, with 4 modules, and Timer_B with one. Timer_A has one module with two channels, two modules with three channels and one with five channels and Timer_B has just one module with seven channels. Each of these timer options are associated with a specific pin and the pin must be configured properly to utilize the functionality. For our project we are going with P1.0 which is associated with TA0.1 (Timer Module 0 channel 1) and P1.1 which is associated with TA0.2 (Timer Module 0 channel 2). The truth table for the control logic for motor 1 and motor 2 are shown in Figure 17 below.

Pin No.	Pin Name	Description
1	GND	Ground
2	*PWM2	PWM input for speed control (Motor 2)
3	DIR2	Direction input (Motor 2)
4	*PWM1	PWM input for speed control (Motor 1)
5	DIR1	Direction input (Motor 1)

*Note that it is not for RC PWM

Figure 16 - Input Pin Assignment for MDD10A Motor Controller (© Crytron Technologies) [53] Reprinted with permission from Crytron Technologies

PWM	DIR	Output A	Output B
Low	X(Don't care)	Low	Low
High	Low	High	Low
High	High	Low	High

Figure 17 - Truth Table of Control Logic for Motor1 and Motor 2 (© Crytron Technologies) [53] Reprinted with permission from Crytron Technologies

Pulse Width Modulation (PWM) is a method widely used in microcontrollers like the MSP430 to control devices such as motors by varying the amount of power delivered to them. Essentially, PWM controls the motor speed by adjusting the duration of the "on" time in a fixed cycle or period, which in turn regulates the average power supplied to the motor. In MSP430 microcontrollers, achieving PWM functionality is streamlined through the Timer modules, utilizing their capacity for precise timing. The setup involves three crucial registers within our selected Timer_A module: TA0CCR0, TA0CCR1, and TA0CCR2. Here, TA0CCR0 is responsible for setting the PWM signal's period across the Timer module, establishing the PWM output's frequency. Per the MDD10A user manual, the maximum PWM frequency is 20KHz. We will experiment to identify the optimal frequency that balances smooth actuator movement with noise reduction. Simultaneously, TA0CCR1 and TA0CCR2 are tasked with determining the duty cycle for channels 1 and 2, respectively. This duty cycle, essentially the fraction of the signal's period when the output remains active (high), has a direct impact on motor speed; a higher duty cycle results in increased speed. The Timer's counting register, TAR, counts up each cycle, allowing for the comparison with values in TA0CCR0, TA0CCR1, and TA0CCR2. By configuring the TA0CCTL1 and TA0CCTL2 capture/control registers to the RESET/SET output mode, the output signal is designed to reset (drop low) upon matching with TA0CCR1 or TA0CCR2, and set (rise high) when the TA0CCR0 compare event occurs. This approach ensures the PWM duty cycle, and consequently, the motor speed, is adjustable based on the predetermined values in the TA0CCRx registers, facilitating refined control over motor functionality with minimal demand on the CPU. Figure 18 below demonstrates different PWM duty cycles, 50%, 75%, and 25%, each maintaining a constant period as determined by the TA0CCRx registers, with the variation in duty cycle affecting the amount of power delivered.

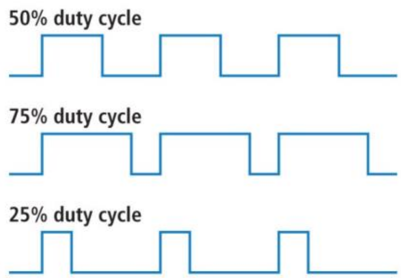

Figure 18 - Pulse Width Modulation Duty Cycle Comparison [54]

Our group also plans to incorporate a form of collision avoidance into our project. At this stage in development, we're exploring a couple of straightforward solutions, though it's premature to determine which will best meet our needs. One option involves using the potentiometer readings from the linear actuators as indicators of obstruction. For instance, if the potentiometer readings halt unexpectedly while the desk is being adjusted, we could automatically cut power to the motor controller to prevent further movement. A simpler alternative could involve installing limit switches around the desk's edge, particularly near where a user's thighs might be, to detect any obstruction directly. We are optimistic that the potentiometer-based approach will be adequate, but we expect to gain more clarity and make necessary adjustments in the second development stage (SD2) as our prototype progresses.

7.1.4 Linear Actuators

This section elaborates on the interfacing of the MSP430FR6980 MCU with the linear actuators' built-in potentiometers, utilizing Analog to Digital Conversion (ADC) to acquire precise feedback on the actuators' positions. Accurate positional information is crucial for adjusting the desk to user-specified heights during the calibration process. Moreover, discrepancies in the movement speeds of the actuators could potentially lead to asynchronous adjustments, resulting in an uneven or tilted desk surface, an outcome that not only compromises the desk's functionality but also risks structural damage. By using the potentiometer readings, we can develop algorithms that ensure synchronous actuator movement, thereby maintaining the desk’s stability and integrity.

ADC transforms continuous analog signals into discrete digital numbers, enabling microcontrollers to process real-world physical data. This transformation occurs through a process known as successive approximation, where the ADC, in essence, narrows down the analog signal's digital equivalent by making a series of educated guesses. Initially, the

ADC samples the analog signal at specified intervals, capturing a snapshot of its value. It then compares this sampled value to a series of voltage levels, starting from a midpoint and adjusting upwards or downwards based on whether the sampled value is higher or lower, respectively. This comparison is repeated, refining the approximation with each step, until the ADC resolves the analog input to a precise digital value. The resolution of an ADC is determined by its bit length, which directly influences its precision. For example, our MSP430FR6989 microcontroller features a 12-bit ADC, meaning it can distinguish between 2^12, or 4096, different levels of input voltage. By converting analog inputs such as sensor data or, in the context of our project, potentiometer readings from linear actuators, into a format that digital systems can interpret and act upon, ADCs serve as essential interfaces between physical signals and digital information processing.

Prior to configuring the ADC within the software, it's essential to calculate the sample-and-hold time. This time is important to ensure that the ADC's internal capacitors are charged adequately to reflect the analog signal's true value, which is pivotal for accurate digitization. Insufficient sample-and-hold time can result in an incomplete charging of the capacitors, thereby skewing the conversion result. Conversely, excessively long hold times could unnecessarily prolong the ADC process, leading to inefficiencies. The following formula dictates the minimum requisite time for this phase:

$$t \geq (R_I + R_E) * (C_I + C_E) * \ln(2^{n+1})$$

The variables R_I and C_I denote the microcontroller's built-in ADC's internal resistance and capacitance, respectively. According to the datasheet for the MCU [55], these values stand at 10k ohms for R_I and 15pF for C_I. R_E and C_E represent the resistance and capacitance external to the ADC, parameters introduced by the components connected to it. Given that the ADC's input is sourced from a 5k ohm potentiometer, this resistance is chosen for R_E. For the external capacitance C_E a relatively small value of 1pF is selected initially; this is likely to be adjusted during the prototyping phase to fine-tune the signal-to-noise ratio and minimize noise in the final signal. The term 'n' corresponds to the bit resolution of the ADC, which in this case is 12 bits. Substituting these values into the formula for the minimum sample-and-hold time, the result is a calculated duration of approximately 2.16us.

To properly time the sample-and-hold duration and conversion process of our ADC module, we utilize the MSP430's built-in MODOSC, which fluctuates between 4 to 5.4 MHz. For configuring the ADC, we must select a number of clock cycles that corresponds to our calculated sample-and-hold time (SHT) of 2.16 microseconds. Multiplying this SHT by the MODOSC's maximum frequency results in about 11.67 cycles. Since ADC settings are constrained to predefined cycle options, we round up to the nearest available cycle count, which is 16 cycles, ensuring that the ADC's capacitors are fully charged within the SHT period without necessitating a clock divider. If the result was larger than the largest available cycle count of 512, a clock divider could be utilized.

Having completed the preliminary calculations, we're ready to configure the ADC12_B module on our MCU. Our initial step involves identifying suitable pins for analog input, specifically those capable of fulfilling this role, denoted as A0 through A31 in the documentation. For our application, we select pins P8.6 (A5) and P8.7 (A4). Given their multipurpose nature, these pins default to general-purpose input/output (GPIO) functionality and thus require configuration for analog input use. The ADC12_B module features a singular conversion core alongside 32 result registers, enabling the sequential execution of multiple conversions with each conversion's outcome being stored in a designated result register. Our focus centers on four crucial registers for configuring the ADC: ADC12CTL0, ADC12CTL1, ADC12CTL2, and ADC12CTL3, alongside the result registers, denoted as ADC12MEMx (x: 0-31), each associated with a corresponding ADC12CTLx register for setup. The outcomes from analog inputs A5 and A4 are designated for storage in ADC12MEM0 and ADC12MEM1, respectively.

Table 28 - Summary of Register Settings for ADC

Register	Field	Bits	Description	Setting
ADC12CTL0	ADC12SHT0x	11-8	Sample-and-hold time	16 ADC12CLK cycles
	ADC12MSC	7	Multiple sample and conversion	enabled
	ADC12ON	6-5	ADC12_B on	enabled
	ADC12ENC	1	Enable Conversion	-Disabled while configuring register -Enabled when finished
ADC12CTL1	ADC12SHP	9	Sample-and-hold pulse-mode select	Sampling signal is sourced from the sampling timer
	ADC12CONSEQx	2-1	Conversion sequence mode select	Sequence of channels
ADC12CTL2	ADC12RES	5-4	Resolution	12 bit (14 clock cycle conversion time)
ADC12CTL3	ADC12CSTARTADDx	4-0	Conversion start address	ADC12MEM0
ADC12MCTL0	ADC12INCHx	4-0	Input channel select	A4
ADC12MCTL1	ADC12EOS	7	End of sequence specifier	End of sequence
	ADC12INCHx	4-0	Input channel select	A5

Configuring the ADC12CTL0 register is our initial step, where we activate the ADC module and deactivate the ENC (Enable Conversion) to permit configuration adjustments. We then set a 16-cycle duration for the sample-and-hold time and enable the option for multiple sample and conversions. Moving to the ADC12CTL1 register, we opt for the "Sequence of channels" setting due to our utilization of two channels. Additionally, we designate the sampling signal to originate from the sampling timer, rather than directly from the sample-input signal. Within ADC12CTL3, we indicate that the initial conversion's results should be stored in ADC12MEM0. We then proceed to configure the memory registers designated for our results: channel A4 is selected as the input for ADC12MCTL0, while for ADC12MCTL1, we choose channel A5 as the input and also mark this register as concluding the conversion sequence. To finalize, we reactivate conversions in the ADC12CTL0 register. Any configurations not explicitly mentioned remain at their default settings, as they align with our project requirements. A summary of the register descriptions and values can be found in Table 28 above.

7.1.5 LCD

This section outlines the process of integrating a CFAF128128B1-0145T TFT LCD display with our MSP430FR6989 MCU to enhance user interaction with the standing desk. The advantage of employing such a display lies in its versatility; unlike a standard 16x2 character LCD that is confined to displaying basic text within a fixed layout, the chosen TFT LCD allows for a fully customizable graphical interface. This flexibility enables us to design a more engaging and dynamic interface, capable of rendering an array of graphics, text, and images to suit any desired layout or design. Initially, the display will greet users with a welcome message upon establishing a connection to the application, personalized with their name, and indicating the current operation mode, manual or automatic. In automatic mode, it will further differentiate between sitting and standing positions. Additionally, the display will prominently show the desk's current height, providing users with immediate and clear feedback on the desk's position. As our project evolves, we plan to possibly expand the LCD's functionality to include more interactive features that will enrich the overall user experience.

The LCD display we have selected is equipped with the Sitronix ST7735S controller, which offers an SPI (Serial Peripheral Interface) for communication with our MCU. While this LCD controller combination provides the capability for rich graphics and intricate displays, it also introduces a level of complexity in programming that surpasses that of a basic character LCD. Crafting a complete driver from scratch for such a sophisticated controller could be a substantial undertaking, akin to a separate project. However, we were able to avoid this potential hurdle thanks to Texas Instruments, which provides sample code for this controller due to its use in the BOOSTXL-EDUMKII Educational BoosterPack, compatible with the MSP430 MCU series, including our model. This sample code required some modifications to align with our application requirements but served as an excellent foundation for rapid prototyping. Additionally, Texas Instruments offers a graphics library known as GrLib. This library is rich with features, offering a suite of graphical functions, including various font sizes and styles, string display capabilities, and the ability to render images and basic shapes like circles, lines, and rectangles.

Our MCU comes with two eUSCI (enhanced universal serial communication interface) modules to facilitate communication with various peripherals. Given that both eUSCI_A and eUSCI_B support SPI (Serial Peripheral Interface) but only eUSCI_A supports UART (Universal Asynchronous Receiver-Transmitter), we have reserved eUSCI_A for future UART communications with a Raspberry Pi. Therefore, for the LCD interfacing, we opted for eUSCI_B. The MSP430FR6989 Family User’s Guide [56] outlines the eUSCI in synchronous mode, detailing the following connections: UCxSIMO (slave in, master out), UCxSOMI (slave out, master in), UCxCLK (SPI clock), and UCxSTE (slave transmit enable). Given that our LCD solely receives data, with no requirement to transmit information back to the MCU, and with no additional peripherals sharing the SPI bus, our setup does not necessitate the use of UCxSOMI (Slave Out, Master In) and UCxSTE (Slave Transmit Enable) pins. Consequently, we adopt a streamlined 3-pin SPI configuration. To further simplify our design, the LCD's CS (Chip Select) pin is directly tied to a GPIO pin, maintained at a low state to ensure the LCD remains constantly selected and ready to receive data.

The interfacing of the MSP430FR6989 MCU with the LCD display was achieved through a zero-insertion force connector on a breakout board. Pin 1 of the LCD, labeled LED+, was connected to pin P3.3 of the MCU which has PWM capability, allowing for future brightness adjustment with high and low signals setting the maximum and minimum brightness levels respectively. Pin 2, labeled LED-, was grounded to complete the backlight circuit. Pin 3, indicating SPI4W/SPI3W_ was connected to the MCU's 3.5V supply to select the 4-wire SPI mode, enabling the use of the D/C_ pin. This same voltage supply was connected to Pin 4, labeled VDD, to power the LCD. Pin 5, another ground, established the common electrical reference. The CS_ pin, labeled as Pin 6, was connected to GPIO P8.4 to keep the LCD in a ready state by holding it low permanently. The RST_ pin, Pin 7, was connected to P9.4 as a hardware reset for the controller. Serial data in/out was managed by Pin 8, SDA, connected to P1.6 configured for UCB0SIMO functionality, and Pin 9, SCL, connected to P1.4 configured for UCB0CLK functionality, served as the clock signal. Finally, Pin 10, D/C_, connected to P2.3, toggled between data and command register selection. Absent was a connection for UCxSOMI since the LCD only receives data, removing the need for a bidirectional SPI line.

Once the physical connections between our MCU and the LCD were established, our next step involved configuring the necessary software functions. The sample code from Texas Instruments provided a basis for this, starting with the function to set up the GPIO and SPI pins. By consulting the MSP430FR6989's datasheet [55], we programmed P1.4 to serve as the UCB0CLK and P1.6 as the UCB0SIMO. The remaining code in this section did not require changes, as it was already suited to our setup.

The next step was configuring the eUSCI Module 0 Channel B for SPI functionality. A summary of the register descriptions and values can be found in Table 29 below. Referring to our MCU's Family User's Guide [56], we configured the eUSCI_B SPI registers to fit our application's needs. Within the UCB0CTLW0 register, we started by engaging the UCSWRST bit, allowing us to reset the module and clear existing settings. We then set the UCCKPH bit to capture data on the first clock edge and transition on the subsequent one, ensuring data integrity. The UCCKPL bit was cleared to define a low polarity as the clock's inactive state, and the UCMSB bit was set to prioritize the transmission of the most significant byte first. We chose an 8-bit character length by clearing the UC7BIT bit, and we established the MCU as the SPI master by setting UCMST. Our constant LCD activation, due to the CS pin being held low, allowed us to clear the UCMODEx bits for a

3-pin SPI operation. Synchronous mode was ensured by setting UCSYNC, and SMCLK was selected as the clock source in the UCSSELx register. We completed the SPI setup by adjusting the UCB0BRW register, setting a clock divider of one by clearing all 16 bits to utilize the default SMCLK frequency of 8MHz, which would provide a swift refresh rate suitable for our LCD. The final step in software configuration was to clear the UCSWRST bit in the UCB0CTLW0 register, exiting the reset state and activating the eUSCI_B module with our customized settings.

Table 29 - Summary of Register Settings for SPI

Register	Field	Bit(s)	Description	Setting
UCB0CTLW0	UCCKPH	15	Clock Phase Select	Data is captured on the first clock edge and transition on the subsequent one
	UCCKPL	14	Clock Polarity Select	The inactive state is low
	UCMSB	13	MSB First Select	MSB first
	UC7BIT	12	Character Length.	8-bit data
	UCMST	11	Master Mode Select	Master mode
	UCMODEx	10-9	eUSCI mode	3-pin SPI
	UCSYNC	8	Synchronous Mode Enable	Synchronous Mode
	UCSSELx	7-6	eUSCI Clock Source Select	SMCLK in master mode
	UCSWRST	0	Software Reset Enable	Enabled at start Disabled at end
UCB0BRW	UCBRx	15-0	Bit Clock Prescaler Setting	Clock divider of 1

For the actual design of the User Interface on the LCD Texas Instruments provides a comprehensive user's guide for the MSP Graphics Library which abstracts interaction with the underlying hardware [57]. This user's guide provides detailed instructions on how to utilize this library to complete a wide range of graphical tasks. The guide covers everything from initializing the library to drawing pixels, lines, and shapes, displaying text in various fonts and sizes, and even rendering bitmap images. Additionally, it includes instructions on creating more complex GUI elements like buttons and sliders and layering graphics for more advanced visuals. The User's Guide also has many software examples which will help us immensely.

7.1.6 Buttons

In this section, we discuss how to interface the MSP430FR6989 microcontroller with three PB6B2RS2M1CAL00Y500 push button switches to enhance the control functionality of the standing desk. Two of these buttons are assigned for manual operation, allowing the user to adjust the desk height upwards or downwards at their discretion. Each button press will incrementally change the desk height, providing a tactile interface for height adjustment. The third button is dedicated to toggling the desk's automatic adjustment feature. Pressing this button will switch between automatic and manual modes, offering the user flexibility in how they interact with the desk's movement.

In selecting the MCU pins for interfacing with our push button switches, we prioritized pins that offered both interrupt and timer capabilities, specifically choosing P2.5, P2.6, and P2.7 to meet these criteria. Interrupt-driven programming was chosen over continuous polling for its superior responsiveness and processing efficiency; it allows the MCU to remain in a low-power state or attend to other tasks until a button press event occurs.
An interrupt acts as an immediate signal that pauses the main execution flow and invokes an interrupt service routine (ISR) to handle the event, ensuring prompt response to user inputs. The MSP430FR6989 MCU associates each pin capable of generating an interrupt with an interrupt flag within an 8-bit variable, such as P2IFG for Port 2, where a flag is set when a pin detects an edge. As the ISR for Port 2 is common to all its pins, the ISR must include logic to determine the specific pin that triggered the interrupt. The incorporation of a timer module expands our interface capabilities, allowing us to implement additional features based on long-press actions if desired.

By connecting the other side of each button to ground, they are configured as active low. This means that a press results in a logic level zero, a state easily detectable by the MCU and consistent with best practices for digital input circuits. This design choice simplifies the electrical design and takes advantage of the internal pull-up resistors available on our MCU, providing a clean and stable logic signal.

Programming the MSP430FR6989 for button input using interrupts involves a series of steps that configure the GPIO pins, enable the necessary pull-up resistors, and set the conditions for interrupt triggering. The steps for setting up each button—P2.5, P2.6, and P2.7, are uniform, differing only in the specific bits manipulated within the registers. To begin, we configure the direction of each button pin as an input by clearing the respective bits in the P2DIR register, following the guidance that a '0' configures a pin as an input. This action would clear bit 5 for P2.5, bit 6 for P2.6, and bit 7 for P2.7. Next, we activate the internal pull-up resistors for these pins by setting bits 5 through 7 in the P2REN register. Next, we ensure these resistors function as pull-ups by setting the same bits in the P2OUT register, which in an unpressed state, will pull the pin high. To configure the interrupt edge select, we set bits 5 through 7 in the P2IES register, specifying that the interrupt flags (P2IFG) should be set on a high-to-low transition, representing a button press. We proceed to clear any existing interrupt flags for these pins by clearing bits 5 through 7 in the P2IFG register, ensuring a clean slate. We then enable interrupts for these pins by setting bits 5 through 7 in the P2IE register, allowing our system to respond to their activations. Finally, before entering the main application loop, we call the _enable_interrupts() function, which is an intrinsic function that sets the global interrupt enable (GIE) bit. This action permits the system to respond to interrupts from our configured buttons, ensuring that each press is detected and handled by the designated ISR.

Once the buttons are connected and configured, the detection of button presses is managed within the Port 2 Interrupt Service Routine (P2 ISR). Within this routine, the specific button that triggered the interrupt can be determined by examining the Port 2 interrupt flags (P2IFG). Each button press sets a corresponding bit in this register, allowing the ISR to identify which button was pressed by checking these flags. For the button assigned to toggle the automatic functionality of the desk, the ISR will modify a Boolean global variable that tracks the state of this feature. When the button is pressed, the ISR will flip the variable from true to false or vice versa. As for the manual control buttons that adjust the desk height, the ISR will call the same motor control function that is used to drive the desk motor via PWM signals. This function will pass a parameter indicating the desired direction: upward if the "up" button is pressed or downward if the "down" button is pressed. The motor control function will then generate the appropriate PWM signal to move the desk in the chosen direction while the button is being held down. It should also be noted that it is the programmer’s responsibility to clear the relevant interrupt flag before leaving the ISR.

7.1.7 Raspberry Pi Communication

This section outlines the bidirectional communication between our MSP430FR6989 MCU and the Raspberry Pi, facilitated through the UART protocol. Due to its simplicity and reliability, UART serves as an ideal choice for transmitting the modest volumes of data required by our system, typically ranging from 1 to 4 bytes per message. The primary objective of this communication channel is to exchange user-specific settings, including standing and sitting height preferences, along with calculated reference weights stored during the initial setup. As part of routine operations, the Raspberry Pi transmits a Boolean flag to indicate the presence of the user, as detected by a webcam. Additionally, the MCU is configured to relay initial calibration data to the Raspberry Pi for storage, ensuring a personalized and precise setup for the user's desk each time they log in.

For successful UART communication, a full duplex connection is established using two wires: one for transmission (TX) and one for reception (RX). Upon consulting the respective datasheets [55] [23],we identified compatible pins on both the MSP430FR6989 MCU and the Raspberry Pi 4. The MSP430FR6989's eUSCI_A module supports UART with pins P2.0 and P2.1 designated as UCA0TXD and UCA0RXD, respectively. Correspondingly, on the Raspberry Pi 4, pins 8 (TXD) and 10 (RXD) were selected for UART communication. We connected the TXD pin of the MSP430FR6989 to the RXD pin of the Raspberry Pi 4 and vice versa to enable two-way communication. Additionally, we established a common ground between the two devices to ensure signal integrity and reliable data transfer.

UART can be configured in many ways, however, for our initial testing and the prototyping phase, we chose a widely recognized standard setup. This configuration employs a 9600 baud rate, 8-bit data size, least significant bit first, no parity bit for error detection, a single stop bit for terminating transmission, and absence of flow control. While we may refine these parameters as our project advances, they establish a reliable baseline. Furthermore, we've enabled oversampling to improve reception fidelity. With oversampling, the receiver's clock operates at sixteen times the baud rate. Consequently, every bit in the transmission lasts for sixteen clock cycles on the receiver's end. The receiver synchronizes with the start of the bit at the first cycle and then samples the signal during the middle of the bit duration, specifically at cycles seven, eight, and nine. These three samples undergo a majority vote to accurately determine the bit's value. This method enhances the reliability of data reception by ensuring that the sampled value is less likely to be affected by noise or timing discrepancies. It is also essential that the UART settings on the Raspberry Pi match those configured on the MSP430FR6989 to ensure seamless communication.

Configuring the UART functionality began with assigning P2.0 and P2.1 as UART pins, as specified in the MSP430FR6989's datasheet [55]. Our next step was to set up the primary UART control register, UCA1CTLW0. We initiated the configuration by setting the UCSWRST bit (bit 0) to enable the software reset state, which conveniently resets all other configuration bits to zero. This reset aligned most settings with our chosen communication standard by default. However, to designate the SMCLK as the UART clock source, we set the UCSSELx bit (bit 7). We then adjusted the baud rate through the UCA1BRW register. Based on the Family User's Guide [56], we entered a value of six to attain a 9600 baud rate using the default 1MHz SMCLK. We then turned to modulation control via the UCA1MCTLW register. Here, we input '8' for the UCBRFx field and '0x20' for the UCBRSx field, adhering to the User's Guide for the recommended configuration based on our clock frequency and desired baud rate. To enhance data integrity, we enabled oversampling by setting the UCOS16 bit (bit 0). Finalizing our setup, we exited the software reset state by clearing the UCSWRST bit in the UCA1CTLW0 register, thereby activating the UART module with our specified settings, ready for communication.

In terms of the structure of the software we plan on using interrupts for telling when the MCU has received a new byte of data. This way we won't have to constantly poll in the main loop to tell when the Raspberry Pi sends a new message. In the USCI_A1 ISR we will check if the UCRXIFG flag has been raised (receive interrupt flag that is raised when the UCA1RXBUF has received a complete character). If it has, we will read the Byte from the buffer and pass it to another function to process the data. The process of reading from the UCA1RXBUG automatically lowers the UCRXIFG flag and we are ready to receive our next byte.

We have also developed a communication protocol between the MSP430FR6989 MCU and the Raspberry Pi, utilizing enums that correspond to unique characters to ensure precise and structured data exchange. Enums, short for enumerations, is a programming concept that assigns readable names to a set of related data such as integers or characters in order to enhance clarity/readability. This method allows for clear designation of command types and data requests, facilitating robust and error-resistant communications.

To initiate communication, when specific information is required, such as height or weight settings during the initial setup of a new user, the Raspberry Pi sends a unique character corresponding to an enum recognized by the MCU. This character acts as a command, prompting the MCU to fetch and send the requested data. The same method is applied for returning users, where different unique characters precede the transmission of data, such as maximum and minimum heights, and weight references for both sitting and standing positions. The protocol also governs routine operational communications. Once the initial settings are configured on the MCU, the Raspberry Pi periodically sends Boolean flags based on webcam detection of the user’s presence. This data helps the MCU decide if a desk height transition is needed. In response, the MCU transmits a confirmation signal to the Raspberry Pi each time the desk transitions between sitting and standing positions, facilitating the Pi’s ability to log the duration spent in each posture. Each data transmission is preceded by a specific character that clarifies the type of data to follow, significantly enhancing our system's error detection capabilities. This approach ensures that both the Raspberry Pi and the MCU are consistently prepared to handle the incoming data correctly, minimizing errors and promoting reliable, smooth communication.

7.1.8 Summary MSP430FR6989 pinout for peripherals

In this section, we provide a comprehensive overview of the MSP430FR6989 microcontroller pin assignments and their associated functions for our project's peripherals. Table 30 below outlines each pin's designated role, ranging from controlling motors and interfacing with an LCD, to handling UART communications with a Raspberry Pi 4. It also includes configurations for input devices like push buttons and sensors such as the HX711 for weight measurement. This pinout summary serves as a reference guide for understanding how the microcontroller interacts with various components.

Table 30 - Summary of MSP430FR6989 Pin Assignment and Function

Pin #	Port	Setting	Component	I/O	Notes
66	P1.0	TA0.1	Motor Controller	Output	Drives PWM for Motor 1
65	P1.1	TA0.2	Motor Controller	Output	Drives PWM for Motor 2
2	P1.4	UCB0CLK	LCD	Output	Serial Clock for SPI
4	P1.6	UCB0SIMO	LCD	Output	Serial Data Out (SIMO)
51	P2.0	UCA0TXD	Raspberry Pi 4	Output	TXD for UART
50	P2.1	UCA0RXD	Raspberry Pi 4	Input	RXD for UART
48	P2.3	GPIO	LCD	Output	D/C selects data or command register on LCD
15	P2.5	GPIO	Push Button	Input	Active Low
16	P2.6	GPIO	Push Button	Input	Active Low
17	P2.7	GPIO	Push Button	Input	Active Low
39	P3.3	GPIO	LCD	Output	LED+ PWM capability if desired
44	P8.0	GPIO	Motor Controller	Output	Direction for Motor 2
45	P8.1	GPIO	Motor Controller	Output	Direction for Motor 1
59	P8.4	GPIO	LCD	Output	CS, tied to ground
61	P8.6	A5	Linear Actuator	Input	Analog Input for Potentiometer
62	P8.7	A4	Linear Actuator	Input	Analog Input for Potentiometer
70	P9.3	GPIO	Hx711	Input	Data Terminal
71	P9.4	GPIO	LCD	Output	Hardware reset pin
73	P9.6	GPIO	Hx711	Output	Serial Clock

7.2 Raspberry Pi 4 Software Design

This section will be used to highlight the design of the software that will be running on the Raspberry Pi 4. The sections will discuss how the data will be communicated between the systems and the software that will be running on the Raspberry Pi 4.

7.2.1 Raspberry Pi 4 Data Communication

It is important to understand how the data transfer and requests of the overall system works before the software design of the Raspberry Pi 4 can be broken down. Figure 19 below showcases how the data transfer and requests flow in relation to the rest of the components and system. While the main functionality of the Raspberry Pi 4 is to run the facial tracking software, it also serves as the communication relay between the MCU and the application that will retrieve and store the user information.

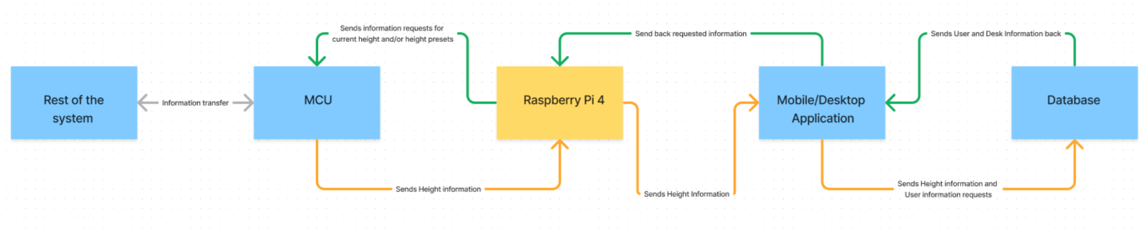

Figure 19 - Data Transfers and Requests Flow Chart

7.2.2 Software on Raspberry Pi 4

There are three main scripts that will be running on the Raspberry Pi 4. This includes the initialize script, face tracking script and Bluetooth script.
Figure 20 below showcases the overall flow of how the software will run and interact with the rest of the components.

The initialize script always runs on the startup of the device. This script will act as the trigger that will start the rest of the scripts. The purpose of this script is to provide automation to the software that will run on the device. Any additional scripts can be added to this first script if there needs to be additional features in the future. Next, two scripts will be launched. The order of launch does not matter for these two scripts but they both need to be running for the system to be working correctly.

One of these scripts is for facial tracking. The open-source libraries used for this portion will be preinstalled on the device. The main library, face_recognition, was selected in the research section under facial tracking and will be used as the main source for facial tracking. This library is dependent on the dlib library and was also installed at the same time as the face_recognition library. Lastly the OpenCV library was used to access the camera and video feed for processing. Together all three of these libraries are used in the facial tracking script to determine if there is a user present at the desk. This information will then be sent to the MCU for additional processing.

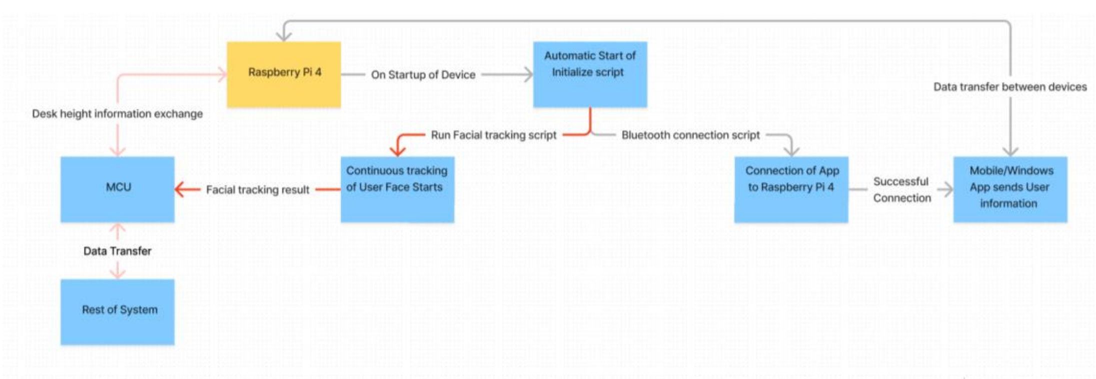

Figure 20 - Software Flowchart of Raspberry Pi 4

The next script that will be processed is the Bluetooth connection script. The main purpose of this script is to automate the Bluetooth connection between the user's device and the Raspberry Pi. This script will also be used for processing, sending, and accessing information between the two devices. The main information that will be transferred during this script is the height of the desk and the save presets that were stored in the online database.

7.3 Application Software Design

Communication with the user is important for this project because there is an initial calibration setup. One such method selected for communication is through an application that is either mobile or desktop. It will also be possible to store this information in an online database for later usage through this application. This section will cover the application design for mobile devices and Window's application as a stretch goal in two major sections. Figure 21 below demonstrates the overall flow of the prototypes. Currently the same flowchart is planned to be used for both the mobile and windows application because cross platform development is possible with flutter at the same time. The same API end points will also be shared with both the mobile and Window's application. These API endpoints will send and retrieve data from the database as shown in Figure 21 in the Raspberry Pi 4 Data Communication.

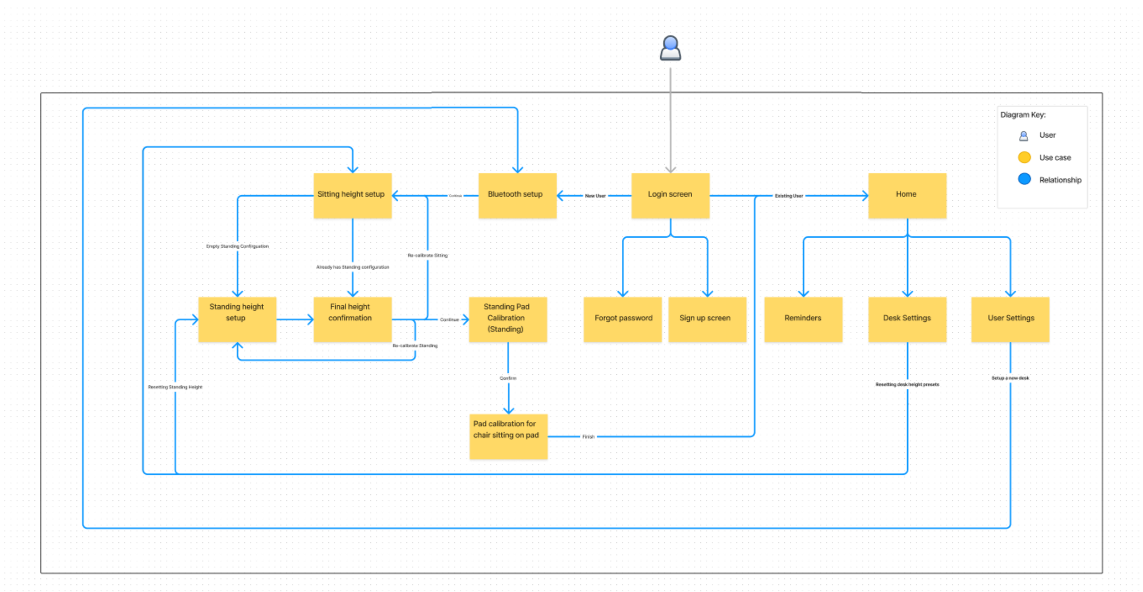

Figure 21 – Use Case Diagram of Applications

The prototypes will be split into three major groups comprising of the user information section, the new user's setup, and main section.

7.3.1 Mobile Prototype

As discussed earlier, communication with the user is key in the calibration step design. This section serves as an in-depth explanation into the various capabilities and specific user interface (UI) designs of our mobile application. To showcase this design Figma was used to create the initial interface prototype. Figma is a widely used online web application for creating prototypes, charts and more. One main benefit to using Figma is that a project can be worked on by multiple members at the same time.

7.3.1.1 User Information

The mobile application is going to be used as the main median between the main tracking system and the database. To be able to service different users there needs to be a way to differentiate between everyone. One such method is by creating an account system that is tied to the email of the user. This will allow each user to be able to connect to the desk and save their settings. Figure 22 below showcases the initial prototype design that will be used for this section of the mobile application.

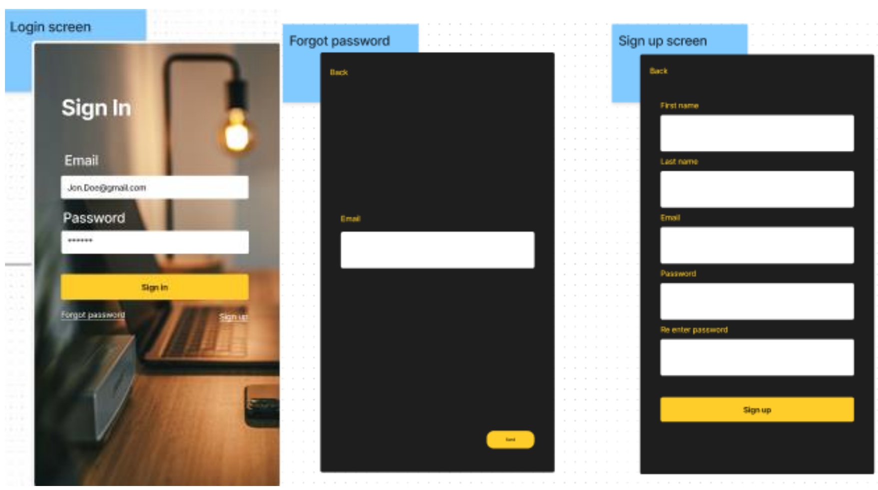

Figure 22 – Sign-in, Sign-up and Forgot password Mobile Interface Prototypes

When the application is opened it will start out on the login page. The reason for this design choice is because the user will most likely only need to sign up once. Whereas they will need to login multiple times. From here there will be two options available to the user. One of the options is the user sign-up page that can be used to create a new account. The other option is for a password reset page. This page will send the user an email with a reset password link. SendGrid will be used for this page to send the actual reset password information. SendGrid is a popular online platform that is used for programmable email service. There is a base tier option that is free for a certain amount of usage. This is ideal for the current project because it is going to be used for a limited amount currently. If there is a need for more use, then it can switch to the higher tier without much impact to the system. The need for a password reset is so that there is a way to recover an account if the user happens to forget the password. This can also be one potential solution to changing the password of a compromised code. Figure 21 shows the use cases and flow of navigation between these sets of pages relates to the rest of the pages.

7.3.1.2 New User Setup

After signing up, the user will be able to login into the application. Initially they will be marked in the system as a user that still needs to complete the initial setup. Figure 23 below showcases the overall flow and connection for this setup.

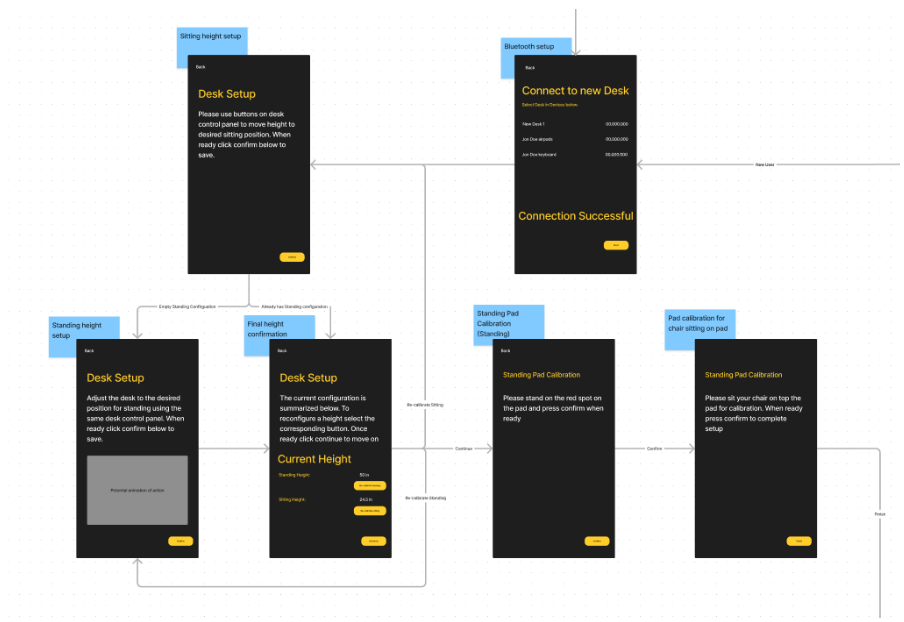

Figure 23 – New User Setup Mobile Interface Prototypes

The setup starts with connecting the application to the desk through Bluetooth. This step was chosen as the initial setup screen because the application needs to be able to communicate with the desk to receive information. Once this step is completed the screens will move to the setup settings for the height. This includes first setting up the height of the desk for sitting and standing position. Following these two screens there will be a confirmation page. The purpose for this page is to allow the user to easily change the configured heights in case there was user error on the initial follow through. After confirming that the saved height settings are correct, the next page will cover the calibration step for the standing pad. The next two pages will then prompt the user to sit in their chair on the standing pad so the weight can be saved for tracking of the user. There will also be a designated spot for the user to stand in for the calibration of the standing weight. After these initial setup steps are completed, the user will be redirected to the home page of the existing users. In the system, the user will then be marked as a returning user and in the future will be directed to the home page of the application once they login.

7.3.1.3 Main Section

This section covers the main section of the mobile application. After the completion of the setup the user will always be directed to this section once they have logged in. The user will automatically land in the metrics page which will serve as the home page. This section will have four main total including the metrics page. The visual depiction of these pages can be seen in Figure 24 below.

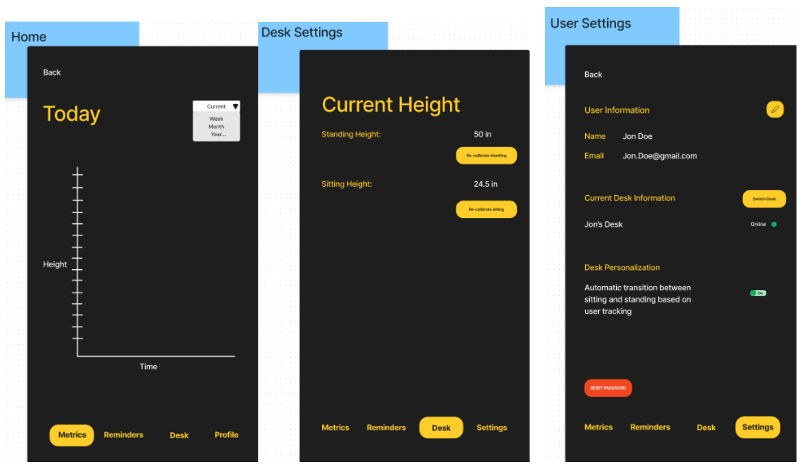

Figure 24 – Metrics, Desk and Settings Mobile Interface Prototype

The metrics page will display the total amount of time that the user spends in each position. The way this page will work is that it will use the time of the user's device to determine the specific time that some activity occurred. The MCU sends the updated height to the Raspberry Pi 4 before the application will receive it. After this the application would then be able to be displayed on the metrics page. The design choice for this is to minimize the amount of data that would need to be transferred from the MCU to the application. Another design choice that was made for this page is to track the height versus time. The reason for this is because the user will be able to use the buttons on the desk to make slight adjustments to the desk height. By tracking the height, the user will be able to see the actual heights that they spend the most time at. It will also serve as a quick visual guide of how much time the user spends sitting versus standing. This is important for the project because one of the main goals of the desk is smart tracking. Where the tracking can be used as a way for the user to adjust how much time they spend in each position.

There will also be the option of changing the date range of the information that will be displayed on this screen. The goal is for two potential ranges and the extra ranges are for the stretch goal. The reason for this is that the mobile screen can only display a certain amount of information. By splitting up the information into different ranges, it will allow for quick display of information that the user would want to see.

This metrics page could be a potential way for the user to see that they spend more time at a different height than their original height. They can then determine that they would like to change the saved height. To change this, they would then go into the desk tab that will have the options of going through the same setup process for saving the sitting and standing step calibration. The design choice for having two separate buttons is so that the user doesn't have to go through the entire setup process again. Each will direct the user to the specified step to just complete one calibration at a time.

The next tab that will be available to the user is the ability to update user and system information in the settings tab. This includes updating the username and email. Another setting that will be available on this screen is the ability to connect to a new desk. While there is going to be only one desk for this project, this was designed with the idea that it could potentially be used for multiple expansions of this project. This setting will also give the users the ability to reconnect to the desk if the connection was lost for one reason or another. Another useful setting that will be on this page is the ability to turn off automatic transition of the desk from sitting to standing. This design choice was for the customization option for the user. While automatic transition of the desk from sitting to standing is one of the main features of U.P.R.I.G.H.T. some may not always want that setting. These users may only want their activity to be tracked so this option gives the user flexibility. The settings tab will also have the option to reset password and log out of the application.

The last potential screen of the mobile application is a reminders tab that will be used to set goals for specific time and duration of each position. The reminders tab is a stretch goal of this section. Figure 25 below demonstrates the current prototype of the reminders tab.

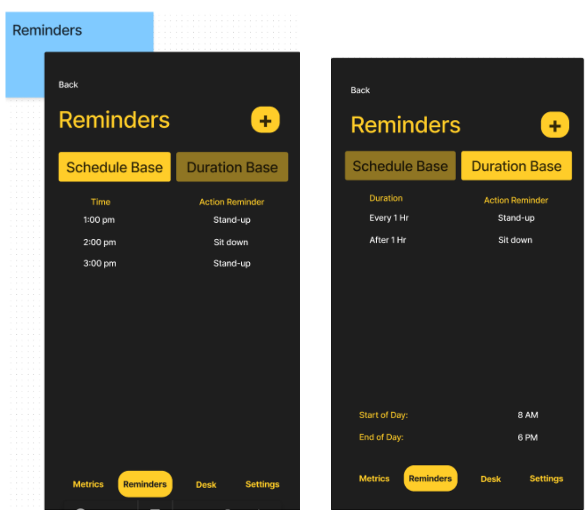

Figure 25 – Reminders Mobile Interface Prototype

The idea of this page is that it would be a nice feature to help encourage users to change positions. There are two main types of reminders on this page to give users different options. The schedule-based reminders are useful for individuals that prefer to have a consistent time of the day to switch to a certain position. The second tab on this page is the duration-based reminder. This reminder will be a persistent reminder that will trigger after a certain amount of time has passed at the current position. Since there is not a set time for this setting, the user would have the option of setting a start and end of the daytime so that the reminders will only occur in these positions. The reminders will only be sent if the user is present at the desk. This will be determined through the combination of the facial tracking and the standing pad.

7.3.1.4 Desktop prototype

A stretch goal of the application section is that we would like to create a cross platform application for mobile and desktop. Using flutter, this would be possible as it was created for this purpose. Although this is a stretch goal a prototype would still need to be created to better understand how it would function in comparison to the mobile app. The three sections in the mobile application would also be present in the desktop version. This includes the user information, initial setup, and main section. Figure 26 below demonstrates the difference in visuals for the user information section. One major difference is that the sign up will exist on the same page as the login as a pop-up modal instead as a stand-alone page. The reason for this design change is that the desktop application is much larger than the mobile page. This allows for more screen space to accommodate a larger bar in addition to the information fields. For this screen it is also possible to use the same SendGrid account to send emails for the desktop application.

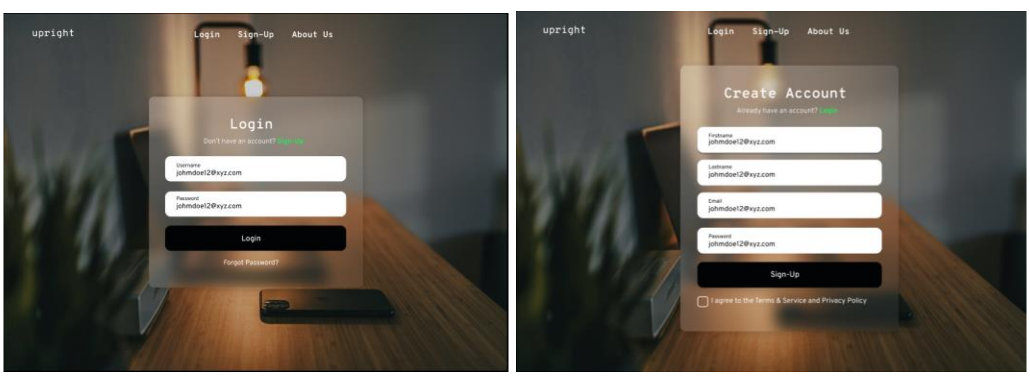

Figure 26 – Login and Sign-up Desktop Interface Prototype

After creating a new user account, the users will go through the same initial setup steps as in the mobile application. The initial setup pages from mobile will be shared with the desktop application. This is possible due to using flutter as the development platform because in flutter the same code can be complied into multiple platforms. The design for the initial setup section was not changed between the mobile and desktop application because they are instructional pages. To minimize confusion between potential difference in instructions between two platforms, it would be best to just share the pages between the applications. This ensures that if the instructions are modified it is reflected in both applications.

The main section will have the same four tabs as in the mobile section. Figure 27 below shows the design changes of the desktop application. One of the main difference between the mobile main section and the desktop main section is that there will be a dedicated home page for the desktop application. The reason for this design difference is that the mobile application has less screen space compared to the desktop. With more screen space it allows for more capability and arrangment.

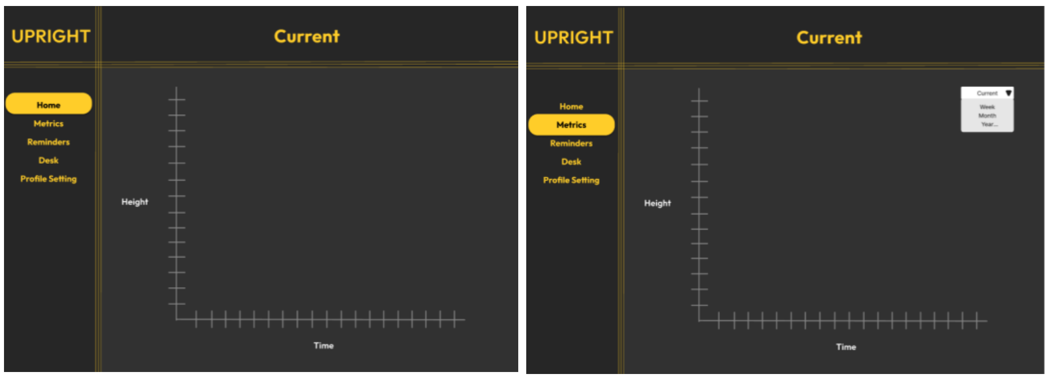

Figure 27 – Home, Metrics Desktop Interface Prototype

The difference between the home page and the metrics page is that it will always only show the current metrics of the day. The home screen will also display suggestions based on the current information gathered for the day. This can include comparison of the previous day and letting the user know how close they are to reaching their target goal.

For the desk and profile settings pages, the biggest change from the mobile application is the design of the pages. The main informational section is going to be shared between the desktop and mobile application as a widget in flutter. This is to ensure that the information is consistent between the applications if there is a change made to one of the screens. Figure 28 demonstrates the main design changes between the mobile and desktop application. The application programming interface (API) endpoints will be shared between these two pages. This design choice is to keep the information consistent and to minimize the database connections. There will be a slight design change to make the main informational section more spread out for visual purposes but the overall functionality of these two screens and the mobile will remain the same.

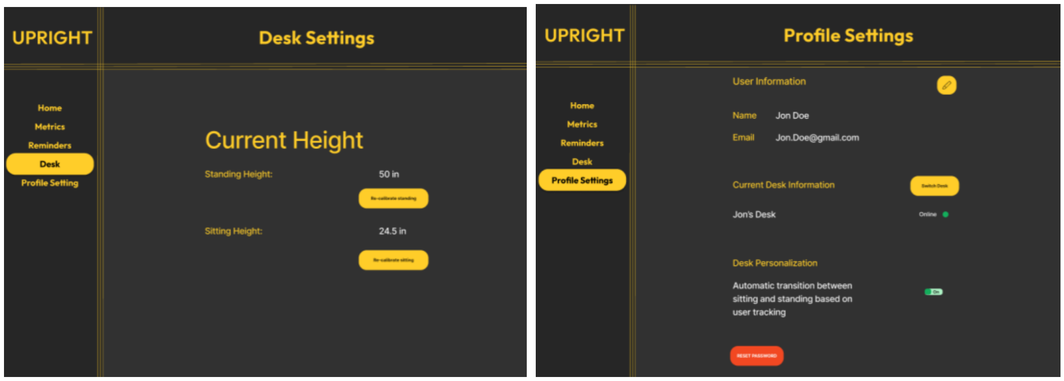

Figure 28 – Desk, Settings Desktop Interface Prototype

The last tab of the application is the reminders page. This screen is going to look like the mobile application with a few minor modifications due to the larger screen. Figure 29 showcases the main visual design difference between the two applications. Most of the functionality will remain the same with a few differences. One of the main differences is that the reminder for the desktop application will be made to be smaller in the bottom right of the screen. The reason for this design choice is that ideally the user will be working on their computer while sitting at the desk. It can be very distracting to suddenly receive a large notification in the middle of work. To minimize distractions while looking at the screen, the idea is to have a small notification at the bottom of the screen close to the time. This way when the user checks the time, they can also see that it is time to change position with minimal disruption to work. This means that while much of the design code can be shared between the two pages the functional code will be slightly different between the two applications.

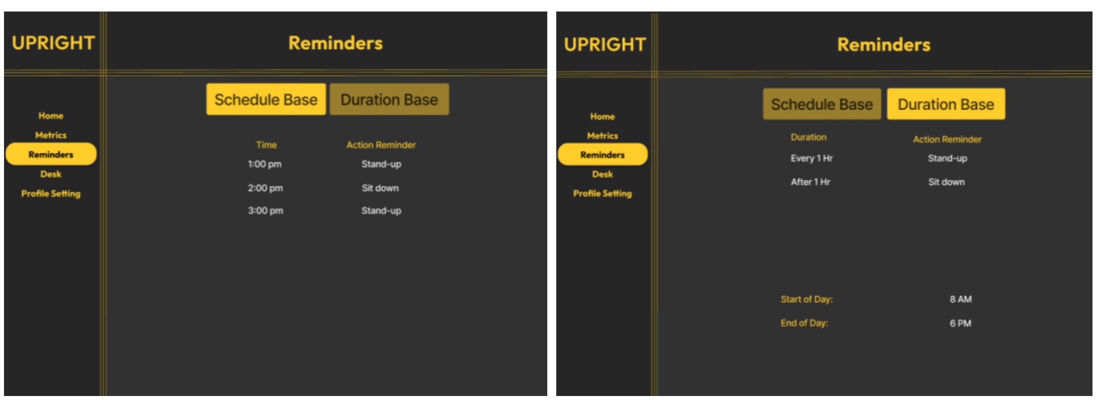

Figure 29 – Reminders Desktop Interface Prototype

While the reminders tab is a stretch goal, it is still important to prototype with these stretch goals at the start so that it will minimize large design changes in the actual implementation of the application and project. Adding features later without a prototype in mind could potentially drive up the cost of rebuilding and designing all the features.

7.3.1.5 Database design

The application detailed throughout this section requires the tracking of many linked data points to work correctly. This tracking will become even more vital as the project gains more users. Currently, the scope is limited to a mere handful of users as the desk application moves through the prototyping phase. For such a small user base, we may be able to neglect implementing a database at all. However, it is vital to look forward to a time when this application is deployed to a wide user base.

Therefore, it is important to implement a database that will track user information and history of using the desk. A UML (Unified Modeling Language) diagram depicting the structure of the database needed to implement the application described in this section is shown in
Figure 30.

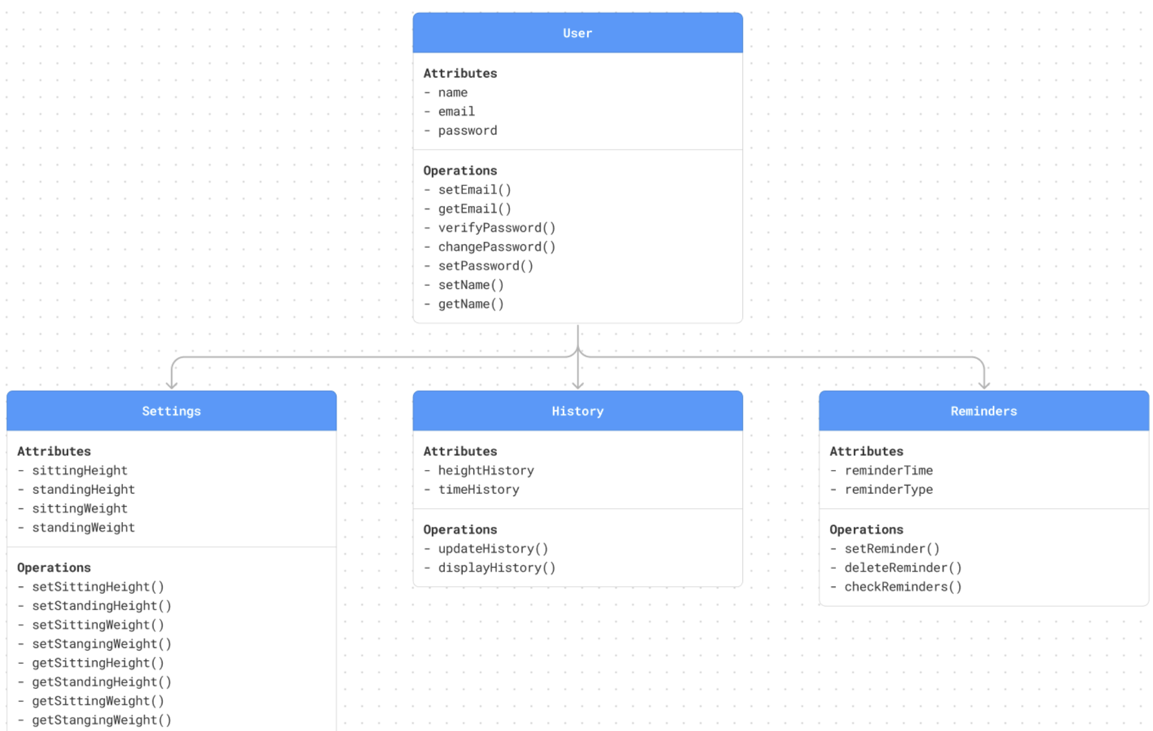

Figure 30 – UML Diagram of Database Structure of the Application

All classes shown in
Figure 30 must have unique instances for each user. The parent class User contains the basic account information that each user enters when first creating an account. Setters for each variable save the entered information into the database. These setters may also be

called when the user elects to update their account information. The getters will primarily be used to display the user information back to the user and to validate the user's password.

The main functionality of the desk will interface directly with the Settings class. Once the user sets these settings, the desk will periodically check the weight sensor readings against the set sitting/standing weights to determine whether the desk should be adjusted. When the determination is made that the desk should be adjusted, the desk again accesses the database to determine which preset height it should adjust to. The user may update these preset values at will. This action would require another usage of the setters to save the new settings into the database.

The History class exists so the user can make informed decisions on when to adjust preset heights. Passively, the sensed height of the desk will be queried and populated into the database's history structures. These structures will have a maximum length corresponding to one year, after which stale data is discarded. When the user goes to see the plot of the desk's height history, the application accesses the time history from the database and generates the plot.

The last class is the Reminders class. This class supports the reminder capability. This capability is currently slated as a stretch goal and is not expected to be implemented. Regardless, the necessary class is mapped out in the UML diagram. In this case, the reminder time and reminder type (sit/stand) are set, deleted, and fetched as a pair. This is necessary as one half of the information is useless without the other half. In addition to the setter and getter, a method is necessary to check the reminder time against actual time to alert the user that it is time to switch modes.

Chapter 8 - System Fabrication/Prototype Construction

In this chapter, we will detail the systematic approach undertaken in the fabrication and construction of the prototype for our automatic standing desk. This project combines mechanical components with smart technology to create a desk that adjusts its height automatically, catering to the ergonomic needs of its individual users. In this chapter, we will discuss the prototype construction as well as the PCB services that were taken into consideration to make the finished system.

8.1 Prototype Construction

The construction of the prototype for our automatic standing desk was an iterative process, crucial for transforming theoretical designs into a tangible product. This section outlines the steps we took in building the prototype, highlighting the techniques and technologies used to ensure the final product met both functional and aesthetic requirements.

The construction began with the desk frame, the foundation on which all other components were built. We opted for a rectangular frame made from high-quality wood, providing a sturdy base resistant to bending and deformation under load. This frame is shown in Figure 31 below.

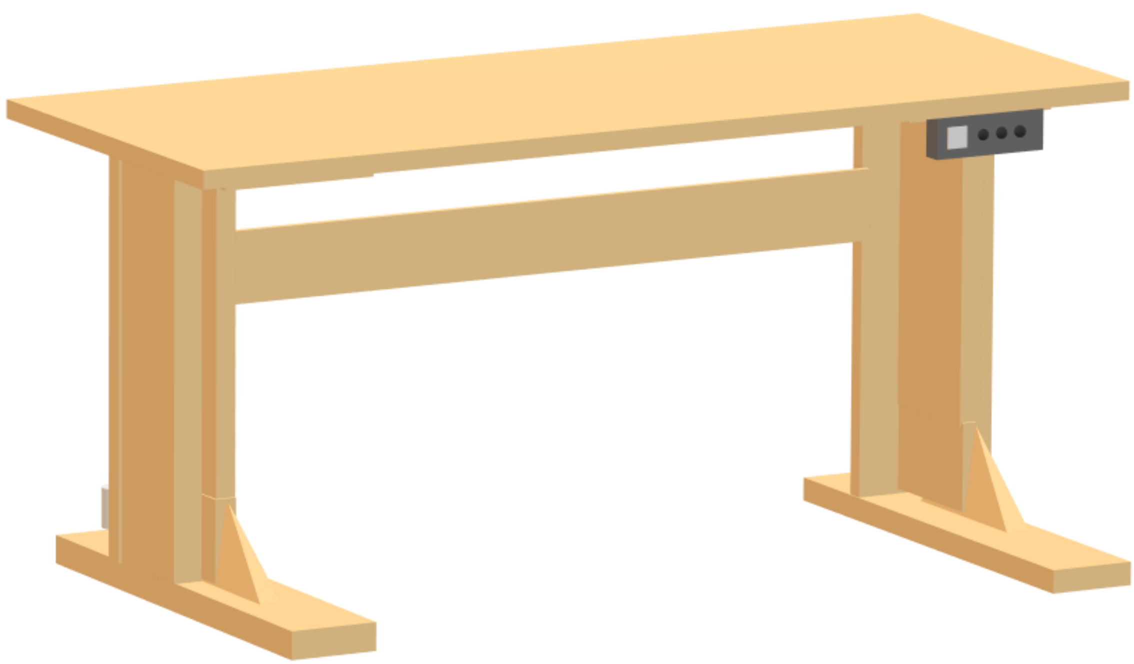

Figure 31 – Overall Prototype Construction of the Standing Desk

For the height-adjustable legs, we utilized the linear actuators, as well as aluminum rails so that the wooden desk legs could go up and down. The rails on the legs should be mounted with precision, to make sure they could slide smoothly without excessive play. Each leg is equipped with its own linear actuator, of which each was carefully selected for its load capacity and extension speed, allowing for seamless height adjustment. This setup is shown in Figure 32 below.

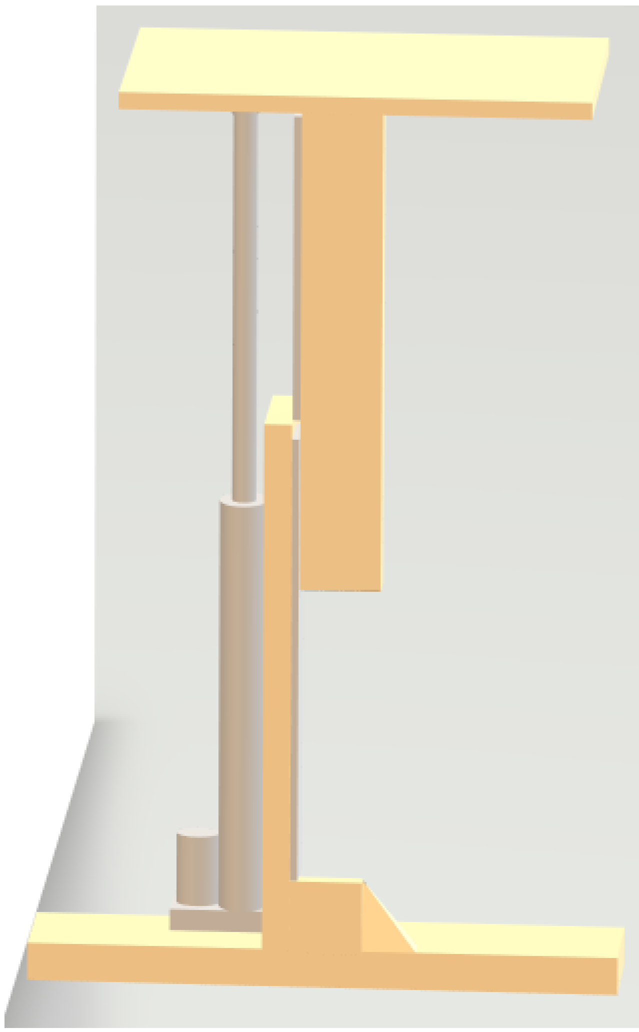

Figure 32 – Prototype Construction for Each Leg

Attention to detail was considered very important in crafting the desk's surface. We will choose a high-quality, scratch-resistant laminate that mimics the texture and appearance of natural wood, offering durability and a touch of elegance. The edges of the desk will most likely be beveled and sealed to prevent chipping and to enhance user safety.

The frame and components can be powder-coated to resist corrosion and wear. The color chosen for the countertop will be chosen to not only consider the aesthetic appeal of the product, but also to match typical office environments, making the desk visually appealing in a professional setting.

Integrating the electronic components was also important in the desk's construction. It involves installing the central PCB with our microcontroller underneath the desk so that it is centrally located between all of the various components. Our printed circuit board will most likely be put inside a housing so that it is not exposed to or is visible to the user.

The software for controlling the desk's mechanics will be developed by our team. It will feature an interface that allows the user to see relevant information at a glance while also maybe incorporating functionality that allows the user to adjust the desk height either manually via the buttons on the control panel or through a mobile application in addition to the automatic functionality. Safety features, such as collision avoidance and overload protection may also be programmed to ensure user safety and equipment longevity.

Once assembled, the prototype will undergo extensive testing to verify its functionality and durability. We will conduct load tests to ensure the desk can withstand the specified maximum weight without structural failure. Cycle tests can also be performed on the telescopic legs to assess the longevity of the mechanical components under repeated use.

Feedback can be solicited from potential users during testing to identify any ergonomic or operational issues. This feedback is invaluable in case we need to make any design modifications to enhance user experience and functionality.

The final assembly involved meticulous scrutiny of every component and connection. After ensuring all mechanical and electronic systems are functioning as intended, the desk will be cleaned, inspected, and prepared for our final demonstration.

The construction of this prototype will hopefully demonstrate our capability to convert an innovative concept into a usable product but also to provide us with a profound understanding of the challenges involved in product design and development.

8.2 PCB Service Considerations for Fabrication

For the crucial task of PCB fabrication in our automatic standing desk project, selecting the right service provider is essential. Both JLCPCB and PCBWay are reputable PCB manufacturers, but they offer distinct features and services. This comparison aims to evaluate both providers across several key factors including cost, quality, turnaround time, and customer service.

Known for its cost-effectiveness, JLCPCB offers competitive pricing, especially attractive for small to medium-sized orders. Their pricing becomes even more economical with larger batch sizes, which is beneficial for scaling production. In contrast, while generally slightly more expensive than JLCPCB, PCBWay offers a flexible pricing structure that can accommodate more complex PCB designs without a significant increase in cost. This is particularly advantageous for projects requiring high-density interconnect (HDI) PCBs or more sophisticated surface finishes.

JLCPCB has a strong reputation for delivering high-quality PCBs suitable for a wide range of applications. Their facilities are equipped with modern manufacturing technologies capable of producing standard through-hole to more advanced surface mount designs. On the other hand, PCBWay is often praised for its exceptional quality and its ability to handle complex PCB designs and specialized requirements, including rigid-flex PCBs and more advanced material options. This makes PCBWay a potentially better choice for projects that anticipate evolving design complexities.

The next consideration to be made involves the turnaround time for each service. JLCPCB offers rapid production with turnaround times as quick as 24 to 48 hours after order confirmation, which is ideal for projects with tight deadlines. PCBWay also provides quick turnaround options, though the speed may vary depending on the complexity of the PCB order. PCBWay's expedited services are comparable to those of JLCPCB but might incur a higher cost for the fastest delivery options.

In terms of customer service and support, JLCPCB features an efficient online ordering system with real-time DFM checks and an active customer service team ready to assist with any inquiries. Their platform is user-friendly, particularly for less experienced users, like our team. In contrast, PCBWay, known for its excellent customer support, offers a more personalized service experience. They provide dedicated technical support for complex projects and can offer design suggestions that may improve the manufacturability and functionality of our PCB.

Concerning scalability and additional services, JLCPCB has excelled scalability from prototypes to full production runs without needing to switch manufacturers, JLCPCB's streamlined production process makes it easy to scale up as project demands increase. On the other hand, PCBWay offers a broader range of related services, including PCB assembly, CNC machining, and 3D printing, which can be beneficial for projects requiring a comprehensive suite of manufacturing services beyond just PCB fabrication.

After an extensive comparison between two leading PCB manufacturers, JLCPCB and PCBWay, we have decided, for the time being, to select PCBWay for the fabrication of the printed circuit board (PCBs) required for our automatic standing desk project. This decision was based on a thorough evaluation of several critical aspects including technological capabilities, service, quality, and additional services offered by PCBWay, which align closely with the unique requirements and future directions of our project.

PCBWay demonstrates a robust capability to handle complex PCB designs and offers advanced technological solutions that are essential for our project. The ability to produce high-density interconnect (HDI) PCBs and utilize specialized materials ensures that the quality of the PCBs will meet the high standards required for the reliability and functionality of our automatic standing desk. This superior fabrication capability is pivotal in developing a product that relies on precise electronic control and long-term durability.

PCBWay's commitment to providing comprehensive service and support is particularly compelling. Their team offers personalized technical support and design optimization advice, which is crucial for a project like ours that may require iterative design adjustments and troubleshooting. The access to dedicated support can facilitate smoother development phases and help in achieving optimal design configurations without extensive delays.

Another decisive factor is PCBWay's ability to scale production seamlessly and provide additional manufacturing services. As our project transitions from prototype to full-scale production, having a single provider like PCBWay that offers PCB fabrication, assembly, and additional services such as CNC machining and 3D printing under one roof is highly advantageous. This integration can streamline our manufacturing process, reduce coordination complexities, and ensure consistent quality across all components.
Although PCBWay's services come at a slightly higher cost compared to JLCPCB, the value added by their advanced capabilities and exceptional service justifies the investment. The flexible pricing structure allows us to manage costs effectively as our needs evolve, especially when dealing with more complex or customized PCB requirements.

Choosing PCBWay, for the time being, as our PCB fabrication partner aligns with our project's goal to develop a highly reliable and innovative automatic standing desk. Their technological prowess, combined with excellent customer support and comprehensive service offerings, provides us with confidence in their ability to meet our specific project demands. This partnership not only supports the current scope of our project but also accommodates future developments and scalability. [58]

8.3 PCB Design Guidelines

The design process of the PCB is not only crucial to the overall success of the U.P.R.I.G.H.T but it is also an essential timesaver when it comes to testing, prototyping, and debugging the physical board. The purpose of this section is to lay out some guidelines and rules that we will stick to when designing the circuit board in order to maximize these goals. First and foremost, utilization of trustworthy software in the design process is the first key to success. Eagle, an Autodesk Fusion software that specializes in PCB design with comprehensive component libraries, lets users intuitively and seamlessly implement schematic diagrams into PCB routing and component placing. This software has been an industry standard since its creation in 1988, and with multiple members of this group having experience with it, Eagle will be the preferred method of PCB design for this project.

If there happens to be a specialized component that is not already in one of the many libraries that come with Eagle, websites like Ultra Librarian will usually have the needed footprint or symbols that can be downloaded into an Eagle script. In the unlikely scenario that a particular piece of hardware cannot be found, Eagle is also equipped to create custom footprints or symbols.

Moving on to the next step of the design process, it is vital that a few other actions be taken before the layout of the PCB actually commences. First, determining PCB design board rules that will govern the design is critical. These rules can stem from industry standards or more specifically the actual capabilities of the chosen PCB fabrication service provider, PCBway for this project. [58] Some of these capabilities can include the size of components, board type and outline, solder type and assembly options. Next, the board outline should be decided upon before the layout begins. This could save a significant amount of time as the entire layout process could be ruined if the outline were to change during the design. Another key factor to keep in mind is that the designated outline of the board should easily fit all components because each one must be accessible in the final build for any testing and debugging. Leading directly from this, it is common practice to place connectors near the edge of the board to simplify assembly and installation. It is also imperative that sensitive components are not placed along the board's edge because they are the most susceptible to EMI. Failing to do these practices could mean additional time required during the debugging process, or even a ruined board in the worst case.

There are a few more considerations to keep in mind while designing the layout of the PCB. Generally, components are grouped together on the board by their function, for instance one part of the board will contain power management components, while other board locations are reserved only for analog or only digital components. This practice can reduce the amount of EMI, while also significantly reducing any trace length especially those that are high current carrying traces that can generate a large quantity of heat. It is also imperative that there be plenty of space in the design for traces and more importantly around components with a high number of pins. It is also standard practice to separate these integrated circuits from each other, typically leaving around 350 – 500 mils between each IC. [59]

Thermal management is another crucial piece of the PCB design process, as heat is the enemy of all circuit boards. The standard practice is to place components that generate heat closer to the center of the board to allow that heat to spread evenly throughout. It is also vital to note if there will be a direction of air flow over the board and design the layout that larger component do not obstruct that air flow to heat generating components. Knowing how much heat is anticipated in the design of the PCB is crucial and allows space to install any additional heat sinks after fabrication to be designed into the board from the beginning. Lastly, and possibly the most vital design factor, is to create a solid ground plane in the PCB. The design of the ground plane should always be continuous without any interruptions, otherwise it could lead to power integrity and signal issues within the board. [59] [60]

Overall, the design of the U.P.R.I.G.H.T's PCB will be crucial to the success of the standing desk's functionality. The brain of the standing desk is the main center point of the PCB design, the MCU and it is vital that it be seamlessly integrated with all the peripheral subsystems within the desk. This is the critical factor for designing the circuit board, and by adhering to the guidelines discussed above should provide a template for success.

Chapter 9 - System Testing and Evaluation

In this chapter, we discuss the preliminary hardware and software tests conducted during the first phase of our senior design project. These tests are focused on evaluating the major components we have obtained early in the project lifecycle to ascertain their suitability and performance in relation to our design requirements. While this section provides an initial overview of our testing activities, it will be expanded significantly in Senior Design 2 as more comprehensive testing is completed. Included is also a brief summary of the overall integration of components and our strategic plan for Senior Design 2.

9.1 Hardware and Software Testing

Testing serves multiple crucial purposes. It begins with function verification, where the functionality of each component is checked to confirm that they meet the specific needs of the project. This process allows for the refinement of each component by testing various functionalities and scenarios, fine-tuning them to align with the project's goals. Such testing also helps uncover issues that may not have been initially apparent, thereby allowing timely corrections.

Additionally, testing plays a vital role in quality assurance. It helps identify inconsistencies in quality among components, detecting defects, bugs, or malfunctions that could lead to premature failures. This ensures that each component not only performs as intended but does so reliably, thereby reducing the risk of future problems.

Compatibility testing is also critical. It ensures that all hardware and software components work together without errors, which is essential for smooth integration and functionality in the final product. This stage is crucial for identifying and correcting bugs that may arise when components interact during integration.

9.1.1 LCD Display

For testing the CFAF128128B1-0145T LCD Display, it will be interfaced with our development board using a 10-position ZIF breakout board as illustrated in Figure 33. The test aims to confirm basic functionality such as power supply to the display and the ability to display basic text.

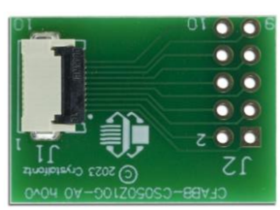

Figure 33 - Crystalfontz 10 position ZIF Breakout Board [61]

9.1.1.1 Blacklight/Power Test

To assess the functionality of the LCD's backlight and to check for any defects in the breakout board, we applied 3.3V to the pins marked LED+ and LED-. This test will confirm the operational status of the backlight and verify that the breakout board is functioning correctly, including the integrity of the soldering on the pins.

9.1.1.2 Graphics Test

This test is to verify the integration and functionality of TI's graphics library and the driver program for the Sitronix ST7735S. We will establish SPI communication on our development board and execute commands to display a variety of basic characters and shapes on the LCD screen.

9.1.1.3 LCD Hardware Tests

To ensure the LCD display performs reliably, we will conduct a series of functional tests. Initially, a power-on test will verify consistent functionality when the display is activated. We will test all display functionalities, including the accuracy and responsiveness of the screen's different inputs, where applicable. Additionally, the capability to adjust settings such as brightness and contrast will be evaluated to ensure they can be easily modified and are effective throughout the display's operational range. Screen transitions and any animations will be assessed for smoothness and correct execution to optimize user experience.

9.1.2 Load Cells/HX711

To test the load cells in conjunction with the HX711 24-bit ADC, we will follow the wiring guidelines provided by the HX711 manufacturer [62]. An Arduino library [63] tailored for creating weight scales with the HX711 and the specific load cells will be used. The testing setup will include an Arduino Uno to facilitate and control the experiment.

9.1.2.1 Weight Test

We will configure the Arduino Uno with the HX711 Arduino library to interface with the load cells. The initial step involves calibrating the load cells to ensure precise measurements. We will then conduct accuracy tests using a range of known weights to verify that the load cells meet our project's specific requirements.

9.1.2.2 Amplifier Hardware Tests

To ensure the long-term reliability and performance of the load cells in our automatic standing desk, we will conduct comprehensive durability and endurance testing. This testing will include fatigue tests, where the load cells are subjected to repeated loading and unloading cycles to simulate years of regular use. These tests help identify any potential failure points or degradation in performance over time. Additionally, we will perform longevity tests to monitor the load cells' performance during extended operational periods. This includes evaluating the consistency and accuracy of the load cell readings over time to ensure there are no drifts or inaccuracies that could affect the desk's functionality.

9.1.3 12V AC/DC Adapter

To test the AC/DC adapter, it will be plugged into a 120V AC receptacle and then stress test from multiple different loads. It is vital that the adapter be able to handle the power requirements of the standing desk and not vary voltage output severely. A small amount of variation will be acceptable, and testing this before integration will ensure that U.P.R.I.G.H.T's power distribution system is safe and secure for installation.

9.1.3.1 Output Voltage Test

The linear actuators will contribute upwards of 99% of power consumption for the entire system, and so the AC/DC adapter will be connected to the actuators as they operate varying loads, starting from nothing, and going until they are under full load capacity. The goal is to ensure that there are no large spikes in the current draw and that the output voltage maintains stability throughout the testing.

9.1.4 Motor Controller

Cytron's MDD10A dual channel motor driver is a crucial component in the functionality of the actuators and U.P.R.I.G.H.T's automated movement. By testing that the actuators can be sufficiently controlled by the Motorcontroller, and that it successfully speaks to the MCU will be confirmation that it is ready for integration into the overall system of the standing desk.

9.1.4.1 Hardware Connection Test

The first test will include verification that the Motor controller can take power from the AC/DC adapter and successfully feed it to each individual actuator. At that point, the on-board test buttons will be used to fully extend and retract the actuators at the same time while the whole system is under different loads. It will be crucial to determine whether the Motor controller dissipates any heat when the actuators are under their full load capacity.

9.1.4.2 Software Connection Test

The second test will start as a very similar test to the first one, however with it being controlled via logic from the MCU. There will be a direction pin and PWM pin connection for each motor that can be used to control the direction and speed of the actuator. Testing and prototyping on this step will be vital to determining the best code to help keep the actuators moving synchronously. From there, full implementation can commence.

9.1.5 Electric Linear Actuators

The linear actuator represents the foundational hardware for the U.P.R.I.G.H.T, if they fail, the rest of the project will also fail immediately. Therefore, testing the actuator's full capabilities is vital for the success of the standing desk. The critical factors for the desk determined at the beginning of research and development, included a load capacity of at least 120 pounds, and a transition speed from sitting to standing (or vice versa) of at least 25mm/s. These characteristics will be the benchmarks that are tested against the actuator's actual capability.

9.1.5.1 Load Capacity and Actuator Speed Test

The aim of this test is to find the definite actuator speeds at varying levels of load. A prototype will be built to simulate how the actuators will operate within the standing desk, and varying loads will be applied to the system from 0 to 120 pounds, with the speed recorded at 20–30-pound intervals. Please see the table below for the tabulated results, along with the voltage outputs at each interval. At a full load capacity of 120 pounds the system was able to achieve the desired speed of 25mm/s.

Table 31 - Data from 9.1.5.1 Test

Load on Prototype	AC/DC Adapter Voltage Output	Time to fully Extend	Actuator Speed
No Load	12.36 V	10.0 s	1.74"/s 45mm/s
8 Pounds	12.05 V	10.5 s	1.65"/s 42mm/s
28 Pounds	11.94 V	11.5 s	1.5"/s 38mm/s
58.5 Pounds	11.78 V	13.5 s	1.29"/s 32.8mm/s
90 Pounds	11.6 V	16 s	1.09"/s 27.7mm/s
120 Pounds	11.45 V	17.5 s	1.00"/s 25.4mm/s

9.1.6 Raspberry Pi 4

The one main use of the Raspberry Pi 4 component is communication between the MCU and the application. This is a critical feature that is used to transmit data that will be stored on a database. Another important feature of the project that will be processed on the Raspberry Pi 4 is the facial tracking software. The face_recognition library is going to be used for this part and it is important that the Raspberry Pi 4 is able to process on the device while accessing the USB web camera. Two tests will be completed to test these features.

9.1.6.1 Software Test

The first test will be ensuring that the facial tracking software can be run on the Raspberry Pi 4 and that it can access the USB camera. After installing the library, a basic script was created for testing that will open up a window to show the output of the facial track results. Then a red box will outline where the face is at and it will follow the person on the screen.

9.1.6.2 Communication Test

For the second test the main feature of communication used will be the Bluetooth functionality on the device. To ensure that the Raspberry Pi 4 model obtained is not faulty, a test was conducted to test the Bluetooth connection of the device. This was completed using a Bluetooth mouse to see if other devices could connect.

9.2 Overall Integration

After individual testing of all components and confirmation that they meet the required specifications for our design, the next step involves assembling and testing the entire system. This stage may necessitate an additional MSP430 development board if the number of required connections exceeds the available pins on a single board. By verifying many of the components individually before full integration, we can reduce the likelihood of errors and decrease the amount of time spent debugging. This systematic approach ensures that integration issues are minimized, facilitating a smoother transition to a fully operational system.

9.3 Plan for Senior Design 2

In the next phase of our senior design project, we will transition from schematic designs to creating our printed circuit boards (PCBs). The construction of the desk, which will serve as the mounting base for our PCBs, will begin. Additionally, we aim to design a thinner enclosure for the load cells compared to the demo version, enabling placement underneath a mat. Testing of each component will be conducted individually, gradually integrating them to ensure both software and hardware compatibility under full operational loads.

To maintain efficiency and ensure continuous progress, our team will commit to constant and open communication. Meetings will be scheduled weekly, alternating between in-person and Zoom sessions to accommodate varying schedules and ensure consistent advancement on our prototype. We will utilize Jira to track our progress, set deadlines, and manage our time effectively, aiming to deliver a functional prototype promptly.

Documentation will be updated regularly to reflect any new developments, completed designs, or significant changes, both on our senior design website and in our paper. This ongoing documentation will include more detailed data and information as it becomes available.

There is significant work ahead, but the team is enthusiastic about moving from planning to execution, building on the extensive groundwork laid in the initial phases of the project.

Chapter 10 - Administrative Content

This chapter will cover the administrative content of the project which includes finance, budget, and overall milestone for the project. This will be represented in three sections total.

10.1 Budget

Budgeting is a crucial part of sustainability for the U.P.R.I.G.H.T, and the price of this desk will make or break its feasibility. One goal of this project is to create a product with a budget that can maximize market longevity. Our aim is to create a price point that matches the standard rates near the middle of the market. A quick search online shows a plethora of small, cheap desks priced right around $100.00, however none of these desks have any programmable or automated features. As discussed in Section 2.4, desks from Uplift are installed with similar functionalities as those envisioned for this project, however they are also quite expensive. The base model starts at $569.00 and ranges up to and over $2,000 [5]. Another similar example comes from Eureka Ergonomics' Ark Standing Desk line, offering their cheapest model at $2,000 as well [64]. Keeping this in mind, if the budget can achieve a price point on the lower end of these examples, the U.P.R.I.G.H.T should be able to have a few competitive advantages: not only will it include a sophisticated mat, but it would also include tracking functionality. However, all expenses for this project will be shared among the group members. To maximize these advantages, while not breaking the bank, the budget will be set at $800.00.

10.2 Bill of Materials

See Table 32 below for the estimated bill of material (BOM) needed to complete this project. The list is a general approximation of cost and will be updated as specific components are researched and selected. Also take note that some of the items included would not be in the final version of the U.P.R.I.G.H.T BOM. Duplicate items such as PCB and microcontrollers are included to ensure the capability for prototyping and demo throughout the design process. To guarantee that this project will operate under budget, these extra line items are included in the bill of material. The BOM shows a total price less than the budget set in the previous section.

Table 32 - Bill of Materials

Item	Estimated Cost	Actual Cost
Materials for Desk	$200.00	TBD
Office Floor Mat	$50.00	TBD
Load Cells	$20.00	$8.99
Housing design for Load Cells	$10.00	TBD
AC/DC Power Supply Convertor	$20.00	$45.00
PCB(s)	$50.00	TBD
MCU	$5.00	$8.70
Development Board and Raspberry Pi	$70.00	$55.00
Motor Control Module	$20.00	$23.50
Linear Actuators	$300.00	$290.00
LCD Display	$30.00	$9.21
Push Buttons	$15.00	$26.93
Housing Design for user interface	$25.00	TBD
Web Camera	$25.00	$0.00
Misc. items	$50.00	TBD
Total:	**$900.00**	TBD

10.3 Project Milestones

Team 11 formed at the beginning of Senior Design I in the spring of 2024 with plans to attend Senior Design II in the summer of 2024. The Table 33 and Table 34 have been created to reflect the milestones and goals for this schedule selection.

Table 33 - Senior Design I Timeline Spring 2024

Task	Start Date	Anticipated End Date	Status
Project Idea Discussion	1/8/2024	1/17/2024	Complete
Project Selection and Committee Formed	1/17/2024	1/26/2024	Complete
Divide and Conquer Completion	1/22/2024	2/2/2024	Complete
30-Page Milestone	2/2/2024	2/23/2024	Complete
Individual System Design	2/2/2024	2/23/2024	Complete
60-Page Milestone	2/23/2024	3/22/2024	Complete
Individual System Testing	3/22/2024	4/5/2024	Current
90-Page Milestone	3/22/2024	4/5/2024	Complete
Breadboard Prototyping	4/5/2024	4/19/2024	Current
120-Page Milestone	4/5/2024	4/19/2024	Complete
Final Draft	4/19/2024	4/23/2024	Complete
Final PCB Design/Ordering	4/23/2024	4/30/2024	Not yet started

Table 34 - Senior Design II Timeline Summer 2024

Task	Start Date	Anticipated End Date	Status
PCB Assembly and Testing	5/13/2024	5/24/2024	Not yet started
System Integration/Testing	5/24/2024	6/21/2024	Not yet started
Practice Project Demo	6/21/2024	7/5/2024	Not yet started
Finalize Documentation	7/5/2024	7/19/2024	Not yet started
Practice Final Presentation	7/19/2024	7/26/2024	Not yet started
Final Presentation	TBD	TBD	Not yet started

Chapter 11 - Conclusion

Next to the conditions faced by blue collar workers, modern office jobs can be seen as low-risk and cushy. However, an office job does not provide a workplace environment free from risk of injury. The simple repetitive stress of sitting at a desk all day can lead to lower back pain and other chronic health issues. In fact, these types of repetitive stress injuries are the number one cause of workplace disability. The economic impacts of this are massive, to say nothing of the human cost.

Many workplaces have taken steps to address these issues by creating more ergonomic workstations. One step towards this has been the adoption of sit/stand desks that allow workers to alternate between sitting and standing throughout the workday. This is greatly beneficial, but the benefits are limited by how much workers adopt the sit/stand feature. Inconvenient use modes or even a lack of motivation lead to workers not utilizing their sit/stand desks.

To address these issues, this proposal detailed the User Position Recognition Integrated Guiding Height Table (U.P.R.I.G.H.T.). U.P.R.I.G.H.T. takes the idea of a standard sit/stand desk and expands upon it. This desk is focused on fitting each individual user. U.P.R.I.G.H.T. maintains a database of user profiles. Each user profile includes a sitting desk height and a standing desk height that the user calibrates at first use. This first use is facilitated by a Bluetooth connection to the user's internet browser or smart phone. This allows the user to access an application that walks them through the process of creating an account and calibrating the desk's height and weight settings.

To further reduce the burden of constantly switching the desk between sitting and standing positions, a weight sensor is integrated into the standing mat. The weight sensor compares the sensed weight of the user with weight stored in the database during the calibration step. If the sensor determines that the user has switched positions, the desk automatically adjusts. This lowers the burden of using a sit/stand desk for the user to the act of merely sitting and standing. It further reduces the need for adjusting the desk once it has switched positions as the preferred desk height has already been predetermined.

That is not to say that the user cannot change their mind. The user can make small adjustments throughout the day to find a height that works for them, even if this deviates from their pre-defined settings. The application tracks the time history of the actual desk height as the user makes adjustments. This tracking is used to populate a chart that the user can access. If the user sees that their actual desk usage deviates from the calibrated preset, they can go in and reset their calibration.

This proposal also went over elements of the project extending beyond a basic product description. The functionalities described above require a suite of hardware and software to be implemented. First, the team evaluated which technologies would best enable the project when compared to similar technologies. Once the technologies were selected for, trade studies were completed for each major software and hardware selection to find the components that best suit the needs of the project without inducing significant costs in terms of finances and training of the team.

One requirement is that the pressure sensor needs to be able to detect the weight of the user within 10% accuracy. To accomplish this, the team has elected to use load cells underneath the mat. This decision was made primarily due to the reliability of the sensors through many load cycles and the precision of the measurements provided to the rest of the system. As for the specific part, we selected the SEN-10245 load cell manufactured by SparkFun Electronics. This load cell had a superior price point and could measure the weights within our use case. This was not an area where spending more increased our performance in a measurable way.

Additionally, U.P.R.I.G.H.T. needs a way to determine which user is using the desk. It was determined that the team would use facial tracking with a camera. Not only does this allow for recognition of the user but it also allows the desk to determine when a user is no longer present and thus avoids unnecessary movement.

This project involves more than software. The desk must physically move in a controlled manner. In that vein, the team has decided to use electrical linear actuators. These actuators allow for automated and precise control over the speed and position of the desk. This is vital as uncontrolled actuation of the desk could potentially cause harm to the user’s body or property. After comparing three candidate electrical linear actuators, the decision was made to proceed with the Model 0041670 actuators. These specific actuators provide both seamless speed transitions and favorable load capacity to speed ratios.

To further assist in maintaining control of the desk, U.P.R.I.G.H.T. will utilize potentiometers. These will provide the system feedback about the desk’s position without requiring recalibration during every power cycle. All of this will be powered through 120V AC power through a converter. This was chosen to avoid the use of batteries which would be an undue annoyance for the end user. Additionally, there would be no issue with portability as the desk would already be in an environment with plenty of access to 120V AC power. The specific motor controller selected in our study was the Cytron Model #MDD10A. It, along with one other controller model, met the critical factors, especially a very high PWM frequency capability. However, the other model had a procurement time of up to a month, so the Cytron model was deemed to be the best choice for U.P.R.I.G.H.T.. Additionally, we have selected the LEDWholesalers Product 3263-12V AC/DC converter. Several options met specifications, but this product is expected to run quietly and would thus lead to a better user experience.

The last technology to consider is the display panel. It was determined that an LCD display would be advantageous for use in U.P.R.I.G.H.T.. This was a decision based on the balance of performance, power efficiency, and cost that LCDs provide. Additionally, it is a widely used and familiar technology.

With these selections made and use cases defined, U.P.R.I.G.H.T. has taken shape in this proposal. We are now at a point where we are ready to execute on this vision and usher in a new era in ergonomic design and forever reduce the instances of workplace disability due to repetitive stress.

Declaration

We hereby declare that we have not copied more than 7 pages from the Large Language Model (LLM). We have utilized LLM for drafting, outlining, comparing, summarizing, and proofreading purposes.

Appendix I - References

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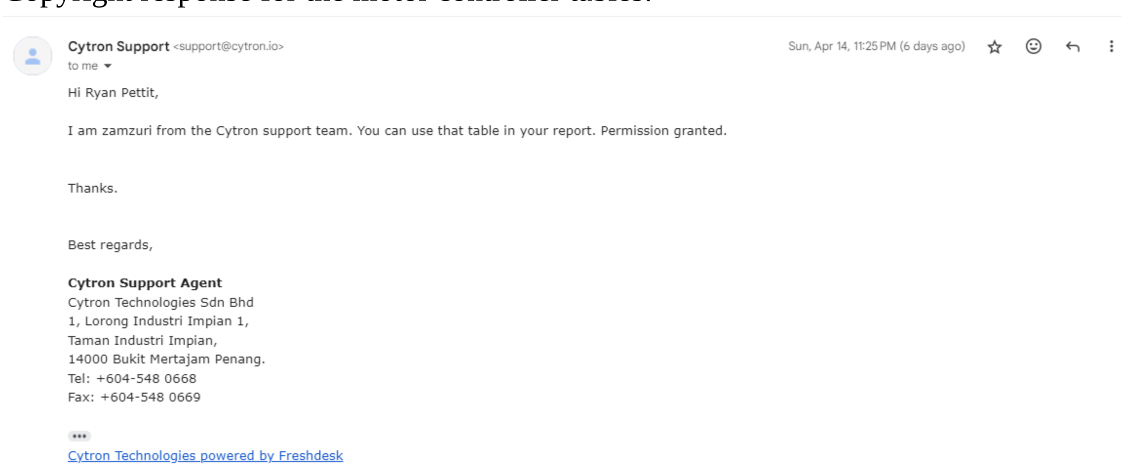
Appendix II – Copyright

Copyright response for the motor controller tables:



Cytron Support <support@cytron.io>
to me
Sun, Apr 14, 11:25 PM (6 days ago)

Hi Ryan Pettit,

I am zamzuri from the Cytron support team. You can use that table in your report. Permission granted.

Thanks.

Best regards,

Cytron Support Agent
Cytron Technologies Sdn Bhd
1, Lorong Industri Impian 1,
Taman Industri Impian,
14000 Bukit Mertajam Penang.
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Cytron Technologies powered by Freshdesk