StepQuest
Gamified Fitness Tracker

60 Page Design Document

EEL 4914 | Senior Design I

Fall 2023 | Group 39

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2.0 Project Description

Maintaining consistent motivation for fitness is a problem for many and this is due to many factors. Some factors include that fitness often becomes less motivating after the initial burst of enthusiasm or is seen as daunting by many that do not find that initial motivation. Maintaining and gaining motivation is a widespread problem amongst new and experienced athletes. We aim to solve this problem by gamifying fitness. Making it more approachable and motivating.

2.1 Motivation & Background

Motivation is crucial for a fitness routine. It is what keeps us going when we walk into the gym or head out onto the pavement for a run. It is what gives us that extra push. For many, keeping up this motivation or even acquiring it, is difficult. Once the initial motivation wears off, it is common for one to lose most if not all their motivation for fitness. This loss of motivation typically leads to giving up fitness altogether. This leads to an unhealthy lifestyle and an overall decline in health. We aim to solve this problem.

By gamifying fitness, it is possible that this will increase one's motivation for fitness. It can also serve to give motivation to those who lacked it initially. Additionally, it can make fitness more approachable and enticing to those who find it to be too boring or too daunting. By having a wearable game tied to one's fitness routine utilizing various biosensors to collect and use data, this could make fitness easier and more fun. By also using other functionality to remind users and gamifying their experience, it would also contribute to making fitness simpler. This solution would therefore make it easier to gain and maintain consistent motivation for fitness goals and allow one to stick to their fitness routine in a sustainable and long-lasting way.

The problems of fitness motivation have many sides to them and are something that have challenged many individuals. Gaining and maintaining fitness motivation is a problem that has permeated our society for a long time and has yet to see a long-lasting solution. Researchers and enthusiasts have tackled this problem many times before but the solutions that have been created have not fully solved the problem. We aim to research and address many of these complexities that are the reason behind the negative impact a lack of fitness motivation has on one's overall well-being.

The problem of gaining and maintaining motivation for fitness is something that goes beyond how old someone is, their gender, and their culture. A small subset of people has the distinct advantage of being able to conjure and maintain their own motivation for fitness and have no problem sticking to their fitness goals.

However, most people tend to be on the opposite side of the spectrum. They typically have difficulty generating and maintaining this motivation for physical activity and struggle to stick to their fitness goals. An increasing intrigue has generated around this problem due to research suggesting how beneficial regular physical activity is. Understanding the fundamental factors of this fitness motivation problem is an integral part in delivering a solution that will truly solve this important problem.

An especially important aspect of this problem is the issue of how to make a solution that is sustainable for a lasting duration. Having a short-term rush of enthusiasm for fitness is common. Seasonal events are often the cause of this psychological phenomena. While they may be enjoyable, the motivation often does not last long, and it is therefore unsustainable. They are not effective and often lead to one discarding their fitness routine and goals.

The critical motivation for trying to solve this fitness motivation issue is the crucial value and significance of physical health. Many people today have very sedentary lifestyles and poor diets, causing many to have a myriad of physical health problems, many of which could be solved with fitness. Regular physical exercise is important for one's physical health. Fitness is closely tied with our lifespan, preventing illness, and our overall general wellbeing.

Besides physical health, consistent physical activity affects our mental health in many ways. When physically active, a decrease in stress occurs and the brain will generate endorphins increasing wellbeing, brain performance, mood, and mental tension. Physical activity aids mental health and helps in tackling the many mental challenges that affect us today. Getting people engaged in consistent physical activity can also be an essential element in aiding one's mental fortitude.

Seeing the complexities and importance of this problem, many have tried to solve the problem in a myriad of ways. Often using technology as a foundational aspect of their solution. Digital tracker apps or wearables are a common solution that many have delivered. They often track one's fitness statistics, deliver reminders, and other basic features, but they do not directly target the problem. They just make fitness easier and more convenient. They do not directly make it more motivating. Nor make it gratifying in any way.

StepQuest aims to actually make fitness motivating. The foundational aspect of our solution is to properly gamify fitness with an idle RPG like game. One controls and plays the game by being physically active. One's mindset is not necessarily focused on the physical activity, but on playing the game. We believe by adding this layer of gamification, this will help to increase one's motivation for fitness in a long-lasting way.

By solving this problem, we aim to create a new way to aid people in their fitness goals. This will result in many great benefits to one's wellbeing. These benefits include improved physical health, decrease in illness, stress relieving properties, greater mental health, and more. By researching and learning from prior solutions, our solution will address the many downfalls and fundamental errors of proceeding solutions. Our solution will address the fundamental root causes of the fitness motivation problem.

2.2 Goals & Objectives

StepQuest aims to satisfy three overarching goals. Firstly, in an increasingly sedentary world, remind and encourage people to exercise in a way that is relatively unobtrusive to their day to day lives. Secondly, make that exercise fun through an interactive game that leaves users feeling both motivated to exercise and rewarded when they do. Finally, the device should offer a user-friendly experience where usage of the device is easy to understand, as is the game.

There are also more specific goals/objectives for both the physical device itself as well as for the software/game. Also worth mentioning is that some goals are considered stretch goals as it may not be possible to implement these features due to time and budget constraints.

The goals for the device are as follows:

- Convenient to wear or carry
  - Small
  - Lightweight
  - Rain-resistant
- Power
  - Rechargeable
  - Sufficient battery life
- Screen to display time and game elements
- Provides a way to interact with the game
- Able to record user footsteps
- Vibration capability

The stretch goals for the device are as follows:

- Power
  - Wireless charging
  - Full-day battery life
- Foldable display screen
- Touch Screen
- Able to record user Heartrate
- Water Resistance

The goals for the software/game component of the device are as follows:

- Idle-type game
- Avatar customization:
    - Skin tone
    - Eye color
    - Hair color and shape
    - Top color
    - Bottom color
- Interactive world map:
    - Town/City like locations
    - Dungeon like locations
- Travel between locations via number of footsteps:
    - Travel produces encounters:
        - Found currency
        - Combat
            - Outcome determined by level, fitness stats, weaponry, armor:
                - Flee, no gained currency or experience
                - Success, gain currency and experience
- Town/City like locations have the following features:
    - Quest board:
        - Offers fitness and patrol tasks
            - All tasks reward currency and experience
            - Patrol tasks provide encounters
    - Shop
        - Purchase items with currency:
            - Cosmetics
            - Weaponry
            - Armor
- User level increased by:
    - Footsteps
    - Quests
    - Successful combat encounters
- Level influences quest difficulty
- Four fitness stats:
    - Endurance
    - Strength
    - Flexibility
    - Speed
- Fitness stats increased by increasing level
- Fitness stats influence:
    - Types of quests
    - Outcome of encounters

The stretch goals for the game component are as follows:

- Avatar customization:
  - Hats
  - Clothing
- More encounter types
- Add health mechanism
  - Add health items to shops
- Fitness stats leveled by completing certain types of exercises

Summary of Goals

In summary there are three types of goals, basic, advanced and stretch. These are listed below.

Basic Goals

- Convenient to wear or carry
- Sufficient Battery Life that is Rechargeable
- Records steps
- Vibration Capability
- Idle RPG style game
- At least 3 in game locations
- Travel System
- Quest Board in Towns
- Level System
- Shops in Towns

Stretch Goals

- Wireless Charging
- Touch Screen
- Additional Encounters in Game
- Health Mechanism in Game
- Companion App for Game
- Water Resistance
- Records heartrate
- Avatar Customization
- Four Fitness Stats

2.3 Background & Market Research

Background Research and Information
Some comparisons could be drawn between the StepQuest project and other applications and products currently on the market. According to Fortune Business Insights, “The global fitness tracker market size was valued at USD 36.34 billion in 2020 and is projected to grow from USD 36.34 billion in 2020 to USD 114.36 billion in 2028, exhibiting a CAGR of 15.4% in the 2021-2028 period.” [1] Not only are fitness trackers increasing in popularity, but games using tracked activity metrics are also on the rise. Niantic’s Pokemon Go and Monster Hunter Now, and Bandai’s Vital Hero bracelet are obvious mentions, with Pokemon Go quickly rising to the top of the revenue charts, beating out previous chart topper, Cany Crush. [2].

Our hope is to innovate on these designs given the shortcomings we’ve found that have precipitated this project.

Current Market Research
Pokemon Go
Pokemon Go was the runaway hit of 2016, becoming the most downloaded app in its first week ever [3]. Astoundingly, users reported taking about an extra 200 steps a day.[4] This is great news for users’ health and an obvious step in the right direction of what our team also hopes to achieve, which is helping users collect their health data and use it to make healthier lifestyle choices.

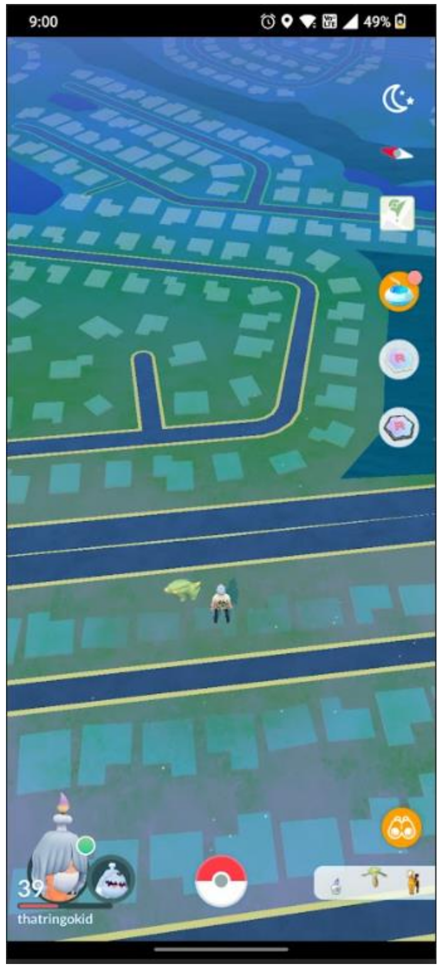


Figure 1. Pokemon Go

One major gameplay choice we would like to address about Pokemon Go's system, and one that especially plague's Niantic's newest game Monster Hunger Now, is the fact that users have to be constantly looking down at their phone during the gameplay experience. While this may seem normal for a mobile game, it is not ideal from a mindfulness perspective, nor is it ideal to be constantly looking down while exercising or being out and interacting with the world. In short, it's too distracting. It is our opinion that users should be able to enjoy the outside while out walking, rather than having to check the screen and be pulled out of their experience, unless that is the experience that they wish to have.

<u>Vital Hero [5]</u>

Bandai's Vital Hero bracelet is a closer step to accomplishing many of the goals that our team is looking to solve. It is a wearable technology that allows users to choose to engage in movement or exercise and motivates them to do so. It tracks steps using an accelerometer, and engages the user with elements of gaming for motivation.

The improvements we would like to implement upon this design is to move away from the “catch-em’-all” gameplay elements and move into more traditional RPG elements. We would also like to obviously get away from the Bandai owned intellectual properties. The idea for our project actually came about from one of our member’s trying to recreate his own version of the Vital Hero, and from there we are happy to pivot.

Habatica [6]

Habatica is an Android application that gamifies the process of the “to-do-list.” This is a departure from the previous items on the list because it allows users to add their own tasks that they’d like to get done. Allowing a “choice” in what tasks to accomplish greatly increases intrinsic motivation, according to self-motivation theory [7]. There is an added bonus to having this app rooted in real-world accomplishments, so the better users do in game- the more they are accomplishing outside of the game. These are gameplay mechanisms we would like to incorporate, and this combination of user-goal setting and fitness tracking has not been present in a wearable option yet.

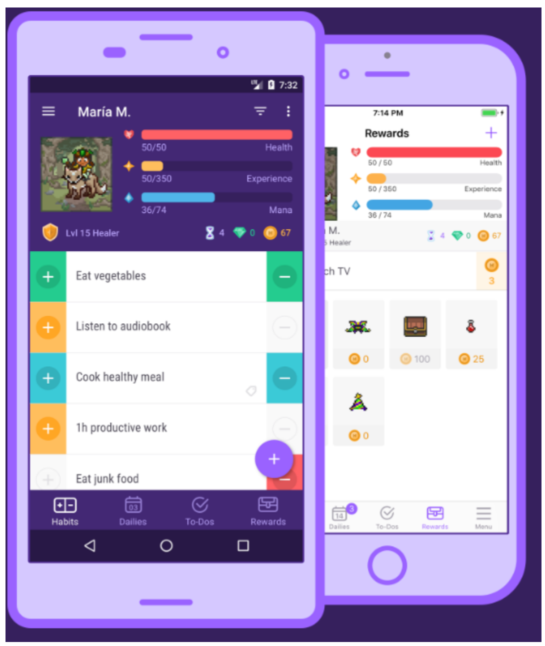


Figure 2. Habatica

Finch [8]

Taking gamified task-tracking a step further, Finch attempts to gamify Cognitive Behavior Therapy. This app holds users accountable for taking care of a virtual pet’s well-being and mental health.

“Every activity you complete on Finch gives you energy points, which you can then use to send your pet on adventures and level up. The adventures help your pet learn new things, develop its own personality traits, and grow, and completing more and more activities when they’re away on an adventure helps them return home sooner.” [9]

Idle Games

This genre of games allow the user to participate in the gaming process from a distance by checking in on their characters and making minimal inputs. The user still gets the dopamine hit from leveling-up and advancing the gameplay, but they are much less involved in the actual combat process. The core mechanic of an idle RPG is that characters automatically engage in battles or other activities without user’s direct input. Characters fight enemies, collect loot, and earn experience points (XP) on their own, even when the game is not actively being played. We aim to adapt this style of gameplay system so that the user can focus on their life and not be pulled from the moment or forced to adopt bad posture from looking down at their phone more than needed.

2.4 Engineering Specifications

In this section, we discuss the engineering specifications for our project. Keeping a record of the specifications will help our group achieve the goals we have set for this project. These specifications are designed to get the best out of the device, hence the market will receive it welcomely. Since the general goal of the project is to gamify workouts so people will fight laziness and start having a healthier lifestyle, we chose convenience and entertainment as our top priorities in the design. From the size of the tracker to the details of the game, everything embraces convenience and merriment. Here, we divided the specifications into two parts. Device Specifications and Game Specifications. They are shown in the tables below.

2.4.1 Device Specifications

A brief outlay of the device specifications that our group decided to move forward with. The table shows the details and constraints of the components that make up the device. Everything here is subject to change; however, this gives us an idea of the device's capabilities and functions.

	Device Specifications	**Details**
1	The size of the device is 43mm (about 1.69 in) at most.	This is an average height among watches. Any larger size will cause an uncomforting wrist for the user, which will discourage the user from wearing the tracker.
2	The range of weight is between 27-35gm	Heavier items will abrupt the user while exercising or storing the device
3	Battery life is 8 hours after a full charge	Will allow users to use during substantial portions of their day-to-day life
4	Batteries are expected to be fully recharged in 150 mins. This device will use 18W USB-C adapter	This is a conservative figure as it could be lower than that.
5	Interaction between the user and device will be through touchscreen and tactile buttons	This gives the user the ability to control and modify the device as they please
6	Counting steps	Using a gyroscope component, we can count the steps of the user with accuracy of 90%

7	Heartbeat monitor (Stretch Goal)	As this is an important measure of one's health, we included a heartbeat monitor on the device.
8	Timekeeping function	Through a Real-Time clock module this device is able to keep record of the real time
9	Turning screen on and off	This saves power as well as helps users rest better during downtime.
10	Useful information will be displayed for the user to make the exercise more practical	such as time, footsteps with 90% accuracy, duration since exercise started, heartbeat, as well as personal information
11	The Device will keep a record of the exercise pattern in a memory of 2mb. This means the user will be able to access their daily exercise for the last day, week or even month.	Showing the user their progress could help motivate them. Also, they can see what the downsides are that they have with their exercise routine
12	Alerts will be used to help remind the user of their last exercise day. A vibration will alert the user if they pass a threshold without exercising.	Many people can use this feature when forgetting to go for a walk or a run

Table 1. Device Specifications

2.4.2 Game Specifications

Here is a summary of the software specifications that we thought would increase the amusement of the user while exercising. Since we think taking care of our health is a personal responsibility, we felt it is only right to have an RPG style for the game. This way players can relate to their character and feel responsible for their wellbeing. We also included levels of difficulty that can be reached by achieving the number of steps or quests. As workouts take many forms, it was necessary for us to add stats for four different qualities. These qualities are endurance, strength, flexibility, and speed.

	Game Specifications	Details
1	RPG Style	The game is in a role-playing game style. That helps the user connect with the game.
2	Customized characters	Users can customize their avatars with the provided skin tones, hair shapes and colors, and eye colors. Players normally enjoy personalizing their characters to meet their aspirations.
3	Leveling system	Each level needs to be opened by footsteps, combat encounter and quests assigned to that level
4	Interactive Map	Digital towns and cities will be built in the software. Each has its own quests and obstacles.
5	Quest board	Each city or town will have a quest board where the user can choose to join a quest. Fitness tasks will reward the players with currency and EXP. Patrol tasks will raise encounters for the players.
6	Shops on the map	Here players can spend their currency buying cosmetics, weapons, and armor. This helps players improve their characters and gain skills and strength.
7	Travelling between various locations on the map	Using real world footsteps players can travel through various locations exploring new quests and combats

Table 2. Game Specifications

2.4.3 Summary of Engineering Specifications

Here, we picked the most important specification that will contribute the most to the efficiency of the project. The highlighted specifications will be demonstrated later in the next semester.

	Engineering Specifications	Details
1	Device Size	The size of the device is no larger than 43mm (about 1.69 in).
2	Battery Life	On full charge battery life is approximately 8 hours.
3	Counting steps	Using a gyroscope component, we can count the steps of the user with a normal and steady gait, with an accuracy of 80%
4	Timekeeping function	Through a Real-Time clock module this device is able to keep time with an accuracy of ± 1 minute per month.
5	Idle RPG Style Game	The game must be an idle role-playing game where the character progresses over time. The game should require no more than 1 hour a day.
6	Interactive Map	Loading different screens in the game should be achievable in less than 1 second. Furthermore, at minimum 3 locations should be available (2 towns, 1 dungeon).
7	Leveling system	Up to 100 levels must be achievable through footsteps, combat encounters, and accepted quests.
8	Quest Completion	At least 3 functional quest types must be available in the game. Patrol tasks which are completed by taking a certain number of steps. Jumping jack task which requires you to do a certain number of jumping jacks. A squat task which requires you to complete a certain number of squats.

Table 3. Engineering Specifications in Summary

2.5 Hardware Block Diagram

Below is the hardware block diagram of the StepQuest wearable device. StepQuest is a digital watch, consisting of several hardware components. The microcontroller is at the heart of the design. Connected to the MCU is the LCD display, input buttons, accelerometer, heartbeat sensor, and vibration module. A rechargeable battery and a power switch will also be incorporated into the design.

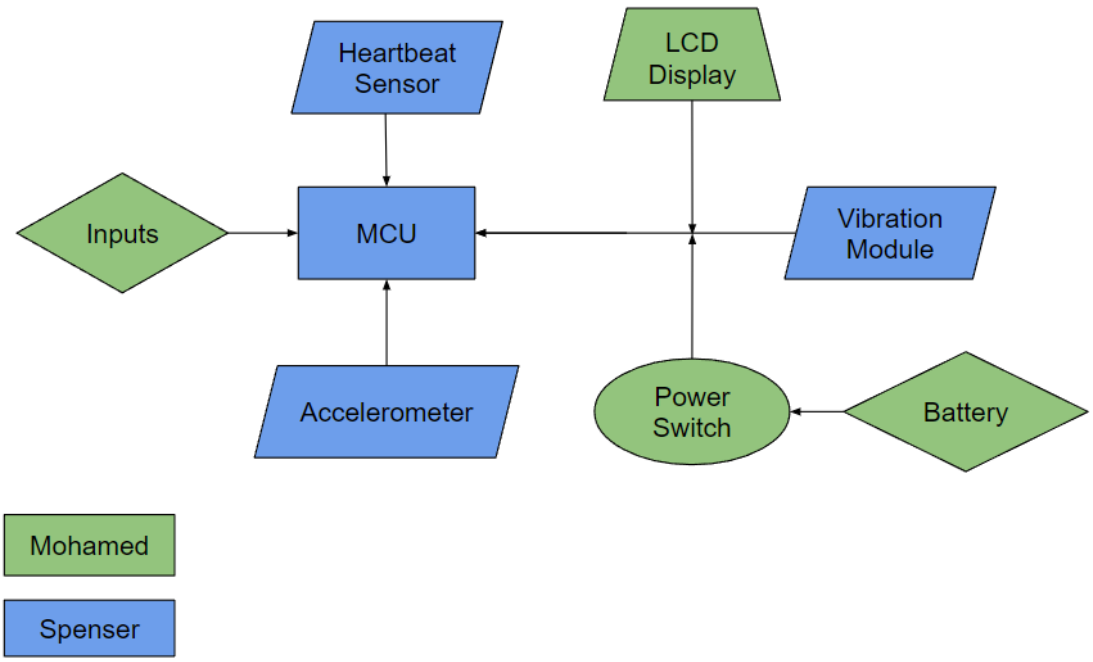


Figure 3. Hardware Diagram

2.6 Software Flowcharts

Below is the software flowchart of the StepQuest code. The home screen will display a significant portion of the important data to the user. From the home screen, several background mechanisms will be running. These include game mechanics, accomplishments, step counting, active points calculations, and time calculations.

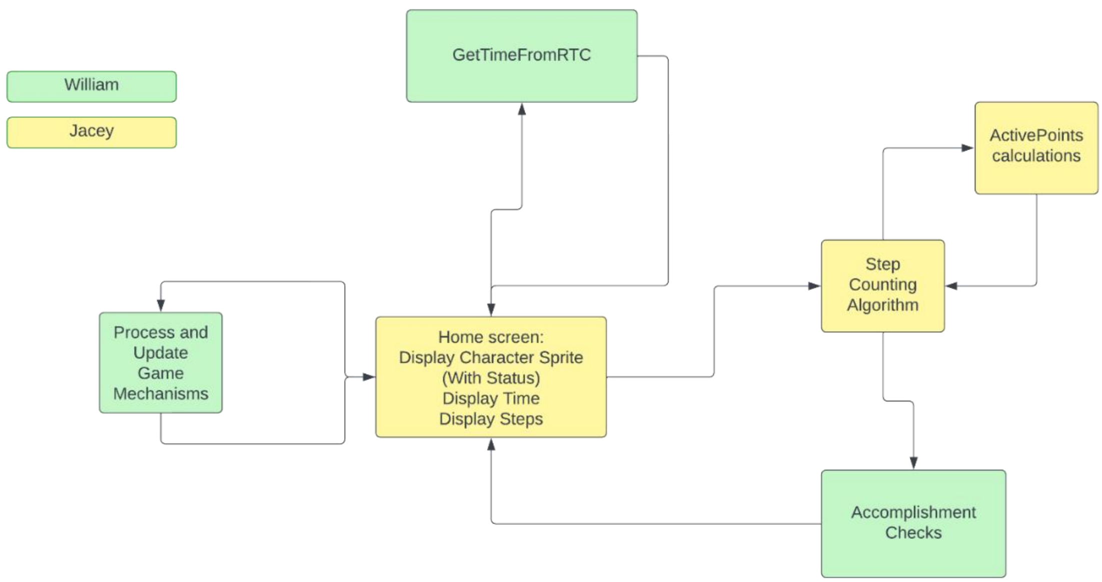


Figure 4. Software Diagram

2.6.1 Gameplay Flow Diagram

As a large segment of our project is the game, which serves to both motivate people to exercise as well as provide gratification for doing so, the gameplay flow is rather important to the project. However, the gameplay flow is large and can be difficult to view when all together. As such, the full diagram will be shown, alongside segments of the diagram to ensure legibility.

Furthermore, a simplified version of the diagram will show who is responsible for which features.

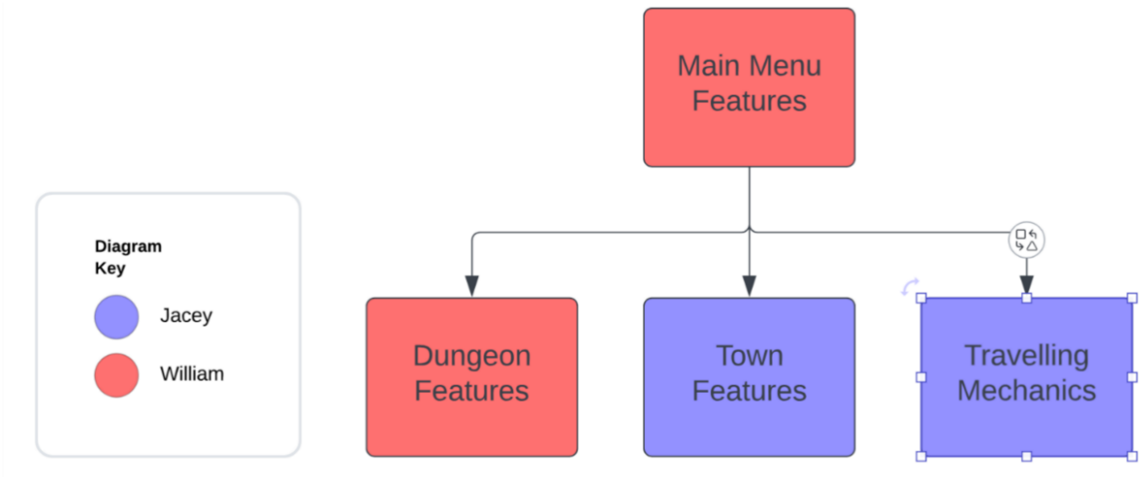


Figure 5. Gameplay Work Divided

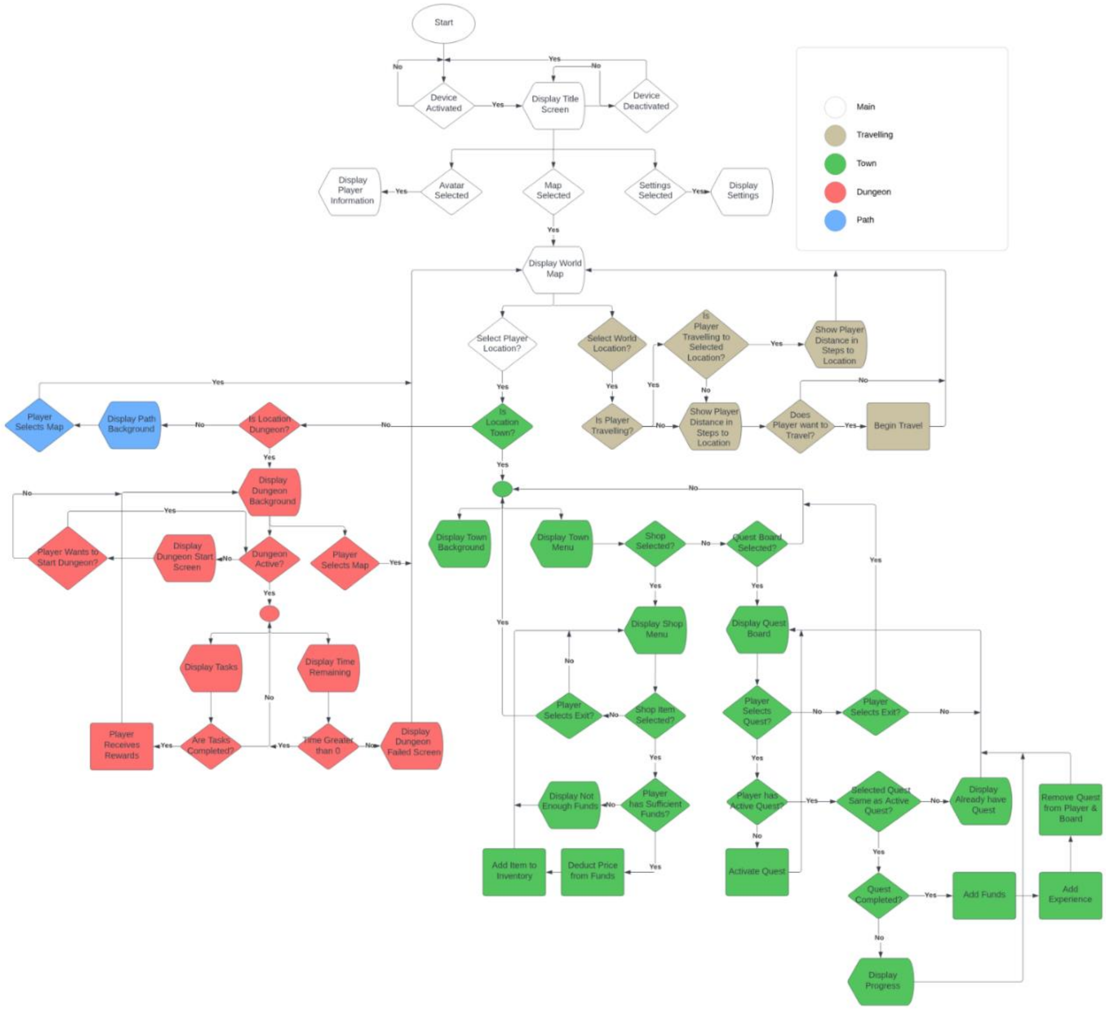


Figure 6. Full Gameplay Flow Diagram

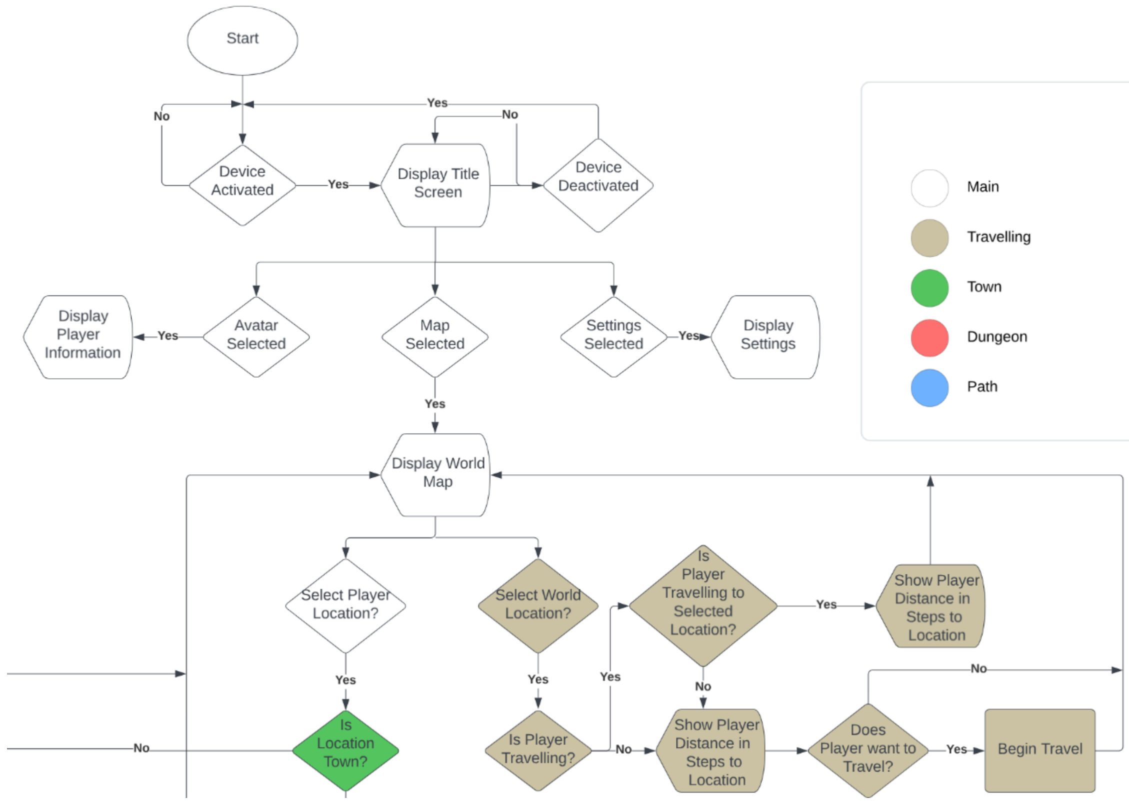


Figure 7. Main Menu & Travelling Diagram

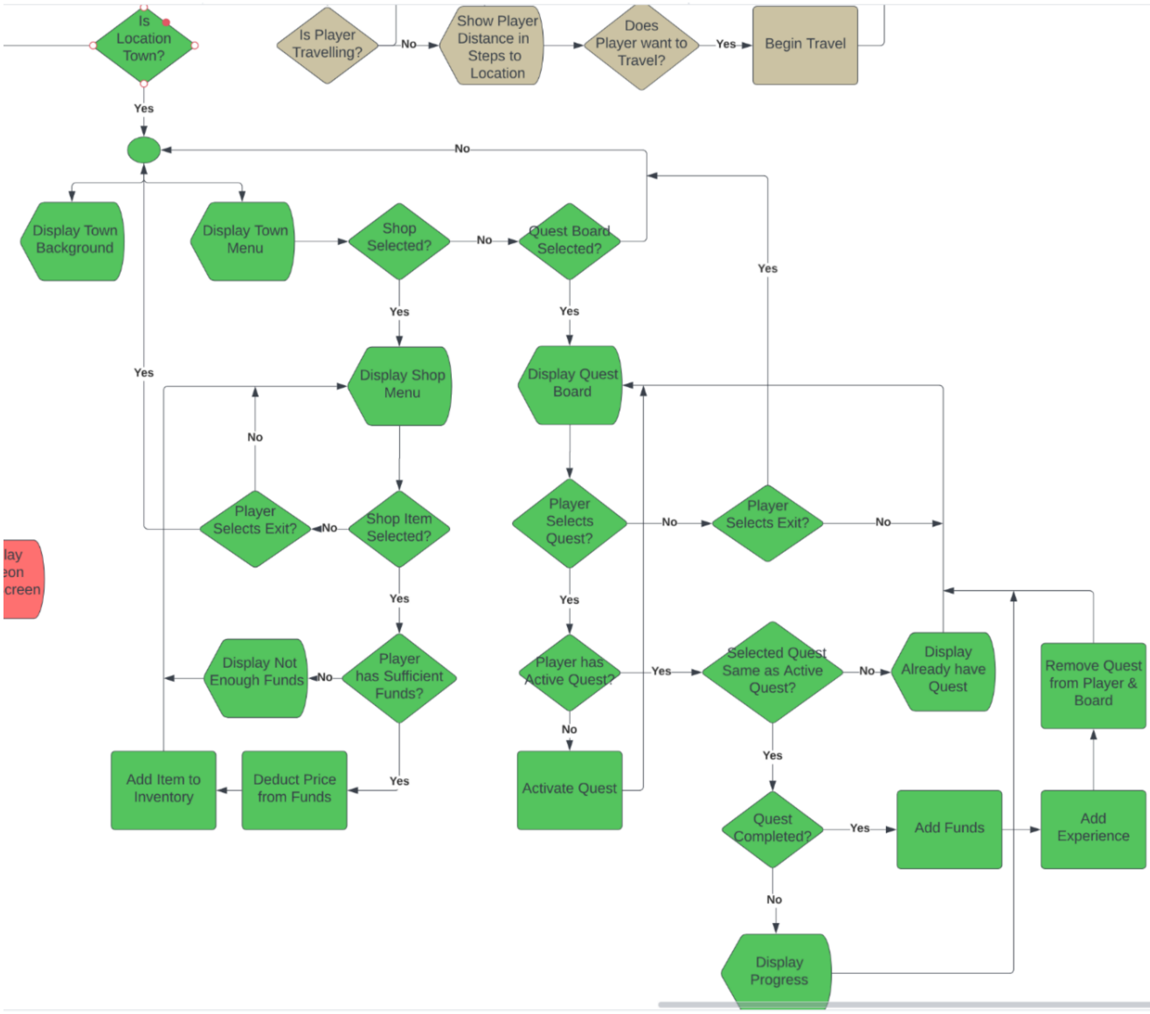


Figure 8. Town Diagram

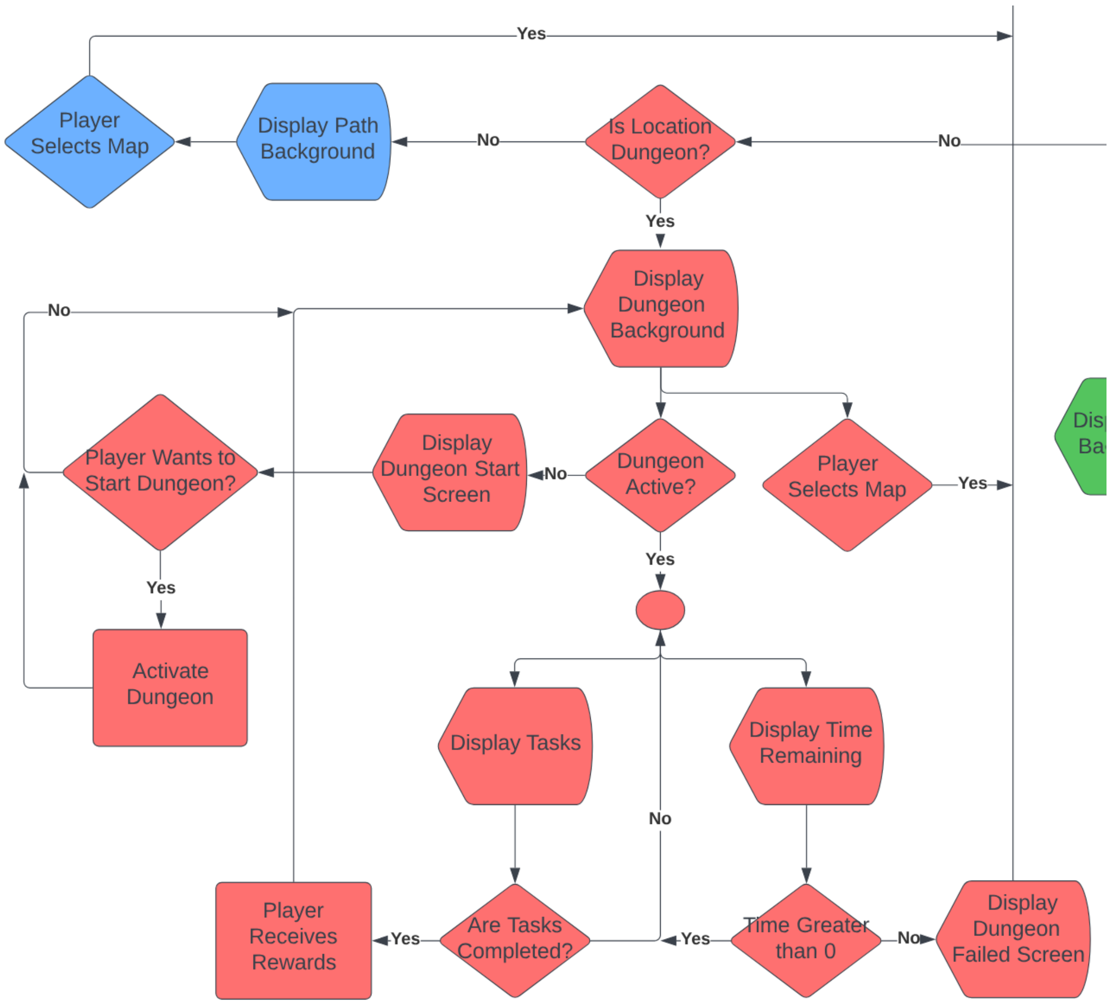


Figure 9. Dungeon & Path Diagram

2.7 House of Quality

A house of quality is a tool used to better plan the design of a product. It communicates the requirements of the user and how they are connected to the methods that the designers use to meet those requirements. It is an important tool to better design the StepQuest device to best meet the needs of the user. Below is the house of quality for the StepQuest device.

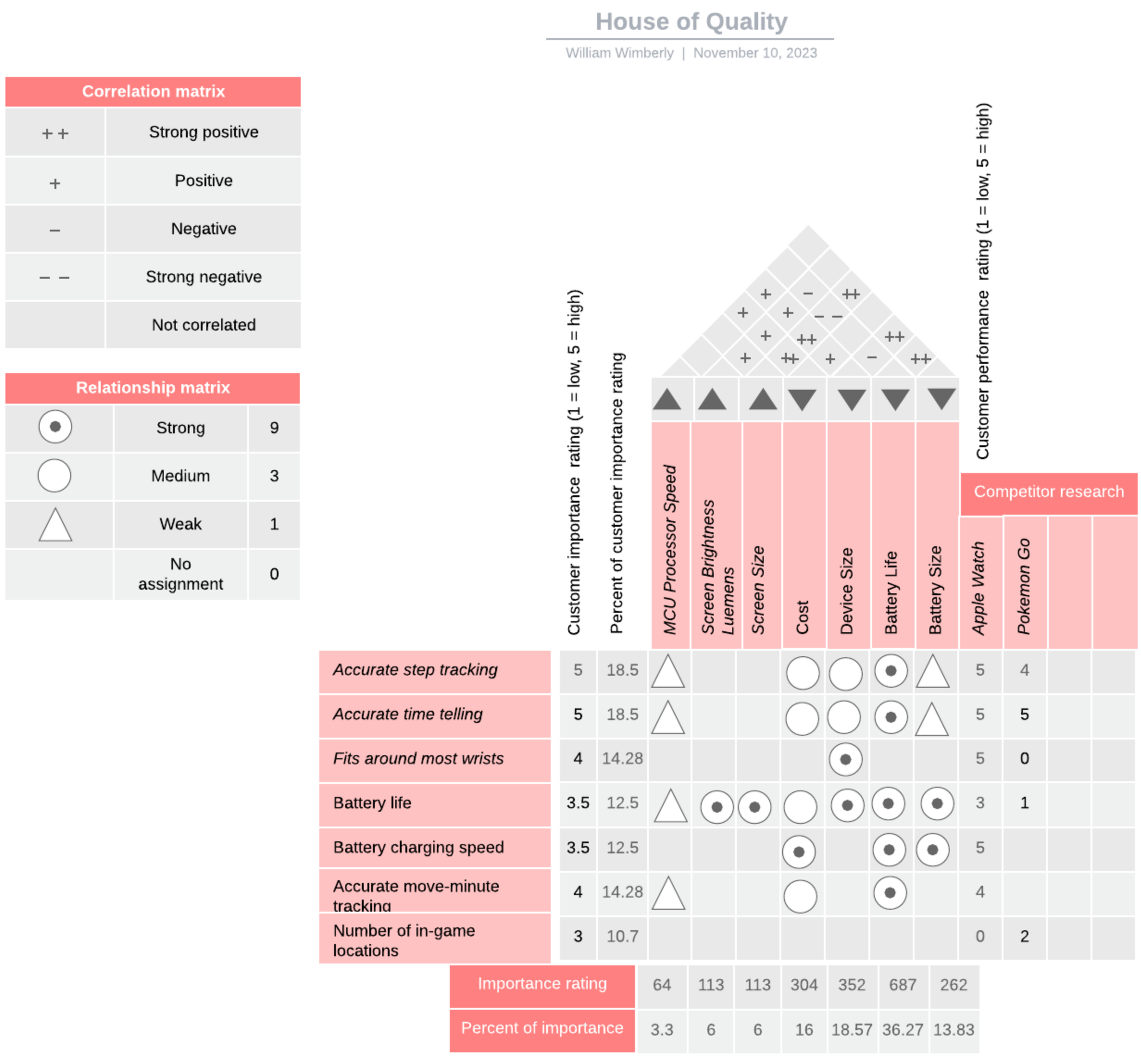


Figure 10. House of Quality

3.0 Research

To find which hardware and software technologies would be the optimal choice for the StepQuest design requires extensive research. Below is the breakdown and comparisons of both the hardware and software technologies that the team researched and chose to integrate into the design of StepQuest.

3.1 Technology Comparison

Several technologies need to be incorporated into the design of StepQuest. These include both hardware and software technologies. Below are the descriptions and the accompanying comparisons of the technologies described. Which technology was ultimately chosen is also included in each technology section.

3.1.1 Step Algorithms

A vital component of most fitness trackers is the ability to accurately record the number of steps taken by the user. StepQuest is no exception. The number of steps taken by the user is used for many reasons including: tracking long-term progress, increasing user level, completing step-based quests, and travelling between in-game locations. With the number of steps contributing to many core mechanics of the game it is vital to ensure that steps are not only counted, but counted accurately.

Typically to count steps an accelerometer is used, sometimes in tandem with a gyroscope. The StepQuest intends to only use an accelerometer at the moment and the below algorithms reflect this intention.

<u>Peak Detection Algorithm</u>

The peak detection algorithm is one of the simplest step counting algorithms. In the plainest terms, this algorithm:

1. Converts accelerometer data into a single vector magnitude.
    a. Optionally apply filters to clean up noise.
2. Identifies peaks through comparison with neighboring points.
3. Counts each identified peak as a step.

This algorithm would be very easy and simple to implement, however it does have flaws. Peak detection done in this way is very susceptible to false positives and negatives. Furthermore, it often loses accuracy when the user is on uneven terrain. Given the importance of accurate step counting in StepQuest, this algorithm likely isn't the best choice.

Improved Peak Detection Algorithm

While peak detection in it's most basic form is far from accurate. Others have worked on this problem before and come up with some improvements. This algorithm is found in the IEEE Sensors Journal [3]. The main focus is to reduce false counting due to moving of a smartphone which may prove useful regardless of if a watch design or attachable waistband device is chosen for the project.

1. Determine the user state, such as whether they are walking or still, as it increases accuracy.
2. Convert the three axis accelerometer data into a single amplitude.
3. Extract local maxima through a comparison of the amplitude to the determined threshold value and the adjacent amplitudes.
4. Apply the following constraints to reduce fake steps due to false walking.
    a. Limit the periodicity between neighboring peaks in the accelerometer data.
    b. Ensure a certain level of similarity between every other step as readings are slightly different between the left and right foot.
    c. Ensure a certain level of continuity is maintained to prevent counting steps when the user is standing still.
5. Estimate the number of steps based on the above peaks with the constraints applied.

While this algorithm is more time consuming to implement and requires the use of several formulas, it shows marked improvement over the basic peak detection algorithm. In the study [3] the average error of this method was found to be 3.54% for normal walking and 4.04% for free walking. Boasting a 6.58% and 9.54% improvement respectively over the basic peak detection algorithm.

Given its relative simplicity compared to some other approaches, alongside its relative accuracy, the improved peak detection algorithm may be a desirable choice for StepQuest.

Zero Crossing Algorithm

The zero crossing algorithm is slightly more complex than the peak detection algorithm, but still rather simple. It works by counting steps whenever the acceleration crosses the zero threshold. The algorithm is as follows:

1. Converts accelerometer data into a single vector magnitude.
    a. Optionally apply filters to clean up noise.
2. Identify instances where the acceleration vector crosses the zero threshold. This is detected when the acceleration changes from positive to negative and vice versa.
3. Counts each crossing as a step

This algorithm is very simple and straightforward to implement. Furthermore, it tends to be more accurate than peak detection. However, this method is still highly susceptible to noise and may need further refinement to improve reliability.

Dynamic Threshold and Dynamic Precision Algorithm

This [5] is a take on the zero-crossing algorithm but with a dynamic threshold rather than one at zero. Instead of setting a permanent cross threshold, it defines a new threshold every fifty samples. The algorithm is as follows:

1. Converts accelerometer data into a single vector magnitude.
    a. Optionally apply filters to clean up noise.
2. If fifty samples have been collected since the last threshold update, update the threshold as follows:
    a. Find the maximum and minimum acceleration vector values.
    b. Set the threshold as (Max + Min)/2
3. Identify instances where the acceleration vector crosses the threshold.
4. Count each crossing as a step

While research [4] has shown that this algorithm can be rather effective for regular gaits, it is more susceptible to unstructured gaits. However, this may prove to be a useful algorithm for StepQuest given its relative simplicity and potential accuracy.

Peak Detection and Dynamic Crossing Combination Algorithm

Another publication [2] put forward another variant of step counting algorithm that combines features of both peak detection and zero crossing detection in order to make it more accurate in various different walking states. The algorithm put forward is as follows:

1. Convert accelerometer data into a single vector magnitude, this reduces dependency on any individual axis.
2. Pass this data through a low-pass filter to reduce noise, using a cutoff frequency of 3 Hz.
3. Classify what motion state the user is in such as walking speed (slow, moderate, fast, etc.)
4. Check minimal peak distance which uses the type of walking to determine what that distance should be and remove peaks in between.
5. Check minimal peak prominence which compares peak height to nearby peak heights to determine and remove false peaks.
6. Remove peaks that are within the dynamic threshold which is calculated by subtracting the average acceleration from the current acceleration.
7. Check the vibration elimination threshold and calculate the vibration difference to check against that threshold via acceleration minus gravity. Remove any peaks within the threshold.
8. Check if a peak has similar periodicity and similarity to previous peaks. This is determined by the time between peaks and similarity in shape to previous peaks that correspond to the same foot. Remove peaks that do not have enough similarity and appropriate periodicity.

In the research and testing done on this algorithm, it showed high accuracy compared to other tested algorithms. With general free walking, it showed an error rate of only 0.58%. However, this is a rather complex algorithm to implement and may be time consuming to implement correctly based on the information in the paper.

<u>Machine Learning Approaches</u>

There are several different Machine Learning Approaches to step counting but Support Vector Machines (SVM) is the focus. This works by mapping the acceleration data to a feature space where those data points can be categorized and separated. This is useful for determining if a data point from the accelerometer is a step.

However, while this approach can achieve great results, it is much more time consuming to implement than the other algorithms mentioned. Furthermore, given that StepQuest is a relatively small device that already intends to have a large software component (i.e.the idle-rpg style game), adding machine learning could prove difficult and very costly.

Conclusions

The algorithms and methods listed above are only a few of many different step counting algorithms. However, experimentation may still be needed in order to determine which algorithm to implement on StepQuest. Though many provide their own research on error rates, these error rates may differ based on where the device is worn, something not yet determined by the StepQuest team.

Given the known information however, both the improved peak detection algorithm and the dynamic thresholding and dynamic precision algorithm may serve the project well. Both are straight forward to implement and not very complex in nature. Testing will be needed to determine if these algorithms can provide the accuracy StepQuest strives for. If these algorithms fail, the Peak Detection and Dynamic Thresholding Algorithm could be used, implementing features found in both of its predecessors with a few more extra filters.

Furthermore, though the wear location of StepQuest has yet to be determined, it seems a waist wear location may be most desirable for accurate step counting. Wearing the device on the wrist, though convenient, can result in worse step counting accuracy due to the wide range of motion performed with the hands and arms.

3.1.2 Vibration Motors

The vibration motor is a crucial element in our alert system. Users sometimes do not respond to alerts on the screen making the alert and notification system ineffective. The use of vibration alerts is common on mobile devices. The vibration motor will be used when the user has an important notification from StepQuest system. These notifications include game events, daily or weekly achievements, reminders for workouts, as well as alarms for missing workout sessions.

Vibration motors come in unique designs. For our purpose, we will discuss the ones that can be implemented in a PCB. Those designs are Eccentric Rotating Mass (ERM), Linear Resonant Actuator (LRA), and Coin vibration motors. Here, we will briefly discuss these three types of motors.

Eccentric rotating mass (ERM)

Eccentric rotating mass (ERM) vibration motors represent one of the most utilized haptic technologies. They bear a strong resemblance to traditional DC motors, harnessing the magnetic field generated by an electric current to propel an object in a circular motion. What sets them apart is that the rotating mass is deliberately positioned off-center from the pivot point, thus earning them the label 'eccentric.'[10]

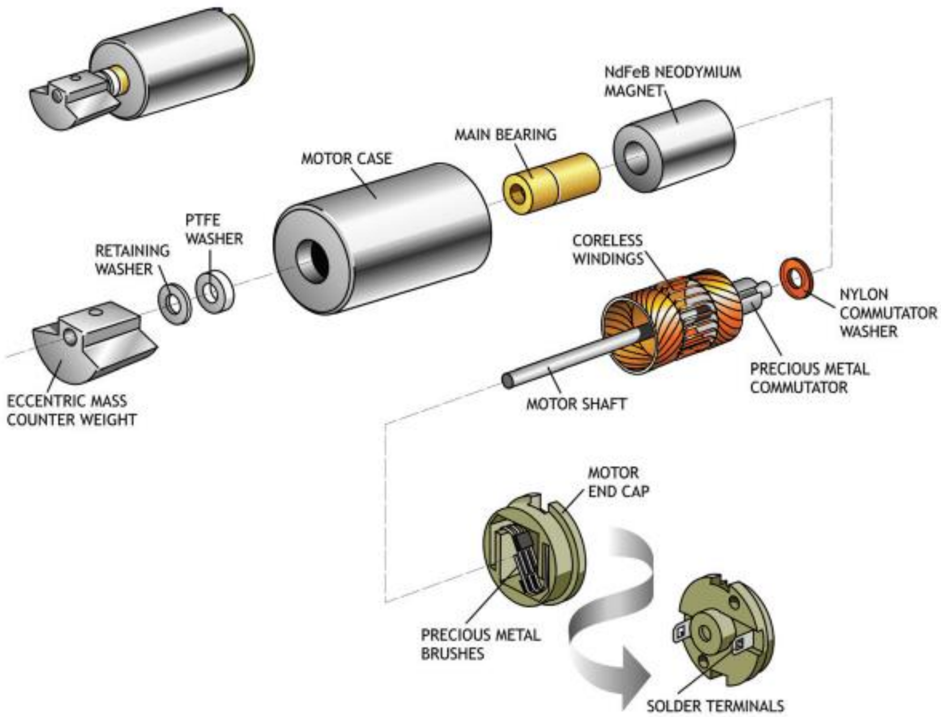


Figure 11. ERM Design

Courtesy of (https://engineeringproductdesign.com/knowledge-base/haptic-actuators/)

These motors generate an uneven centripetal force, causing them to oscillate back and forth. This motion, in turn, generates lateral vibrations, creating side-to-side movement. The strength of these vibrations in an eccentric rotating mass vibration motor is contingent upon the supplied DC current. Due to their simplicity, various types of these motors are available to suit diverse applications.[11]

Linear resonant actuator (LRA)

A linear resonant actuator (LRA) is a kind of vibrational motor that employs a combination of magnetic fields and electrical currents to produce an oscillating force along a single axis. Linear resonant actuators use an alternating current (AC) voltage to activate a voice coil. This coil is pushed against a moving mass connected to a spring. When the voice coil operates at the same resonant frequency as the spring, it generates a magnetic field, resulting in the entire actuator vibrating with a noticeable force.[12]

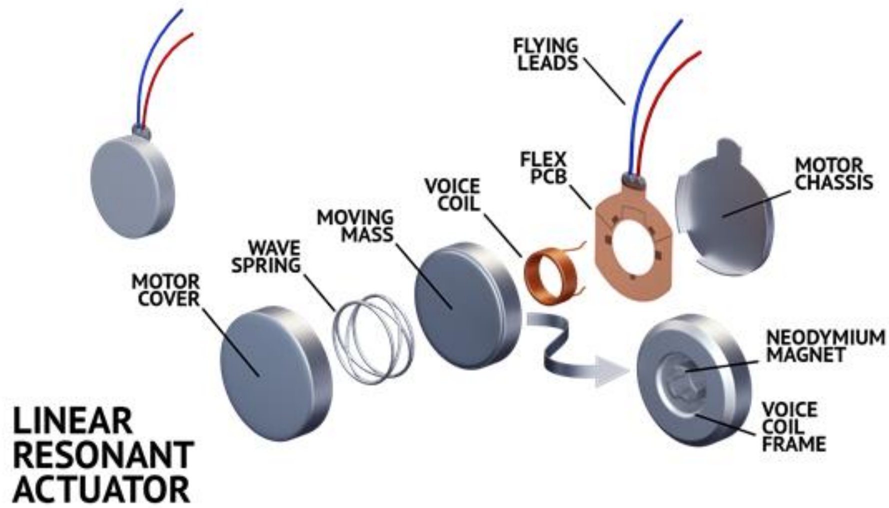


Figure 12. LRA Design

From (https://e2e.ti.com/blogs_/b/analogwire/posts/how-does-a-linear-resonant-actuator-work)

Both the frequency and the magnitude of the actuator's vibrations can be modified by adjusting the AC input. Nevertheless, to generate a substantial force, the actuator must always operate at its resonant frequency. Consequently, linear resonant actuators are most effective within a limited frequency range, making them suitable for applications requiring precise frequency control and haptic waveform generation.

These actuators offer a direct alternative to eccentric rotating mass vibration motors and deliver several advantages over them. These advantages encompass more efficient energy utilization and enhance haptic performance.[14]

Coin vibration motors

Coin vibration motors, also known as pancake or flat motors, are compact and widely used in various electronic devices and applications where space is at a premium. These motors are typically small, circular in shape, and designed to produce vibrations. They consist of a flat, coil-like structure sandwiched between a top and bottom cover. When an electric current flows through the coil, it interacts with a magnetic field, causing the motor to vibrate. Coin vibration motors find applications in mobile phones for haptic feedback, wearable devices, gaming controllers, and even medical devices, where their compact size and low power consumption make them an ideal choice for providing tactile feedback to users.[12]

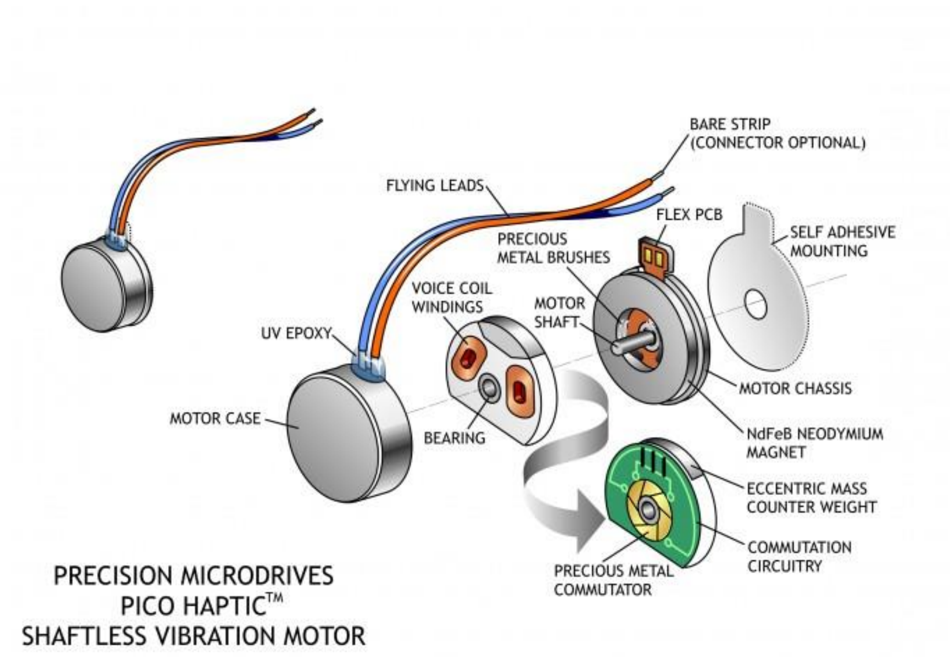


Figure 13. Coin Vibration Motors Design

Courtesy of (https://www.precisionmicrodrives.com/coin-vibration-motors)

One of the key advantages of coin vibration motors is their versatility and ease of integration into compact electronic devices. Their slim profile allows them to be seamlessly embedded into various form factors without adding significant bulk or weight. Moreover, they offer precise control over vibration intensity, allowing for a tailored haptic experience. Coin vibration motors play a crucial role in enhancing user interaction with devices, providing tactile alerts, notifications, and feedback, thereby enhancing the overall user experience in a wide range of portable and handheld devices.

Conclusions

The three options here have their advantages and disadvantages. ERMs can be difficult to implement on a PCP because of the exposed shaft that rotates around itself making the vibrations. This will require us to make room for anything around the motor to ensure that other components do not get damaged by the ERM.

As for the LRA, the two main disadvantages are the bulky shape and AC current requirement. The bulky design with thickness of up to 5mm results in forcing the design of the other components to minimize to a point where soldering the components will be impossible. Also, the AC power requires building an DC-AC voltage converter, which can be easily avoided by choosing one of the other two designs.

As for the coin motor, the only disadvantage is the low RPM. This could be a major disadvantage if StepQuest were a larger device. For our project, the device is scaled to be wearable, which means it does not need a powerful vibration motor to make it effective. In addition, coin motors are the easiest to mount on a PCB. Coin motors can be implemented like any other component on the hardware. It could be soldered or the use of adhesive permanent material. Hence, the coin motor design stands out for our purposes.

3.1.3 Heart Rate Monitoring

Heart rate monitoring was planned as a potential feature of StepQuest from its initial conception. However, within the group there has been some debate on whether this should be a necessary feature or a stretch goal. This distinction will be determined by a few things such as how good of an indicator heart rate is of fitness, complications with accurately portraying exercise level with heart rate, and obstacles of implementing a heart rate monitor into StepQuest.

To begin the question must be asked, how good of an indicator is heart rate of one’s fitness level? It’s common knowledge that typically, the harder one works out, the higher their heart rate will be. However, even with similar exercises, heart rate can vary widely between different users.

First of all, as one exercises the heart becomes more efficient at moving blood throughout the body. This means that the more a user exercises, the lower their heart rate will be, both at rest and during exercise. This would mean that setting a level for an in-game quest to reach or maintain a certain heart rate may need to vary from user to user to accommodate this difference.

Furthermore, there are several factors about the user that can also impact their heart rate. According to [15] these include age, genetics, gender, medication, air temperature and even stress levels. Some of these details wouldn’t be difficult to obtain from the user, such as age and gender questions during setup of the device. However, it would be impossible to know things like genetics, the impact of current medications and stress levels of the user. These factors would impact what heart rate is reasonable and even safe for a user to reach or maintain for a quest.

With all these factors impacting a user's heart rate, it would be difficult to accurately portray the exercise level of a given user with heart rate. However, there is a potential solution to this problem.

Many health and exercise related resources make general recommendations on what the target heart rate of a human should be based on age alone. To do so, they first determine the maximum heart rate or MHR by subtracting the person’s age from 220. From there, sources vary on what percentage of the MHR should determine the target heart rate. Most sources agree on a low end of 50% and though there seems to be more opinions on the optimal high end, most sources seem to push for 85% of the MHR.

While these numbers are easy to calculate as long as the user inputs their age, they don't hold accurate for all users. As mentioned earlier, there are many factors outside of StepQuest's knowledge that can impact what the target heart rate may be for any given user. Furthermore, though many trusted sites and organizations, including the American Heart Association, tout this strategy for calculating target heart rate, they don't account for differences in gender.

According to [19] a journal in the National Library of Medicine, there is a notable difference in average heart rates between biological men and woman. "The average adult male heart rate is between 70 and 72 beats per minute, while the average for adult women is between 78 and 82 beats." They state that this difference is largely due to woman typically having smaller hearts than their male counterparts which causes their hearts to beat faster to match the same output.

However, it would be difficult to accurately account for this when determining appropriate heart rate goals for a given user. Furthermore, as most large and trusted sources tout this method of calculating the target heart rate, it may be best unaltered.

Still, if this method were to be used in StepQuest, it would likely be best to stick with a more moderate target heart rate for quests. Starting at the easiest levels of reaching and maintaining a target heart rate of 50% of the MHR to no more than 75% or 80%. While this could potentially make heart rate quests very easy for some users it is better than the alternative. That being encouraging users to maintain an unhealthily high heart rate which could cause bodily harm to them.

Given the above, it appears that adding a heart rate monitor to StepQuest would be useful. It is a relatively good indicator of fitness and safe quests using heart rate could be implemented fairly easily. However, the cost of such a device must also be accounted for. Furthermore, different models provide different features and potential flaws. The most important factors for any given heart rate monitor are the cost, delivery time, current availability, power supply, does a test device exist and, do libraries to utilize the device already exist.

Compared to other components of StepQuest, the heart rate monitor appears to be one of the costliest. While it is a good indicator of fitness and could be implemented without too much difficulty it will up the cost of each unit. However, in this day and age most fitness watches are expected to have a heart rate monitor and in order to fit in among its competitors it would likely be best for StepQuest to follow suit.

3.1.4 Integrated Development Environment

Choosing the right development environment for this project would come down to familiarity, ease of use, and ability to debug, among other important options that will be discussed. When choosing an IDE for an embedded platform, the options are typically limited to Arduino, which works with most things, the platform's own proprietary software suite, or occasionally a C compiler. Currently, we are lucky to have some newer options in the mix that look quite promising that we wanted to explore.

PlatformIO is a Visual Studio Code plugin developed for embedded systems that offers a much more modern experience than the Arduino IDE, and more importantly, debugging. Squareline Studios promises “Next generation UI editor for individuals and professionals to design and develop beautiful UIs for your embedded devices quickly and easily.” Of course, the other option is the tried and true Arduino IDE, since both of our microcontroller options, the Raspberry Pi Pico and the ESP32 are Arduino compatible. While the Arduino library is a great tool to make our jobs easier, specifically here we will be looking at the IDE in comparison with the others. [20][21][22]

For each IDE, the following will be assessed:

<u>Productivity:</u> An IDE can help streamline various development tasks, such as code writing, debugging, and testing, making developers more productive. An important feature in an embedded environment is considering the availability of libraries. IDEs also often include features like auto-completion, code templates, and easy navigation, which help in writing code faster and with fewer errors.

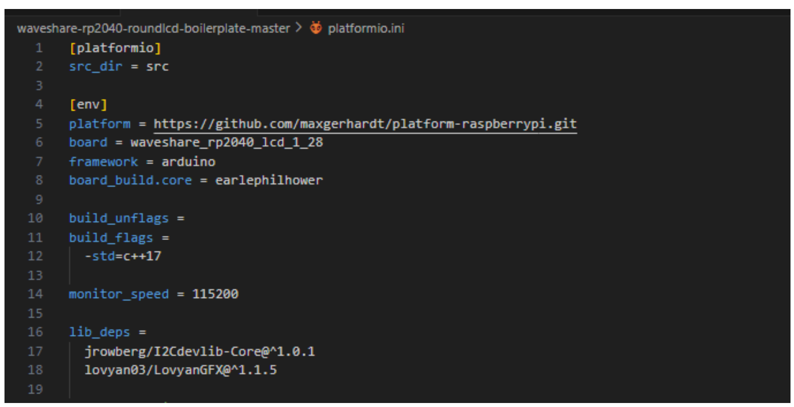
<u>Version Control:</u> Many modern IDEs integrate with version control systems like Git, making it easier to track changes, collaborate with others, and manage code repositories.

Familiarity/ Learning Curve: This includes documentation and support, previous experience, and balancing ease of use with complexity.

PlatformIO

Productivity: PlatformIO has many features that make it a productivity powerhouse. In our eyes, topping the list for PIO in this category is integration with VS code, which includes other extensions such as code completion and Github Copilot. Copilot integrates AI to help with code completion by automatically running a line through ChatGPT and predicting the best next line or rest of the line. This can be a huge timesaver, and since it's scraped all of the internet, is essentially like having every tutorial available at your fingertips.

There is however, a little setup involved with every project in PIO. Where something like Arduino might have a user set up a board via drop-down menus, PIO uses a JSON file to associate settings. This can be a much more daunting task as it is a newer technology and there are not as many documents out to help with getting started. For this, the Arduino IDE gets the point, as the drop-down menus are much less scary.


waveshare-rp2040-roundlcd-boilerplate-master > platformio.ini

```
[platformio]
src_dir = src

[env]
platform = https://github.com/maxgerhardt/platform-raspberrypi.git
board = waveshare_rp2040_lcd_1_28
framework = arduino
board_build.core = earlephilhower

build_unflags =
build_flags =
  -std=c++17

monitor_speed = 115200

lib_deps =
  jrowberg/I2Cdevlib-Core@^1.0.1
  lovyan03/LovyanGFX@^1.1.5
```

Figure 14. PIO's board select interface

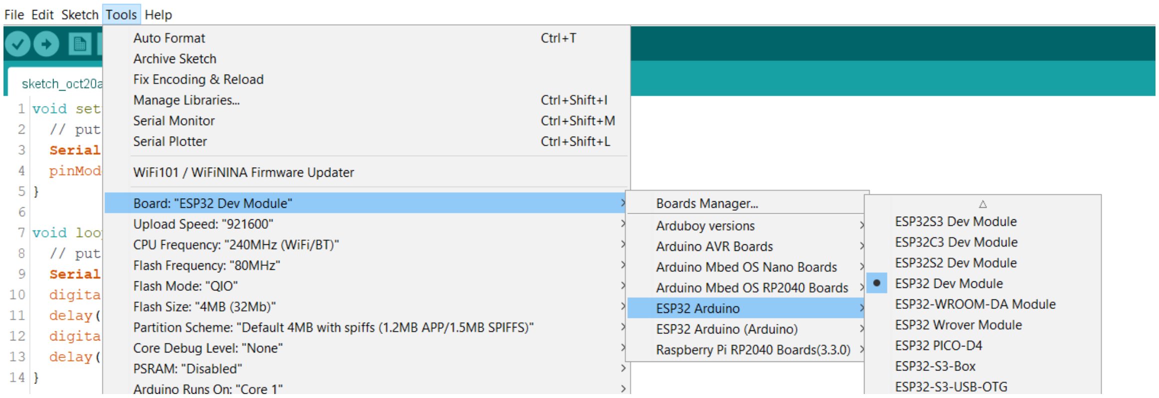


Figure 15. Arduino's Board Select Interface

One very cool feature is the ability to "import" an Arduino project. Unfortunately, however this did not seem to be as automatic as it sounds. Given all of the different board manufacturers, setups, arrangements, etc. this is understandable, but it did prove to be easier to just restart the project as a PIO project, rather than importing. I suspect for more straight foreword setups this would actually work, but for us, no points here.

<u>Version Control:</u> The great thing about version control with PlatformIO is that it's built into VSCode, so all of the Git features like branch creation, repository control, it's all built in and easy. PIO is a superstar in this category.

<u>Familiarity/ Learning Curve:</u> This is where PlatformIO loses most of its points. For this project, we need a tool that we can pick up quickly and use to get the job done. And if not, it needs to be worth the cost of having to learn. In this case not being able to quickly jump in to a project is not where we have the luxury to start. Having to learn the different board setup options, and how to import libraries correctly into platform IO, when we already have a working solution with Arduino isn't really worth it. We already have a working solution with the Arduino IDE, and the Git workflow is easy enough through Gitbash that it doesn't not seem worth it to add extra layers of complication and extra unknowns into a project. This is not worth the risk for this project, at this time.

<u>SquareLine Studios</u>

SquareLine Studios is a graphical component to the LVGL display library, which is built on top of the Tft_espi and Arduino_Gfx libraries. Squareline is the company who makes LVGL, the library, and SquareLine Studios is a graphical environment that is meant to help the user interact with that library in an "easy-to-use" GUI. Easy-to-use is in quotes because this tool does have a steep learning curve.

Productivity: The GUI for LVGL, SquareLine Studios, is very new. Even so, SS and the LVGL library that it is built on look to be an embedded developer's dream for UI creation. The use of an "Adobe Suite" like graphical UI to build in widgets, graphs, icons, etc. are all made to be easily selectable and to be cross platform. The main crux of this program is a UI based tool for designing UI on embedded systems. As such it spits out UI code (either C, Python, Arduino, etc.) for use in your project. It's great that it's cross platform, and the features look rich.

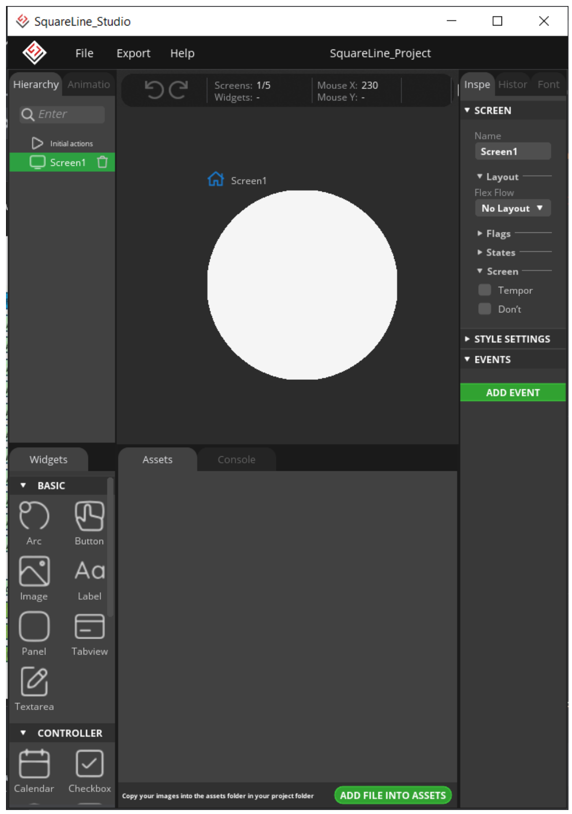


Figure 16. Square Line Studio User Interface

Version Control: Now, SS is lacking in the version control department as it basically just exports UI code for your project to use. As such this code would be integrated into your project, and use whatever version control you had set up. So, realistically this tool could be used with PlatformIO or Arduino's version control.

Familiarity/ Learning Curve: This is where SS takes a huge loss. This program is not that intuitive to use and requires major tweaking to get it working with our project. However it is able to gain some points back because, due to it's popularity, there are a few decent tutorials and guides out there on the internet, such as this one, which helped. [23]

Behind the scene, what SS outputs is based on an Arduino library, so it is at least possible to tweak your outputs in code once you get them in the ballpark. Beyond that the demo results are STUNNING and are at least worth a shot to experiment with this tool as an add on.

Arduino IDE

Arduino is the tried-and-true IDE of the embedded world. It's the environment that most are familiar with, and it's the most low-risk. This is especially true given that our project uses the Arduino library, also due to its familiarity.

Productivity: This IDE isn't winning any awards for trailblazing new features. Instead, what makes it great is that it is very straightforward to be productive in. Users write their code in the window, include any files that they need at the top, select their board from the top, and they are off to the races. The basic features that are included are great: Serial Monitor, Library Manager, Examples, etc. The new version even offers a Debugger, which was a huge missing feature for a long time. It is very easy to be productive in this program, which makes it a core tool. What it lacks will have to be made up for in other programs, such as SquareLine's keen eye for UI.

Version Control: There are no version control features to speak of in this IDE. This means that using this IDE would also involve adding more tools into the mix, like GitBash for version control. This isn't great but GitBash is fairly trivial to use for basic cases, so it is certainly manageable. One notable mention is the online version of the Arduino IDE, which stores your code in the cloud. This could theoretically open up cloud-based sharing of code, but it is too new of a tool, and doesn't exactly offer the robustness of a Github repository, so it's not really in the scope of this project.

Familiarity/ Learning Curve: Now this is where the Arduino IDE shines. It is *the* choice for embedded development because it pairs so well with the Arduino library which most embedded projects are able to use, and which our project uses. It is the trusted baseline. While it may not have all of the bells and whistles, the features mentioned in productivity make it enough to be easy to jump into and get work done. There are countless tutorials that use this IDE, and what's great is many companies release example code that uses this IDE and provide example sketches already working in this environment. This is the hands-down winner in familiarity and ease of use.

Conclusions

For this project, given that the display that we're using doesn't have a ton of documentation, but the microcontroller is widely popular, we will be jumping around IDEs. After all, sometimes you need many tools to accomplish a job. For designing the bones of the UI we are going to try to make SquareLine studios work for us. But, at a point I know we will have to switch back to the tried and true and perform some tweaks in Arduino. While PlatformIO has a ton of great features, it's simply a learning curve that we cannot afford on top of all the other learning curves. We considered using it as version control since it makes it easy to push to Git, but using Gitbash for version control to manually push is much cleaner since it doesn't involve having to do board setup in 2 different places. So for this project, the winners are SquareLine and LVGL for initial UI setup, and the Arduino IDE for tried and true ease of use.

IDE	Productivity	Version Control	Ease of Use
PlatformIO	Many features, but complicated	Github Sync	3 - Somewhat
SquareLine Studios	Looks Great, slower to use	None	2 – Relatively difficult
Arduino IDE	Straightforward and bare bones	None	5 – The Easiest there is

Table 4. IDE Comparison

3.1.5 PCB Design Software

PCB design software is critical for electronic circuit development. PCB design software is used to generate a layout for a printed circuit board design. The software then allows the production of the corresponding formatted files that PCB manufactures require to fabricate a PCB. This software provides a wide array of tools and features that are utilized to outline, design, evaluate, and generate a PCB.

PCB design software provides a wide array of tools and features that one can use to create and test printed circuit boards. Auto-routing and layout checking are common features amongst many PCB design programs. They allow for the automatic generation of the optimal connection routes and make sure that the PCB is within the proper design standards. These features are very common and similar amongst PCB design software's, but some programs provide features and tools that others do not. Some of which make PCB design software stand out in comparison. Some standout features include 3-dimensional viewing of the PCB, having the ability to commit, push, and pull designs, linking with PCB manufactures, and simulation tools.

Another important factor in choosing a PCB design software is its ease of use. Ease of use can drastically affect design procedures. PCB design software that is straight-forward and easy to use makes learning curves faster and more efficient design procedures. This allows for the design and creation process of a PCB to be quicker and easier. A user-friendly software reduces the possibility of design mistakes, which if occurring often can drastically slow down the PCB creation process. It also reduces the need for online and community support, which can save time and aggravation for the PCB designer. Having an easy-to-use PCB design software guarantees that an engineer can put all their energy and attention into the PCB design itself as opposed to finding errors within the PCB design and fixing them using documentation and technical support. Familiarity with a specific PCB design software would also be an imphouseortant factor to consider, but this may not be applicable depending on an engineer's experience with designing and creating PCBs within PCB design software. In the evaluation of the possible choices for PCB design software, the ideal software requires notable ease of use and familiarity with the program if possible. This will provide a user-friendly and streamlined design workflow, that falls within the needs of the project's guidelines. This will increase efficiency and caliber of produced PCB designs.

A PCB design software's collaboration ability is another crucial factor to consider. Proper collaboration is an important part of the engineering and design process. Using PCB design software that has well defined collaborative abilities and functionality is vital to any engineering project. In the evaluation of the possible choices for PCB design software, the ideal software requires robust collaborative abilities and accompanying features.

It will need to provide a large array of collaborative functionality that allow for cohesive teamwork amongst all engineers. The chosen PCB design software must allow engineers to work on the same PCB design concurrently, despite one's locality, allowing for simultaneous teamwork. This also allows for more streamlined communication between engineers, since all engineers will be working with the same designs and be able to edit them in real-time for all members to observe and comment on. Some modern PCB design software provides git-type functionality, allowing for engineers to commit, push, pull, etc. edited designs, further increasing the collaborative efforts and efficiency of the design process. While this specific functionality may not be provided with all PCB design software, it would be important to choose one that provides it, as it drastically enhances the design and collaborative process. Being able to integrate with other tools and software, specifically a PCB manufactures software, would be ideal, creating a more streamlined design and creation process that will increase efficiency. All mentioned collaborative functionality will improve the workflow of all engineers working on the PCB design but will also aid in the success of the PCB design by decreasing communication errors and increasing collaborative ability.

<u>Flux.ai</u>

Flux.ai has all the basic PCB design features that one would expect with PCB design software. It has auto-routing, layout checking, 3-dimensinal views of PCB, etc. The simulation tools that Flux.ai has available are basic. Only numerical data is shown, and there are no graphical outputs. Not many component simulation features are available, and due to the community driven nature of Flux.ai, not all components are capable of being simulated. Flux.ai is easy to use and is straightforward. It has a user-friendly user interface and display layout. No team members are familiar with Flux.ai and have never used it before. It has a large community that creates many tutorials, offering a large database for support and learning. It also has a large library of tutorials, in both text and video format. Flux.ai's primary advantage lies in its collaborative abilities and features. It offers Git type functionality, that other PCB design software does not have available. With this Git type functionality, a user can commit, push, pull, fork, checkout, and merge PCB and circuit designs. Flux.ai also allows users to simultaneously work on the same designs, but on different machines. This is a feature that some PCB design software lacks but is invaluable when collaborating with others.

Eagle/Fusion360

Eagle/Fusion360 (now known as just as Fusion360) also has all the basic circuit and PCB design tools and features that one would expect a PCB design program to have. It provides auto-routing, layout checking, 3-dimensinal views of PCB, etc. Where Fusion360 stands out amongst the other choices is in its maturity. Fusion360 has been around for a long time and is used by many professionals. Therefore, it contains are large library of components and circuit creation features. It also has many features to help prevent and fix design errors and flaws made by the user. Fusion360 offers the most extensive simulation tools amongst the other choices. The simulation tools available offer numerical and graphical output. Fusion360 does offer a large library of tutorials, both in text and video format. Due to its maturity, it has a large community, and a large database of tutorials and learning information online.

Fusion360 is not the most user-friendly option and therefore not the easiest PCB design software to use for a new user. Its user interface has many options and can be daunting for new users. It also offers a large library of components to use, but the design and layout of the component selector feature is not user-friendly. The lack of ease of use of Fusion360 will lead to a larger learning curve and there will likely be more errors made in designs. All team members have a small amount of experience with Fusion360, but not enough to make this the obvious choice. It does offer basic collaborative features. Such as the ability to concurrently work on the same design, while being on different machines. It also allows you to share and review designs with users, but its collaborative features do not compare to Flux.ai's.

KiCAD

KiCAD also provides all the features and capabilities that a user would expect in PCB design software. It provides auto-routing, layout checking, 3-dimensinal views of PCB, etc. KiCAD offers the most basic feature set out of all the options. It has moderately advanced simulation tools available. While not being as extensive as Fusion360's simulation capabilities, it is better than Flux.ai's. KiCAD's strengths lie in its ease of use, it is the easiest to use and most user-friendly PCB design software out of all the options. It has a simple user interface that is not cluttered with features and tools, allowing for a less confusing and daunting experience for new users. Its component library is standard, and is simple to use, further adding to its ease of use. KiCAD is also a mature software, so it offers a large library of tutorials, made both my KiCAD and the community. No team members have experience with KiCAD. KiCAD offers weak collaborative features, making it a poor choice for a team. KiCAD offers no ability to work on a design concurrently or review designs with other users.

	Flux.ai	**Eagle/Fusion36**	**KiCAD**
Features	• Has expected basic features. • 3-dimensional viewing of PCB is available. • Simulation tools are available but are basic. • Git type functionality is available.	• Has expected basic features. • Most mature software of the choices. • Offers large component library. • 3-dimensional viewing of PCB is available. • More advanced simulation tools are available. • Git type functionality is not available.	• Has expected basic features. • 3-dimensional viewing of PCB is available. • Simulation tools are available but are basic. • Git type functionality is not available.
Ease of Use	• Easy to use. • User friendly. • No team members are familiar with this program. • Has a large community for support and a	• Not as easy to use. • Not as user friendly. • Team members are slightly familiar with this program.	• Easy to use User friendly. • Team members are not familiar with this program. • Has a library of tutorials.

	large library of tutorials.	• Has a large community for support and a large library of tutorials.	• Simple user interface and feature set.
Collaboration	• Has the most collaborative functionality. • Git type functionality (push, pull, fork, etc.) is available. • Concurrent work is available.	• Has collaborative features, but not as many as Flux.ai. • Concurrent work is available.	• Has weak collaborative features. • Concurrent work is not available.

Table 5. PCB Design Software Comparison

<u>Conclusions</u>

We ultimately decided to select Fusion360. The primary reason for this selection is that the Fusion360 PCB design software is very mature. This means that there will be an abundance of learning material and resources online. It also has a very large component library, the largest of all three options. For these reasons, we chose to use Fusion360 as the PCB design software for this project.

3.1.6 Turn on/off Software

How to turn on and off the StepQuest watch is an important topic for the project as a whole. While it has yet to be determined whether a touch screen or buttons will be used to interact with the game, a few things can still be elaborated on.

Firstly, whether or not the device will utilize an algorithm to determine whether or not the user is attempting to interact with it. This is similar to other fitness watch products on the market such as the Apple Watch. However, research on the subject found no public sources of an algorithm using a gyroscope. Furthermore, the only information found on this type of algorithm came from the original patent [24]. These patents also revealed the further complication that another algorithm that detects whether the watch is being worn in the first place, must also be implemented [25].

Due to these unforeseen complications, implementing a sort of turn-on algorithm should be regarded as a stretch goal rather than a main feature and will likely not be implemented. This is largely due not only to the complexity of detecting if the arm is raised in a manner to use the watch, but also due to the unforeseen difficulty of creating an algorithm to detect if the device is even being worn. This means that to turn StepQuest on, the device will either detect touch for a touch screen or turn on at a button press if buttons are decided to be used instead.

As for turning off the device, rather than having a power button it would likely be more effective to have a timer from the last interaction. By default, if the last interaction with the device was fifty seconds ago, the screen would dim, indicating the device will soon power down. If no interaction is detected for a further ten seconds, the device will power down. It likely would be easy to implement a setting to change this power down time to a shorter one such as thirty seconds or a longer one such as a few minutes.

3.1.7 USB Types

One important part of the circuit is the port and the connector used. Since the 1990s, many tech companies have agreed to use USB (Universal Serial Bus) as their official peripheral connector protocol, hence the name universal. USB’s uses are various; not only USB helps delivering power and transfer data, but also helps connecting peripherals, backing up data, programming embedded systems. In addition, USB is used in connecting debugging tools that many verification engineers use today to debug software and hardware systems. Since the start of USB, many developments have occurred in this connector. Starting with USB-type A, following it by USB-type B, and finally USB-type C. Since we are interested in powering our StepQuest device, we will only discuss USB-A, USB-MicroB, and USB-C.In this table, the differences of USB-types connectors are illustrated. [26]

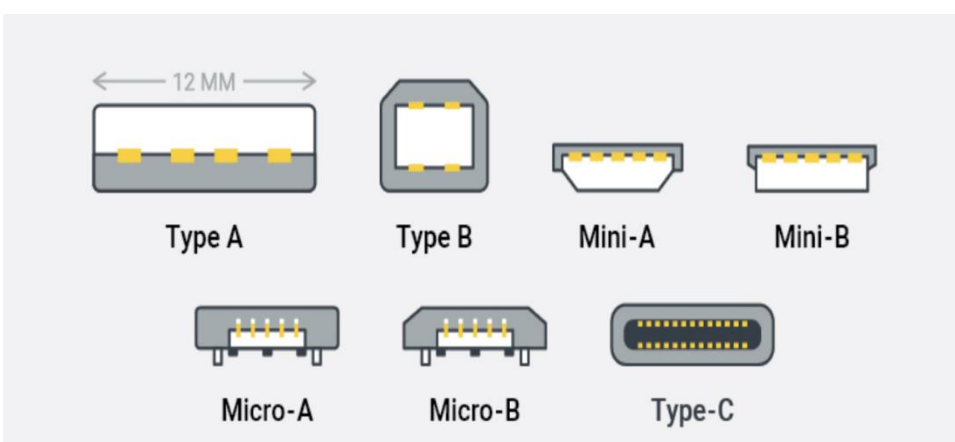


Figure 17. USB-types Pins Configurations

From (https://www.onlogic.com/company/io-hub/usb-type-c-and-usb-3-1-explained/)

USB Type	**USB-A**	**USB-Micro B**	**USB-C**
Pins Configuratio n	4 pins: VCC (5V), Upstream Data, Downstream Data, and GND	5 pins: VCC (5V), Upstream Data, Downstream Data, ID, and GND	24 pins shown in the figure below
Shape	Flat Rectangular	Rectangular with slight rounding on upper end	Wide oval shape
Most Recent Technology Supported	USB 3.2 generation	USB 3.2 generation	USB 4.0 generation
Flippablity	Not flippable	Not flippable	Flippable
Cost per Meter	$7	$8	$17

Table 6. USB-Types Comparison

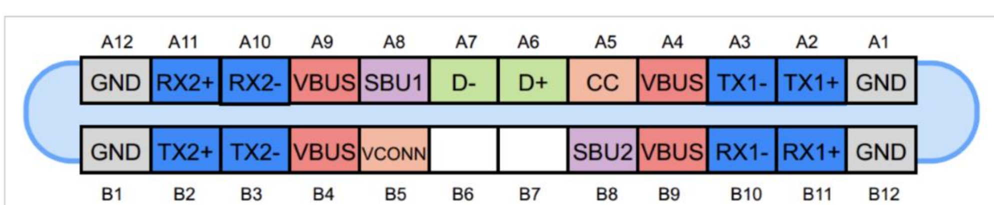


Figure 18. The pins of type-c cable

From (https://www.allaboutcircuits.com/technical-articles/introduction-to-usb-type-c-which-pins-power-delivery-data-transfer/)

USB Generations

Evolving technology made it necessary to develop the technology of USB, primarily by improving the specs. Since 1996, USB has been improved a dozen times, which led to improving its speed and compatibility. Here, we will discuss the USB generations and highlight these improvements. It is worth noting that USB speed has increased (mention the number). Also, features that usually come with USB connectors were not originally in the earlier versions of USB like recharging batteries. [28]

USB 1.0 and USB 1.1

USB 1.0/1.1 ports: It was introduced in 1996 (USB 1.0) and revised in 1998 (USB 1.1). It had a maximum data transfer rate of 12 Mbps (megabits per second) and low power consumption. USB 1.0/1.1 were widely used to connect basic components such as keyboards, mice, and printers.[28]

USB 2.0

The introduction of USB 2.0 in 2000 resulted in a significant increase in data transfer speeds with a maximum of 480 Mbps. The power supply to some appliances has also been improved. USB 2.0 was the most common USB standard for many years and is still widely used for a variety of peripherals. [27]

USB 3.2 (USB 3.1 Generation 1)

Technological advances have played a key role in the widespread use of IoT devices especially in industrial applications and as a result, the demand for more bandwidth has increased dramatically to enable more reliable data transfer rates and it is not difficult. USB 3.2 Gen 1, also known as SuperSpeed USB 5Gbps, provides data transfer speeds of up to 5Gbps. Most notably, USB 3.2 iterations adopted full-duplex mode, allowing two connected devices to send and receive data simultaneously, dramatically increasing data transfer speeds. As a result, this version of USB has received a lot of attention from industry, especially due to the significant improvement in data transfer rates, especially when operating in full-duplex mode Connections include USB Type A, Type B and Micro B SuperSpeed connectors.[28]

USB 3.2 (USB 3.1 Generation 2)

USB 3.2 Gen 2, pre-viously known as USB 3.1, now offers an incredible data transfe-r speed of up to 10 Gigabits per se-cond, earning the name "Supe-rSpeed USB 10 Gbps" to avoid any confusion. This significant upgrade double-s the previous USB's maximum transfer rate-, providing a substantial boost in performance for storage and display applications in computing. Additionally, both USB 3.2 Ge-n 1 and Gen 2 have embrace-d USB Power Delivery (PD), e-nabling them to deliver up to a re-markable 100 watts of power through compatible hardware-, reaching a maximum of 20V at 5A. [28]

USB 3.2 - 2*2 (USB 3.2 superspeed)

In August 2017, USB 3.2 Gen 2x2 was introduced, featuring a notable enhancement in compatibility, primarily focusing on the USB Type-C connector. This iteration of USB boasts an impressive data transfer speed of up to 20Gbps, often referred to as SuperSpeed USB 20Gbps. Furthermore, the Type-C port supports reversible insertion, simplifying its usage in various applications.

USB 4.0

USB 4.0, unveiled in 2019, represents a significant leap forward in USB technology. This latest iteration promises blazing-fast data transfer speeds of up to 40Gbps, doubling the maximum speed of its predecessor, USB 3.2 Gen 2x2. USB 4.0 also brings a notable enhancement in versatility and compatibility, as it incorporates Thunderbolt 3 technology, making it capable of supporting multiple high-resolution displays and other high-bandwidth applications. Furthermore, USB 4.0 maintains backward compatibility with previous USB generations, ensuring that it can work seamlessly with existing USB devices and connectors. With its impressive speed and expanded capabilities, USB 4.0 is poised to meet the demands of modern computing, enabling faster data transfers and more versatile connectivity options for a wide range of devices, from laptops to external storage, monitors, and more.

In the table below, some of the specs of USB generations are summarized.

Specification	**Known as**	**USB-Type supported**	**Assumed Speed**	**Tested Speed**
USB 2.0	none	USB-A USB-B USB Micro A USB Micro B USB Mini A USB Mini B	480 Mbps	42.76/43.35 Mbps
USB 3.2 Gen1	USB 3.0	USB-A USB-B USB Micro B USB-C	5 Gbps	465.16/463.80 Gbps

USB 3.2 Gen2	USB 3.1	USB-A USB-B USB Micro B USB-C	10 Gbps	1068.63/1038.85 Gbps
USB 3.2 Gen 2*2	USB 3.2 Superspeed	USB-C	20 Gbps	2086.65/2009.56 Gbps
USB 4	USB4 Gen 2×2 USB4 20Gbps	USB-C	10 Gbps, 20 Gbps, 40 Gbps (depends on host specs)	1069.43/1044.11 Gbps

Table 7. USB Generation Specs Comparison

Conclusions

USB generations presented here have similar specs and functions, however implementing the unfit choice could cause a lot of setbacks near the manufacturing process. We decided to go with 3.2 Gen 1 because it offers a safe choice among the rest of the options. It provides a reasonable speed of 5 Gpbs and has an outstanding performance with similar projects. Also, it helps to note that there is a good amount of content and tutorials when it comes to implementing this version of USB.

3.1.8 Casing

The casing for a digital watch is a crucial part of the overall design. The most important role a digital watch case provides is protection for the internal components of the PCB. It does this by providing protection from falls, scratches, moisture, etc. The case of a digital watch also provides aesthetics to the product. Several factors need to be considered due to design factors and constraints. The dimensions and shape, material, protection of the display, placement of buttons, battery placement, weight, fabrication, customization, and price.

The dimensions and shape of a watch case is a foundational part of the design of a watch. The case must be able to house all the electronic components and the PCB. It must also allow the user to easily access the input devices, such as buttons or potentiometers. It must also be able to hold a small battery and make it accessible to the user. Besides functional aspects of the dimensions and shape of the watch case, it also contributes to the wearability and comfort of the device. It must be ergonomic and comfortable for a user to wear for extended periods of time. It must effectively fit on a user's wrist, while also being size adjustable, being able to accommodate an array of wrist sizes. The aesthetics are also affected by the size and dimensions of the watch case. The watch case must not be bulky, making for a sleeker and more stylish appearance.

The material used to construct the watchcase is also an important factor to consider. The material of the case contributes to several physical characteristics of the watch, including the toughness, mass, and looks. The durability of the material used will directly affect the longevity of the watch. Selecting a durable and tough material will better protect the internal electronic components and the PCB from regular usage and possible damage. It will also affect the weight of the watchcase. The lighter a wearable device is, the more comfortable it will be to wear for long periods of time and during physical activity, especially when worn on the wrist. The material used will also affect the overall look of the watch, directly contributing to the athletics. Some prefer the look of a metal watch, aluminum and stainless steel are commonly used in these applications. For others, they prefer the aesthetics of a plastic watch.

Water resistance of a watch is something that many users look for as a feature of their watch. A digital watch often needs to be water resistant for everyday usage, especially when worn during physical activity or when outdoors. There are various methods to make a watch case more resistant to water and several levels of water resistance ratings. Seals can be used or designed as one piece to prevent moisture from entering the case. Regardless of the method used to make the case water resistant, the design must accommodate this and keep it in mind.

The watch case must be able to offer protection to the physical display of the device. The display must be shielded from abrasions, drops, and elemental factors, such as moisture and heat. The display protection must both protect the display and allow the user to read the display. To make the display readable, a clear material of some kind must be used. This will likely have to be shaped to the dimensions of the specific digital display that is used in the final product design, utilizing a raised bezel to accommodate the physical display. Various plastics or crystalline materials are often used for these applications. They offer both impressive protective and transparency characteristics.

Buttons and other input components are an integral part of using a digital watch. Buttons aid in changing the time and using various features programmed into the digital device. The case of the watch must accommodate these input devices and allow the user to easily access them and press them with no resistance. The locations of these buttons must also be easily accessed and placed in intuitive locations on the watch case, depending on the design of the device. The case may even offer some form of protection and water resistance to the buttons, depending on the characteristics of the buttons chosen.

The watch case must also be able to accommodate the battery. The battery in a watch is often located on the bottom of the watch, below the PCB, allowing for the battery to be out of the way of the internal electronic components and it may also help with protecting those components from the heat expelled from the battery during long usage times. The battery must be accessible by the user in some way. This allows the user to change the battery when it loses enough power to turn on the device. This can be accomplished with a two-piece design of the case, where the bottom of the watch case can be screwed on and off by the user. A panel covering the battery on the bottom of the watch case is also a common design, making the case one solid piece, with a small often metal, panel covering the battery, that can be put in place with several small screws. This one-piece design offers the most physical protection, and aids in making the device water resistant.

Due to the smaller volume of the device, proper weight and stability of the watch is paramount. A wearable device, especially one worn on the wrist, can easily be uncomfortable. This leads to the user not wanting to use the device. The watch case has a lot of influence on this factor and must be properly weighted and balanced to ensure comfort and stability. The weight and balance must be comparable to a modern digital fitness watch that can be found on the public markets. Proper weighting and balance are primarily for comfort when worn on the wrist. The displacement of mass on the wrist must be even over the entire surface area, this will ensure optimal weight distribution. Keeping the overall width of the device as low as possible will help keep a low center of gravity, resulting in a stable wearable device. Distributing the internal components evenly over the PCB, paying particular attention to the heavier components, will also aid in keeping the design balanced. Keeping the weight down can be accomplished by manufacturing the case out of a light material, such as plastic, and reducing the overall volume of the watch case, making the design ergonomic and efficient.

The method of assembly and manufacturing is also an important factor to consider. The watchcase must realistically be able to be assembled and manufactured, taking the team's experience and resources into account. The design of the watchcase should allow for a streamlined and efficient assembly process. Keeping the number of individual parts to a minimum, which will ensure that the design coincides with the desired specifications and attributes. The manufacturing process must also be efficient to ensure that the design aligns with the specifications. Keeping the overall design of the case simple, and reducing complexity where possible, ensuring that the manufacturing and construction process is not costly and is as efficient as possible. The case must be able to be created with accuracy and detail. This will allow for the case to be customized to the design and specifications of internal components and PCB.

The price of the watchcase design is another factor to assess. The price of materials and construction must be kept to a minimum. The design of the watchcase must align with the team's budget, allowing for the proper distribution of funds in other areas of the project. There are several strategies to reduce the cost of the watchcase design. The primary method is to use a construction material that is very low in cost, such as plastic. Another strategy is to design the case in such a way as to reduce the amount of material that is used when manufacturing it. This can be done by reducing the design's infill, making it slightly hollow, and by reducing the complexity of the design.

3D Printing

3D printing is one possible option for manufacturing the watchcase. The primary advantage of using 3D printing as the method for fabricating the watchcase is that the design can be highly customizable, allowing for the creation of a detailed design. 3D printing is capable of fabricating complex internal constructs and features that are imperceivable from the user, something that many other fabrication methods are not capable of. There is a wide array of materials that can be used in 3D printing, such as many types of plastics, which vary in physical and chemical properties. The material that best fits the design specifications would be selected, such as PLA or ABS, which both align well with the design specifications of the case design. 3D printing is also an inexpensive manufacturing process. The material selection available with 3D printing is low-priced. Also, 3D printing is a manufacturing is an additive process, unlike other manufacturing processes what are subtractive. 3D printing therefore reduces waste material, further reducing the cost. 3D printing allows for fast prototyping of designs. This could be a crucial factor if the watchcase design needs adjustments or alterations in the future.

Repurpose

Repurposing and modifying an existing watchcase is another possible option for creating the watchcase. The main advantage with this fabrication method is that much of the work would already be done, the repurposed watchcase would just need to be modified to fit the PCB and internal components. Since the watchcase that would be modified is already a commercial design, it would align with many of the design specifications. The dimensions and the overall shape of the repurposed watchcase would already be that of a digital watch, so little to no modifications would need required for factors like screen protection, battery placement, waterproofing, etc. Having the balance, the case alterations and the PCB design could be problematic, if not impossible. The PCB design is unlikely to easily fit in any commercially available watchcase, as the PCB and internal electrical components of commercially available digital watches are smaller and more efficiently design than our PCB could ever be, given the features and design specifications of the fitness watch. Also, the display of fitness watch does not match commercially available digital watches, so modifying an existing watchcase would be difficult, so much that it is likely not a realistic option.

Handcraft

Repurposing existing materials and fabricating a watchcase is another possible option. This strategy's strength is that while there may be some requisite modification expertise, it would require little specialized skills or experience to execute. It also allows for high amounts of customizability, but not as much as 3D printing. Creating a watchcase from hand may take longer than 3D printing, it does not require any experience with computer assisted design software or techniques. Basic tools such as saws, screwdrivers, pliers, etc. would likely be the only tools necessary. Materials could be purchased, or they could be harvested from existing products and devices. All the tools and construction materials are easily available and inexpensive. The downside to this method is that while the design can be highly customized, since the watchcase is being fabricated by hand, it cannot be complex. 3D printing allows for far more complexity in the design, while also allowing for the design to be highly customizable.

	3D Printing	**Repurpose**	**Handcraft**
Dimension & Shape	• Completely customizable.	• Constricted by repurposed dimensions.	• Highly customizable.
Material	• PLA or ABS.	• Plastic.	• Plastic
Protection	• High protection.	• High protection.	• High protection. •
Customizability	• Completely customizable.	• Lowest customizability.	• Highly customizable.
Fabrication	• 3D printer.	• No fabrication needed.	• By hand.
Time	• Longest construction time of all options.	• Lowest construction time of all options.	• Moderate construction time.

Cost	• < $10	• $10-$20	• < $10

Table 8. Case Design Comparison

Conclusions

We ultimately decided to select 3D printing. The primary reason for this selection is that 3D printing is the most accurate and customizable fabrication method. The watchcase will need to fit the PCB and contour around any components as necessary, this would be difficult with the other options. For these reasons, we chose to use 3D printing as the fabrication method for creating the case of the watch.

3.1.9 Water Resistance

Water resistance for a digital watch is a critical part of the design. With a water-resistant watch, a watch becomes resistant to the damaging effects of water and moisture. There are several ways to make a watch water resistant, depending on the desired resistance rating. Resistance ratings determine how much moisture a device can withstand before being compromised. Several factors need to be considered due to design factors and constraints. Case type, inputs used, maintenance, moisture saturation capabilities, and longevity.

Two-Piece Design

A common case design for digital watches is to use a two-piece construction. The main body of the case being one piece, and the circular second piece located on the underside of the case. The main body will have a threaded hole, where the second piece will also be threaded, and it can be inserted and removed from the main body by rotating it. The main purpose for this design is to let the user access the battery at any time, it also allows them to access some of the internal electronics, if the watch is designed in a manner that allows them to. A gasket will be placed on the base of the threads, preventing moisture from entering from the underside of the case. The O-rings will be placed at the base of the input buttons, also preventing moisture from seeping in. This design may be more affected by physical damage, since it will be less efficient at absorbing external forces that are acting upon it.

One-Piece Design

Using a one-piece watch case design is also a viable option. The one-piece design will be constructed using the same methods as the two-piece design, except that the case will be one solid piece. By making the case one-piece, this will make it more efficient at absorbing external forces, adding to the longevity of the watch case. There will also be less places for moisture to enter, so the water resistance of the case will be greater. The user will be unable to access the internals of the watch. This will pose a problem when the battery needs to be replaced.

Table Waterproofing Method Comparison

	Two-Piece	**One-Piece**
Water Resistance	Less efficient at resisting moisture. Design will be able to withstand splashes and short durations of submergence, but not for extended periods of time.	More efficient at resisting moisture. Inputs will be the only locations moisture can enter. Design will be able to withstand splashes and longer durations of submergence.
Durability	Less durable. Less efficient at absorbing external forces such as drops.	More durable. More efficient at absorbing external forces such as drops.
Maintenance	Maintenance will be possible by user. Allowing them to change battery.	Maintenance will likely not be possible for the user. The battery will not be able to be accessed, so it will not be able to be changed.

Table 9. Waterproofing Method Comparison

<u>Conclusions</u>

We decided to select a two-piece case design. The primary reason for this selection is that it will be more feasible to integrate with the PCB and it allows the user to access the battery. A one-piece case design may be better for resisting moisture, but it will not only be difficult to integrate the PCB, but the user will not be able to access the battery. For these reasons, we chose to use a two-piece design for the case of the watch.

3.2 Part Comparison

Several components are required in the design of StepQuest. Both the hardware and software aspects of the components need to be taken into account. To determine which component is the best choice, research is required. Below is the breakdown, explanation, and comparisons of the components that the team researched, and ultimately decided to use for the design of StepQuest.

3.2.1 Inertial Measurement Unit

An IMU or Inertial Measurement Unit, is a type of sensor that records the velocity and orientation of the device. Typically, this is accomplished using a combination of an accelerometer and a gyroscope. As step counting is a vital component of StepQuest, an IMU is necessary in order to record acceleration to which a step counting algorithm will be applied. There are many varieties of IMUs available on the market but the most important factors for StepQuest are as follows. What MCU's it can interface with, cost, time to delivery, power supply, whether it is available as a SMD, and whether a test unit is available.

<u>MPU-6050</u>

This device provides not only an accelerometer but also a gyroscope which could potentially be used in tandem with the accelerometer for greater accuracy. There is a lot of documentation regarding how to use this device with both Arduino and ESP32 chips. However, the power supply is a bit on the higher side with a minimum of 3.3V and a maximum of 5V, not to mention it is not available as a SMD. The cost isn't too high at $6.49 for 1 device and the delivery time is sufficiently short. A test unit does exist which is an added benefit.

<u>LIS2DW12TR</u>

This device only contains an accelerometer which is the basic requirement for step counting. The power supply is rather low with a minimum of 1.62V and a maximum of 3.6V, furthermore the cost is low at $2.70 per unit and it is available as a SMD. The shipping time is also sufficiently low. Furthermore, an Arduino library already exists for the accelerometer which is advertised as also being compatible with esp32 architectures. A test unit does exist but has low stock which could prevent us from obtaining it in the necessary time.

<u>MC3479</u>

This device also only contains a 3-axis accelerometer but that is the basic requirement for StepQuest. This device allows setting of the sample rate and is also a low power device with a voltage range of 1.7 V to 3.6 V. The cost is the lowest yet at $1.66 and has over 200,000 in stock. However, though an Arduino library exists for the device, there is no mention of compatibility with ESP32 which is something that the team would have to look into on our own. However, an evaluation board does exist if we wished to test it.

Factors	MPU-6050	LIS2DW12TR	MC3479

ESP32 Compatibility	Yes	Yes	No
Power Supply	3.3V / 5V	1.62V / 3.6V	1.7 V / 3.6 V
Cost	$13.95 for 1	$2.70 for 1	$1.66 for 1

Table 10. Internal Measurement Unit Comparison

Conclusion

Given the accelerometers available on the market, I believe that it would be worth looking into the LIS2DW12TR. An Arduino library already exists and furthermore that library is compatible with ESP32 which keeps our options for MCUs open. It’s also the lowest voltage option and though not the cheapest, it’s far from the most expensive. The LIS2DW12TR is also readily available with over 16,000 in stock as of October 4th. Overall, it checks all the boxes for what StepQuest needs in an IMU and seems to be the best choice.

3.2.2 Battery

Rechargeable batteries are not just important but utterly essential in mobile devices. The battery specifications in a mobile device greatly impact the overall value and usability of the device. In the case of StepQuest, which can be seen as a mobile device in its own right, the choice of battery is absolutely critical to the design's success. Key factors like battery capacity, the speed of recharging, and the physical size of the battery all weigh heavily in the decision-making process.

A high-capacity battery ensures that StepQuest can keep up with users' demands, while fast recharging capabilities enhance user experience by minimizing downtime. Additionally, a compact battery design is essential for maintaining the device's portability and sleek form factor. The right battery choice can ultimately make or break the overall functionality and desirability of StepQuest as a mobile device.

For the purpose of the discussion, we will focus on rechargeable batteries as they fit our device’s purpose. There are many rechargeable batteries that can be used in this project; however, we will limit the discussion to three types of these batteries. Nickel-Metal Hydride (NiMH) AA batteries, Lithium-Ion (Li-ion) DTP (603443) batteries, and Lithium-ion polymer (LiPo) batteries.

	NiMH (AA)	**Li-ion (DTP603443)**	**LiPo (DTP301120)**
Capacity	2500mAh	850mAh	40mAh

Compatibility	Compatible with connector	Compatible	Compatible
Dimensions	14.5 mm diameter and 50.5 mm	43mm*34mm*6mm	20mm*11mm*3mm
Cost	$33 for the battery and the connector [30]	$11 [31]	$4.95[32]

Table 11. Battery Comparison

Conclusion

We chose Li-ion DTP (603443) batteries because of the properties it offers. This type of battery is considered safe and easy to implement. Unlike NiMH (AA) batteries, Li-ion DTP (603443) batteries do not need a connector with it. This makes the hardware design straight forward. Li-ion batteries are affordable and can be found easily in the market. LiPo batteries are expensive and difficult to find in the market. In addition, they come in small capacities. If we could find a larger LiPo in capacity, the size of the battery will exceed the constraint we have set earlier for the PCB design.

3.2.3 Wall USB Adapter Plug

Wall USB adapters are important to convert an AC Current from the wall outlet to a stable DC current to charge the battery. There is an abundance of options that serve the same functions, so we decided to show specs of one of them. In the table below, the specs of the selected adapter are shown:

Specs	
Output Voltage	5V DC
Minimum Load	0.01A
Rated Load	2A
Output power	10W
Rated Voltage	100-240V AC
Variation Range	90-264V AC
Rated Frequency	50/60 Hz
Variation frequency	47/63 Hz

Table 12. USB Adapter Specs

3.2.4 Coin Vibration Motors

The options of vibration motors are plenty, but they have almost the same specs and features. Choosing either part will not leave a drastic impact on the overall performance of the project. The table below illustrates the options found by us. These two options are provided by SparkFun and DFRobot.

Specs	FIT0774	B1034.FL45-00-015
RPM	11000+-2500 RPM	13000+-3000 RPM
Dimensions	10mm (Diameter) / 2.7mm (Thickness)	10mm (Diameter) / Not specified (Thickness)
Rated Voltage	3V	3V
Rated Current	50mA	60mA
Cost	$1	$2.25
Vendor	DFRobot	SparkFun

Table 13. Coin vibration Motors Comparison

The size, rated current, and cost make FIT0774 the best fit for our design. Note that the vendor of B1034.FL45-00-015 (SparkFun) does not specify the thickness of the part which makes choosing this model a risk.

3.2.5 Heartrate Monitors

While it is still uncertain whether StepQuest will choose to implement a heartrate monitor, the following comparison determines which would be the best choice if it is chosen to implement such a feature.

<u>MAX30102</u>

This heart rate sensor has the ability to not only detect heart rate but also to determine blood oxygen levels. This device already has a thorough Arduino library that allows the device to detect heart beats and find the heart rate which will make it easier to implement. However, some previous users have claimed that this library isn't the most accurate and that it has difficulty detecting heart rate when in motion or if the pressure of the sensor against the skin changes. Given our use case, this would be very problematic. Still, there are many other code examples to calculate the heart rate using this device as it seems to be rather commonly used.

Other factors for this device are that it recommends an operating voltage of 1.8 V with a minimum voltage of 1.7 V and a maximum of 2 V. It is also readily available with over 8000 units available. However, the device is rather costly at $12.43 per unit. Test devices that can be used on a breadboard also exist for a similar price point. Expected delivery time is about 1 week.

SFH 7070

This is a much cheaper option at only $3.02 per unit, however that lowered price comes at a cost. As far as I could find, there doesn't appear to be an existing library that can be used to detect heart rate so it'd have to be made from scratch. Furthermore, there appears to be less information on how to use the unit in general. The data sheet is also fairly sparse compared to others with only a maximum voltage of 5 V mentioned and no minimum to be found. It is fairly available with over 5000 units currently available but no testing device to be found. Despite it's significantly cheaper cost, it likely isn't a great option for StepQuest. Expected delivery time is about 1 week.

PulseSensor

This sensor is about as ready to go as it can come. It comes in an appealing circular shape that would likely work well with the planned wristwatch design of StepQuest as well. This company sells the hardware for the pulse sensor and then provides its own software to detect heart rate which simplifies things immensely. According to the company it is designed to work with Arduino and all maker platforms so that shouldn't be a problem.

A few users have claimed that sharp movements can mess up the device, similar to MAX30102 and that it needs to be kept motionless on the skin to work well. It can take in 3 V or 5 V and is readily available on Amazon though no supply count was available. This option is the most expensive of the bunch as it comes with everything you need at $24.99 per unit. Expected delivery time is about 1 week.

There is also some question on how it will interface in the final product as it comes with cables already attached to the sensor. Furthermore, no test device exists as it is less a mountable device but a full heartbeat sensor kit meant for ease of use.

	MAX30102	**SFR 7070**	**PulseSensor**
Cost	$12.43	$3.02	$24.99
Delivery Time	1 Week	1 Week	1 Week
Availability	Over 8000	Over 5000	Currently Available, amount unknown
Existing Libraries	Yes	No	Yes
Voltage	1.7 V – 2 V	5 V	3 V – 5 V
Test Unit	Yes	No	No

Table 14. Pulse Sensor Comparison

Given all the information the MAX30102 seems to be the best option. It is cheaper than PulseSensor though not the cheapest option and is the most readily available of the bunch. Furthermore, it supports the lowest voltage, has a test unit that can be bought and has many existing libraries and projects existing on the internet for reference making it the safest choice.

3.2.6 Micro-USB Li-Po Charger

As Li-Ion batteries can be damaged if not charged safely, it requires us to find the best available charger. The different features and specs that chargers offer give us a space to weigh the pros and cons of choosing one charger over the other. The specs and features that interest us are size, maximum supply current, LED indicator, and cost.

	DFR0667	MCP73831	MCP73831T
Size	25mm*16.5mm	21mm*19mm	30mm*20mm
Max current	500mA	500mA (with soldered jumper closed)	500mA
LED status indicator	Yes	Yes	Yes
Cost	$6	$7	$10
Vendor	DFROBOT	Adafruit	Sparkfun

Table 15. Charger comparison

Conclusions

After careful consideration of the options listed here, we chose the DFR0667 because of the collective features it has. Plus, the low cost and small size of the part makes our design much easier. Below are the figures for the three different chargers:

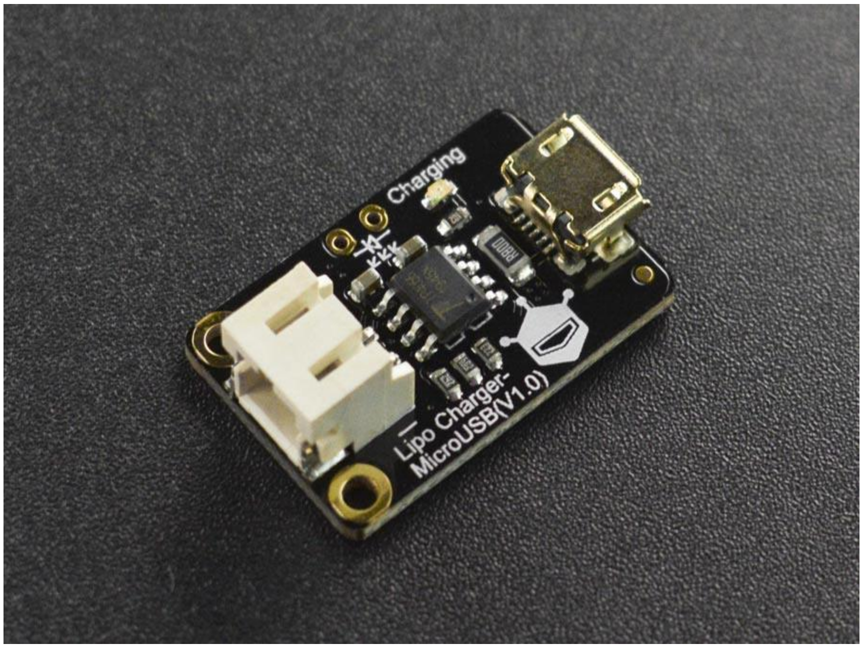


Figure 19. DRF0067

From (www.digikey.com)

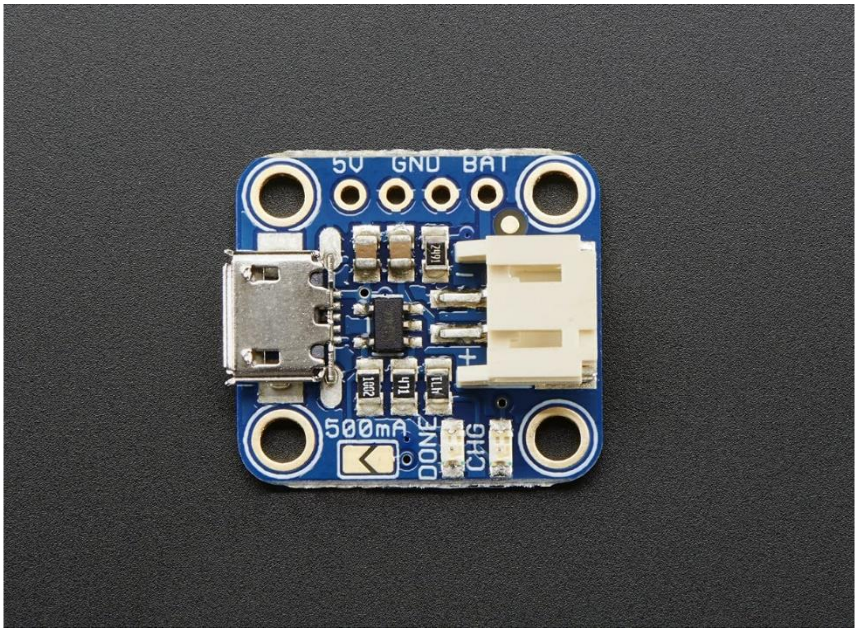


Figure 20. MCP73831

From (www.digikey.com)

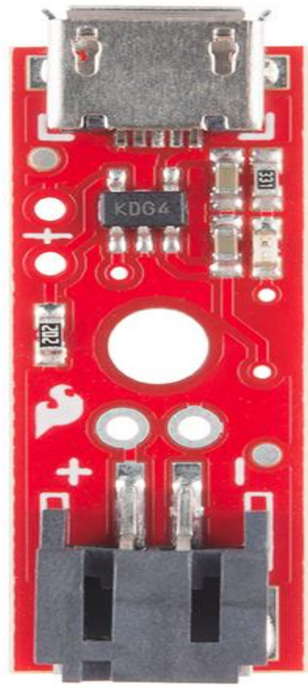


Figure 21. MCP73831T

From (www.sparkfun.com)

3.2.7 Time

Real Time Clock Module

There are multiple options when considering keeping time for the ESP32 microcontroller. There are Real-Time Clock (RTC) Modules like the DS3231 which have the benefits of accuracy and can keep time even when the ESP32 is powered off. This option requires an extra chip, memory component, and battery holder and typically interfaces with the ESP32 using I2C or SPI like other peripherals. ESP32 can periodically sync its time with the RTC module, ensuring it has the correct local time.

Unfortunately this option drives up cost, space, and complexity which is a pretty big negative for this project. To prototype with, RTC module development boards can run around $10 - $20 from Adafruit[43]. Not only is this way too expensive to learn how to use the tool, that may not even include the memory circuit to store the time once the power from the system is no longer applied. Beyond this, our team would have to put in extra design to implement this circuit, which just adds un-needed complexity.

Onboard RTC

It should be noted that the ESP32 does have its own onboard mechanisms for timing, including an RTC that keeps persistence when the MCU is in deep sleep power saving mode. However, this does not remember the time once power is no longer applied.

“RTC timer: This timer allows time keeping in various sleep modes, and can also persist time keeping across any resets (with the exception of power-on resets which reset the RTC timer). The frequency deviation depends on the RTC Timer Clock Sources and affects the accuracy only in sleep modes, in which case the time will be measured at 6.6667 μs resolution.

High-resolution timer: This timer is not available in sleep modes and will not persist over a reset, but has greater accuracy. The timer uses the APB_CLK clock source (typically 80 MHz), which has a frequency deviation of less than ±10 ppm. Time will be measured at 1 μs resolution.” [44]

This solution has the benefits of not having to purchase and design an external module or design any extra circuits. The internal clock hardware is more designed for micro-scale timers, so it does not keep time as accurately as the external module, but it should not be bad enough for our uses. While ESP32 documentation doesn’t specify how inaccurate the onboard clocks can be since they often vary by environment, anecdotal examples show “While in deep sleep, the RTC time is wrong by 76 seconds after 3.5 hours.” [45]. While we do not plan on putting the device into deep sleep for that long, it Is possible that this is within the realm of use cases. The good news is that we can combine this with another option.

Network Time Protocol (NTP)

One of the reasons the ESP32 was chosen as the MCU is that it can connect to the internet using Wi-Fi. Network Time Protocol (NTP) is used to synchronize the ESP32's clock with an NTP server on the internet. According to NTP.org, “The NTP Project conducts Research and Development in NTP, a protocol designed to synchronize the clocks of computers over a network to a common timebase. NTP is what ensures the reliability of billions of devices around the world, under the sea, and even in space. Accurate timekeeping is vital to the many applications which have revolutionized and are essential to our daily lives: satellites, GPS, 5G, financial services, healthcare, and more. [46]. Even Microsoft Windows uses the NTP protocol.[47]

The benefit of this is being able to sync to a time server (when on Wifi) that will keep our time more accurate, even thought the onboard clocks may have driven it to inaccuracy.

GPS Module

One further mechanism that could be considered to retrieve accurate time and location information would be a GPS module. GPS modules can provide precise time and can set the ESP32's clock. This approach is a bit extreme since we don't need GPS location data. This has the same downfalls as the external real time clock module which requires extra engineering and design efforts to implement. For these reasons, we will not be using GPS.

Notable Findings

An interesting even that doesn't necessarily affect this project, but does affect those syncing time form an NTP server into a 32-bit integer, is the "Year 2038 Problem"

"The year 2038 problem (also known as Y2038, Y2K38, Y2K38 superbug or the Epochalypse) is a time formatting bug in computer systems with representing times after 03:14:07 UTC on 19 January 2038.

The problem exists in systems which measure Unix time – the number of seconds elapsed since the Unix epoch (00:00:00 UTC on 1 January 1970) – and store it in a signed 32-bit integer. The data type is only capable of representing integers between −(231) and 231 − 1, meaning the latest time that can be properly encoded is 231 − 1 seconds after epoch (03:14:07 UTC on 19 January 2038). Attempting to increment to the following second (03:14:08) will cause the integer to overflow, setting its value to −(231) which systems will interpret as 231 seconds before epoch (20:45:52 UTC on 13 December 1901). The problem is similar in nature to the year 2000 problem."[48].

While the timeline of our project doesn't fall into this date range, it is interesting to think that there will be another computer time storage problem like we experienced in Y2k. I believe companies have probably learned from this and have been updating their formats accordingly. Linux has solved this problem already, and I believe post Vista Windows has. [49]

Time Keeping Choice	Ease of Implementation	Cost	Space
ESP32 Onboard RTC	+ Already included	+ Free	+ Already included
External RTC Module	- Extra Work	- Expensive	- More space
NTP	+ Already included	+ Free	+ Already included
GPS	- Extra Work	- Expensive	- More space

Table 16. GPS Module Comparison

Conclusion

Onboard RTC with NTP synchronization has been chosen as our method of timekeeping. While initially considering an external DS321 RTC module for time-keeping efforts, it has become clear in the research that this is not really a requirement. While our end user should expect accurate timekeeping, it is reasonable to expect relative accuracy with the ESP32s onboard timing and clock mechanisms. Every 12 hours, we can connect to the NTP server via WIFI to sync up any errors in the time.

In the initial stages, we were considering using an external DS321 Real-Time Clock (RTC) module to ensure accurate timekeeping for our project. However, further research has shown that using this external module is not actually necessary. The ESP32, which we are using for our project, has its own onboard timing and clock mechanisms that can provide reasonable accuracy for timekeeping. While it may not be as precise as an external RTC module, it should still meet the requirements of our end users.

To ensure that any errors in the time are corrected, we have implemented a solution where the ESP32 will connect to an NTP (Network Time Protocol) server every 12 hours via WIFI. This will allow it to synchronize its internal clock with the server's accurate time, adjusting for any discrepancies that may have occurred.

By periodically synchronizing with the NTP server, we can maintain relative accuracy in timekeeping without the need for an external RTC module. This approach strikes a balance between accuracy and practicality for our project.

3.2.8 Boost Converter

Switched mode power supplies serve a variety of purposes, including their application as DC to DC converters. In many cases, a DC power source, like a battery, may be on hand, but its voltage is not suitable for the intended system. For instance, electric vehicle motors often require much higher voltages, around 500V, which exceed the capacity of a single battery. Even if an array of batteries were employed, the resulting added weight and space requirements would render it impractical. To address this issue, the solution is to employ fewer batteries and elevate the available DC voltage to the necessary level using a boost converter.[50]

Another drawback associated with batteries, regardless of their size, is that their output voltage diminishes as the stored charge is depleted, eventually falling too low to sustain the powered circuit. Nevertheless, by utilizing a boost converter to elevate this low output voltage back to a useful level, the lifespan of the battery can be extended.

	TPS61033X	TPS61299	TPS61253
Vout Max (V)	5.5	5.5	5.25
Size	2.10 mm × 1.20 mm	1.6-mm x 1.6-mm	1.2 mm × 1.3 mm
Switch current limit(A)	1.8	1.5	4.5

Table 17. Boost Converter Comparison

Conclusions

Since the options are very similar to each other, there will be no major difference in choosing either part. The reason we decided to go with TPS61033X option is because of the reasonable size that will help us during soldering.

3.2.9 Microcontroller Unit

Choosing the “brains” to this project was one of the most important choices that had to be made, aside from the screen, which is what the user sees the most. The microcontroller unit (MCU) we select to power our project will control how smoothly our project can run, what features it has, and to some degree, how difficult our project will be to pull together.

At the forefront of our considerations when it came to choosing the ideal MCU were chip availability, cost, size, available documentation, and compatibility with Arduino. Chip availability is a cornerstone, as we needed a component that could be reliably sourced to ensure our project could be finished. Cost-efficiency was another vital factor, as it influenced our project's budget and viability. The compact size of the MCU was crucial, especially in our project that should be about the size of a watch that users can wear comfortably on their wrist. Easily accessible documentation was also deemed essential for smooth development and troubleshooting. Lastly, compatibility with Arduino, a widely used platform for electronics prototyping and development, was important as we had decided to use that as a programming language and library to ease our efforts in programming the device.

Our options for MCU started off with the ESP32, and the RP2040W. The ESP32 is a well known microcontroller frequently seen in the IOT project space because of its built in WiFi and Bluetooth capabilities. The ESP has a huge community behind it as it has been around at least the ten years that I myself have been messing with hobby electronics, which means it has plenty of useful documentation to use.

The RP2040 is the newcomer to the IOT scene. Bluetooth was just unlocked in the firmware of this MCU (although it’s been available since the board’s conception, just not active) in June of 2023 [52] . Since users have not had as deep of a history with this unit, it is understandable that the documentation in the form of user projects is going to be less available. One great thing about the RP2040W though is that it does offer a smaller, available package that would keep our sizing down.

Figure 22. ESP32

Documentation

Espressif offers great documentation for all of their ESP32 chip options. [53]. There are open source dev board guides with schematics and their own documentation, and each chip has its own documentation manual. This helps ensure that our team can create our own board for the MCU and see examples of how the company created theirs.

Beyond this, it is so helpful to have access to the vast community of projects that have been completed using the ESP that makers have provided their own resources for. Drawing from this collective pool of knowledge and experience, we can leverage existing projects as valuable references when tackling challenges. so that we can "stand on the shoulders of giants as the saying goes, benefiting from the wisdom and innovative solutions shared by those who have ventured into similar territories.

Arduino compatibility

The ESP32 is well known for the wide variety of programming languages that can be used to command it. Python, Lua, C/C++, and Arduino to name a few. [54]. The main language we were looking for is Arduino because it is so well documented and widely used by others who have shared their projects with the community. This should help ease our workload due to the teams familiarity with the language as well.

Cost and Availability

Compare	Part	Description		Manufacturer	Stock	Price	
	ESP32-C3	400KB 22 3V~3.6V RISC-V 160MHz QFN-32-E...	Extended Part	Espressif Systems	2823	1 +	$1.2585
	ESP32-C3FN4	QFN-32(5x5) Microcontroller Units (MCUs/MPU...	Extended Part	Espressif Systems	0	1 +	$1.8294
	ESP32-C3FN4	QFN-32(5x5) Microcontroller Units (MCUs/MPU...	Extended Part	Espressif Systems	4994	1 +	$1.4804
	ESP32-C3FH4	QFN-32-EP(5x5) Microcontroller Units (MCUs/M...	Extended Part	Espressif Systems	3499	1 +	$1.5543
	ESP32-PICO-V3 Standard Only	LGA-48 Microcontroller Units (MCUs/MPUs/SO...	Extended Part	Espressif Systems	79	1 +	$3.2550

Figure 23. MCU Cost and Availability

The ESP32 runs between $1 - $5, which is an astounding price for the powerhouse that it is. 2 cores, 32-bit processor with up to 16mb of flash, is a great deal. And checking with JLCPCB there are plenty of chips actually available for order through their pick and place system[55].

Size

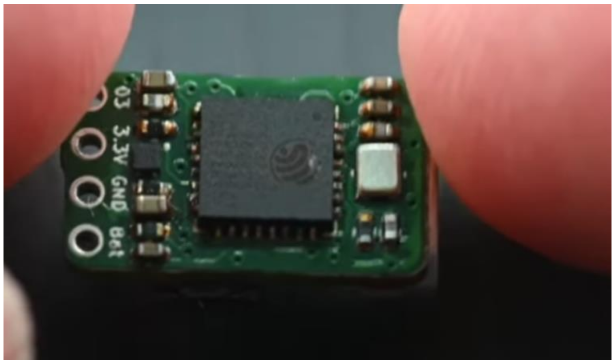


Figure 24. ESP Size

While ultra small ESP builds have been accomplished, the default size of most working modules is 18x25.5mm[56]. This is pretty large for just the required module, but WiFi antennas and the required circuitry seem to add to the space requirements. Since this is a small portion of the size of the screen's PCB, I believe this could still be a viable option.

RP2040W

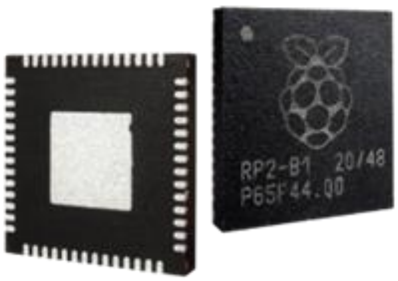


Figure 25. RP2040

The RP2040, "features a dual-core Arm Cortex-M0+ processor with 264kB internal RAM and support for up to 16MB of off-chip flash. A wide range of flexible I/O options includes I2C, SPI, and - uniquely - Programmable I/O (PIO). These support endless possible applications for this small and affordable package" [58]. This chip is most notably featured on the Raspberry Pi Pico, its development board.

Documentation

The RP2040 itself has pretty decent documentation from the company. It is on-par with Espressif's in quality and thoroughness. There are data sheets and design guidelines for making a development board and a useable custom board starting place.

The place where the RP2040 really falls short is community documentation. There just aren't as many related and available projects for the Rpi -Pico vs the ESP32 development board. The weight for this category is so heavy because it really helps to see exactly what others have done that are making similar projects to ours. It is important to note that the original predecessor prototype for this project was done using the RP2040 MCU. This is where the lack of other projects really sunk in. It was so hard to find others experiencing the same issues as I was because all of the projects like ours were using the ESP32. This is a major point awarded to the ESP.

Arduino compatibility

One thing the RP2040 almost had going for it is the fact that you can program using the Arduino language/ library. Not only Arduino, but different varieties of Python, C/C++ as well. Unfortunately the wireless features that we would be looking for are well documented in the C language, but we'd like to use Arduino as it makes everything so much simpler. There are very few examples of connecting to the internet and using the wireless of the RP2040 through Arduino that are out there and easy to find. Ultimately, this was a very disappointing discovery for such a promising chip. Perhaps in a few years more examples will be available.

Cost and Availability

One area the RP2040 certainly competes with the ESP is the cost and availability. The development board for both can be purchase for around $6 at the time of writing. However, the RP2040 chip itself is MUCH cheaper, and still very in stock at .98 per [60]. Whereas the ESP clocked in at around $3 - $4. Not really important on the small scale of our project, but if we were scaling it would be.

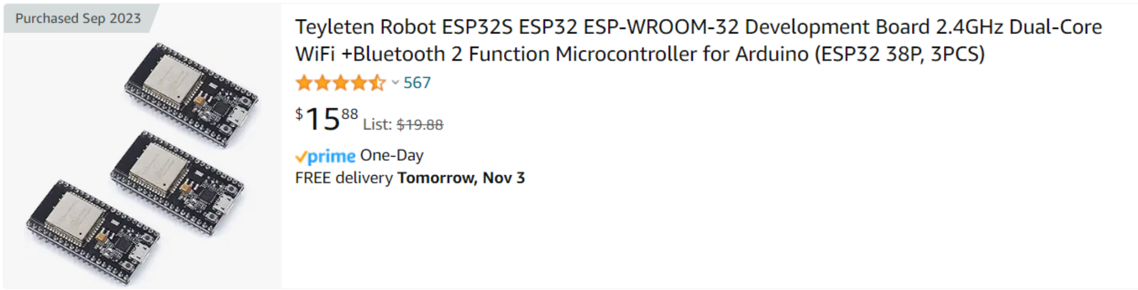
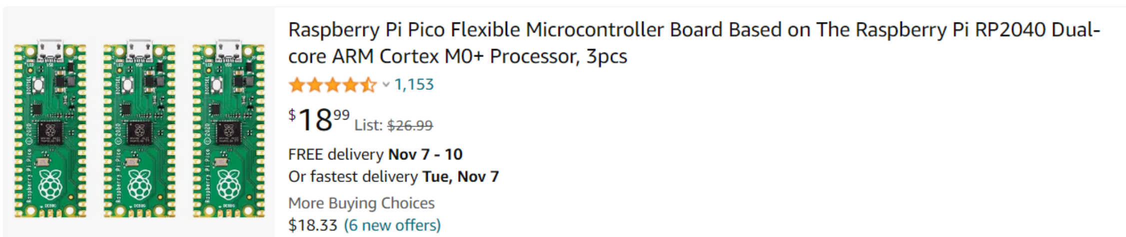


Figure 26. ESP32 Listing



Figures 27. RP Pico Listing

<u>Size</u>

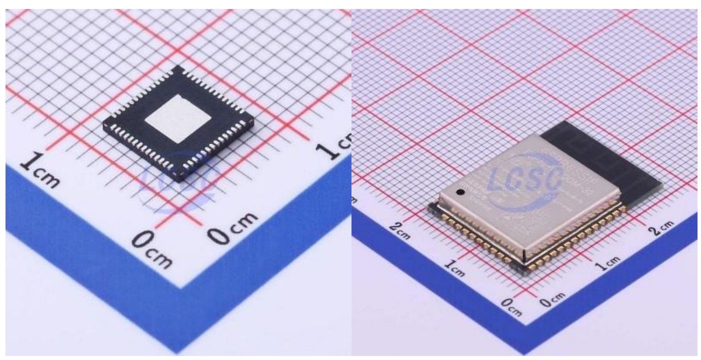


Figure 28. Rp2040(Left) vs ESP32(right)

Another area the RP2040 and ESP are close in is the size of their modules. However, somehow the RP packs their required circuits and components into a MUCH smaller package.[60] Unfortunately neither size really has a “minimum size” board example, as this would depend on the features required. Although hobbyists are constantly trying to minimize in this area. Even though the ESP is twice the size of the RP, it also *includes an antenna* meant for connecting to wireless networks. The RP does NOT contain an antennae, so the WiFi feature are considered extra and must be built into the chip. This would be adding extra complexity, parts and space. This is a huge detriment to the RP, and could also explain why there are so much fewer *connected* projects built with this chip. For this reason, the point goes to ESP.

The Results

	Cost	Availability	Size	Compatibility With Arduino	Documentation
ESP32	~$3	Very	2cm	Yes	Very good Even better from community
RP2040	~$1+ Wifi parts	Very	1mm + anten na	Yes	Very good Missing extra community support
ATmega328P	~$3 + wifi parts	Very	<1cm + anten na	Yes	N/a

Table 18. MCU Comparison

Conclusions

Going into this research I expected the RP2040 to be the winning choice, or have it at least be very close in running with the ESP32. After all, it was newer and newer must be better. It turns out that the huge community support offered by the ESP32 projects that have already been and are currently in development are more vital than manufacturer documentation. The ESP has plenty of user anecdotal advice and documentation, whereas the RP2040 struggles. Not only this, but the ESP is built to handle wireless communications in its module by default, which is a huge comfort in knowing that our needs will be handled. The size of the units are certainly comparable, especially if you consider that the RP2040 does not include the required wireless capabilities in its module size. It is also nice to see that chip availability and price has returned for the most part to pre-covid levels. All of the chips researched were available and priced as expected (cheap).

3.2.10 Screen Technology

Since the screen technology is the most noticeable piece of hardware for this project, it requires dutiful consideration. Choosing a screen that looks good, is in a shape that the user expects for a fitness tracker, and most importantly one that allows them to interact with the on-screen content are all crucial requirements. It was a little hard to find contenders for this category as many of the "hobbyist" screens either come with an MCU attached already, or just aren't in a pleasing shape.

The main areas of focus for the choice of screen are "standalone" – meaning it does not come with an MCU built in already, shape either round or rectangular which are the current expected shapes of other fitness trackers on the market, and time to ship, and price. We do not want to be waiting on a screen to ship from China for 6 months. We do not have that kind of time, and we do not want to make this project unreasonably expensive because of the screen component. Although, the screen is going to be the most expensive piece of hardware for this project as its something we can't make ourselves.

There are 3 main screens being considered:

The Waveshare 1.28 inch Touch Screen[1],	The Waveshare 1.28 inch Display[2]	Adafruit 1.54" 240x240[3]
		

Table 19. Screen Technology

<u>Appearance</u>

As can be seen, all 3 displays look quite good. The rectangular display from Adafruit comes in a slightly larger dimensions, but since they aren't too much bigger and would still be comfortable on a user's wrist, it ends up being a positive being able to convey more information at once. Each display is 240x 240 resolution, and each are the same size with the Adafruit eking some extra space.

However, one area that the Waveshare models win in is styling. The Adafruit display has no beveling, and just looks like an electronics display component. It's very industrial and dry. The Waveshare models have piano gloss black beveled edges, and looks much more modern. Both Waveshares have the electronic connections hidden behind the screen area as well, which won't make a difference in our project, but it does make the product look sleeker. I think the Waveshares are a clear win here.

Price

Currently the Adafruit screen looks to be the cheapest option at around $17. However, Adafruit is located in New York and having ordered with them before I know that shipping is at least $10, so that actually puts it at around $27 + tax. The Waveshare twins come in at around $20 + tax for the non-touch, and around $28 + tax for the capacitive touch screen model. In this case the Waveshare without touch option comes through the winner, however it could be noted that the touch screen carries extra value to the end user.

Shipping Time

Both Waveshare models are in stock on Amazon which is how we discovered them. This gives them guaranteed 3 days or less delivery. Unfortunately for the Adafruit they are shipping from NY and without adding any erroneous shipping costs, it would take at least 4 days to arrive. This is not much in the grand scheme of things, however the point still goes to the Waveshare options.

Features/ Usability

Adafruit is well known for having great documentation, a community forum, and an actual customer service email. This gives it major points in this category. However, after doing some research, it looked like many users had trouble with actually getting the screen working correctly with the TFT_Espi library we plan on using, which LVGL runs on[65]. This does take off some minor points.

Waveshare is a company out of China who is not really well known for their great documentation or customer service. However, I have had to contact their customer service with an issue I had before, and they got back to me to help me solve my problem at least as good as Adafruit would have. Not only this but they have an entire Wiki document devoted to their products, which usually contain libraries, usage examples, and other helpful documents. I will say that they are not as good as Adafruits and the libraries often need some tinkering, so I would say Adafruit get's the point in this part.

However, there is one elephant in the room that hasn't been talked about, the touch screen feature. The only acceptably shaped, acceptably featured display module with a touch screen is the Waveshare 1.28in 240x240 touch screen module. Simply because of that feature, and because there are no readily available contenders, this screen has to be the one that we chose.

	Appearance	Price	Features/ Usability	Shipping Time
Waveshare	Very modern	~$20	Good	Fast
Waveshare Touch	Very Modern	~$28	Good + Touch	Fast
Adafruit Rectangle	Very industrial	~$20 + $10 shipping	Great - touch	Poor

Table 20. Screen Comparison

Conclusions

The clear choice during the research was the touch model round display from Waveshare. It has the market to itself right now due to its touch feature, and sleek modern style. The library that comes with the device is not the best, but it can be re-written if totally necessary.

4.0 Standards & Design Constraints

For the design of StepQuest, several standards and design constraints need to be considered. The standards affect both the hardware and software aspects of the design. The constraints are tied primarily to the size and formfactor of a wearable device. Below is the breakdown and explanation of the standards and design constraints that are used in the design of StepQuest.

4.1 Standards

In the design of StepQuest, many hardware and software standards are used. These standards are important to consider and implement in order to better improve the overall design of the StepQuest device. Below are the descriptions of the standards that were used in the design of the StepQuest device.

4.1.1 Water Resistance

Water resistance is an important aspect to consider when designing an electronic device. When exposed to even small amounts of moisture, electronic devices can experience malfunctions, possibly catastrophic ones, causing the device to be rendered nonfunctioning permanently. It is important to understand the water resistance standards and ratings for electronic devices when designing one. This allows the device to be built in such a way as to best protect the internal components and electrical parts of the device and the PCB.

The International Electrotechnical Commission has created a set of standards and ratings to follow for water resistance. This set of standards are called the ingress protection (IP) ratings. The ingress protection ratings test the resilience of a device against the invasion of moisture and/or dust. It also tests the ease of getting to and being contacted by potentially dangerous components within the device that are particularly suspectable to moisture and/or dust. The ingress protection ratings are commonly used throughout industry and manufacturing practices.

The ingress protection rating is made up of two numbers. The first numeral is associated with the level of defense against solid particulates. This number is on a scale of 0 to 6, where 0 has no defense and 6 allows for no entry of particulates. The second numeral is associated with the level of defense against liquids and moisture. This number is on a scale of 0 to 9, where 0 is having no defense and 9 allows for high-pressured warm water from varying angles.

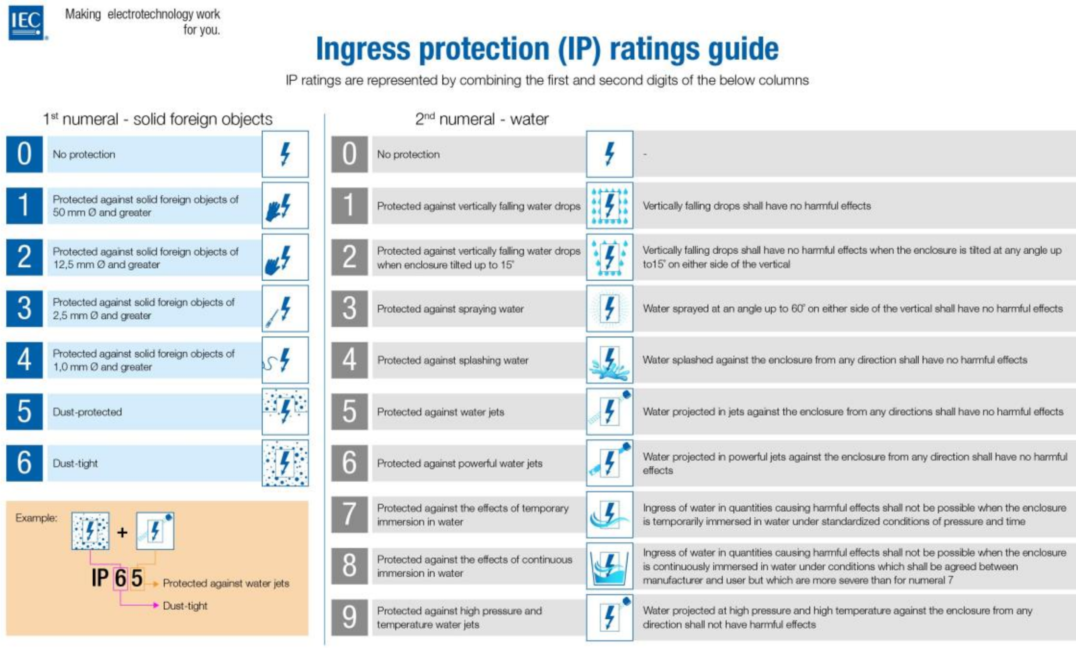


Figure 29. Ingress Protection (IP) Rating

4.1.2 Wireless Specifications

Esp32 features 802.11 b/g/n 2.4Ghz Wi-Fi and Bluetooth 4.2 BR/EDR BLE compliant.

The selection of the ESP32 microcontroller as the core component of our project was made after careful consideration of its capabilities, and one of the standout features is its ability to communicate on a wireless network. This capability allows our project to connect to a server to sync up our user's time, but it also would allow us to access a web-app to add even more functionality for our end-user. It should be noted that connecting to a web-app is a stretch goal. However, it's crucial to recognize that the effectiveness of this communication relies heavily on the adherence to correct protocols and modern standards.

<u>802.11 Standards</u>

In the realm of wireless communication, protocols and standards act as the language and guidelines that govern the interaction between devices. They ensure that data is transmitted reliably, securely, and efficiently. As such, the selection of appropriate communication protocols is not merely a matter of preference, but a necessity to ensure the seamless operation of our project.

Our team acknowledges that adherence to these protocols and standards is not solely an internal expectation but a critical consideration for the end user as well.

Modern users have come to expect certain levels of performance, security, and reliability in their connected devices. They rely on the underlying communication technology to be robust and compatible with their existing networks and devices.

By choosing the right communication protocols and adhering to modern standards, we can guarantee that our project will not only meet the technical requirements we've set but also deliver a user experience that aligns with contemporary expectations. This ensures that our system will seamlessly integrate into the user's existing network environment, providing a hassle-free and reliable connection.

Modern standards often come with enhanced security measures, which is of great importance in a world increasingly concerned with data privacy and protection. Adhering to these standards can help safeguard the privacy and security of user data, assuring our end users that their information is handled with care and diligence.

The standards employed for wireless communications are often 802.11. IEEE describes them as follows:

- IEEE 802.11**™** is the pioneering 2.4 GHz Wi-Fi standard mentioned above from 1997, and it is still referred to by that nomenclature. This standard and its subsequent amendments are the basis for Wi-Fi wireless networks and represent the world’s most widely used wireless computer networking protocols.
- IEEE 802.11b™, or Wi-Fi 1, was introduced to the market in 1999 with Apple’s announcement. It also operated at 2.4 GHz, but to reduce interference from microwave ovens, cordless phones, baby monitors, and other sources, and to achieve higher data rates, it incorporated modulation schemes called direct-sequence spread spectrum/complementary code keying (DSSS/CCK). Wi-Fi 1 enabled wireless communications at distances of ~38m indoors and ~140m outdoors.
- IEEE 802.11g™, or Wi-Fi 3, was introduced in 2003. It allowed for faster data rates of up to 54 Mbit/s in the same 2.4 GHz frequency band as IEEE 802.11b, thanks to an OFDM multi-carrier modulation scheme and other enhancements. This was appealing to mass market users, as 2.4 GHz devices were less expensive than 5 GHz devices.
- IEEE 802.11n™, or Wi-Fi 4, was introduced in 2009 to support the 2.4 GHz and 5GHz frequency bands, with up to 600 Mbit/s data rates, multiple channels within each frequency band, and other features. IEEE 802.11n data throughputs enabled the use of WLAN networks in place of wired networks, a significant feature enabling new use cases and reduced operational costs for end users and IT organizations.“ [67]

The ESP is able to use up to 802.11n according to the data sheet, which isn't the ultimate latest, but we are not looking for blazing Wifi speeds when all we are doing is syncing our time data. It takes time for the technology to make its way into products.

Bluetooth Standards

Bluetooth Standards have undergone a rapid evolution over the years, with a notable transition from IEEE (Institute of Electrical and Electronics Engineers) oversight to the management by a dedicated special interest group. This transition reflects the dynamic nature of the technology and its growing importance in the world of wireless communication.

Originally, Bluetooth standards were maintained by the IEEE. The IEEE played a crucial role in establishing the initial protocols and standards that formed the basis of Bluetooth technology. However, as Bluetooth technology continued to advance, a dedicated special interest group, known as the Bluetooth Special Interest Group (SIG), took over the responsibility of developing and overseeing the standards.

The Bluetooth SIG is a consortium of companies and organizations committed to advancing Bluetooth technology. This transition allowed for more focused and agile development of Bluetooth standards, enabling the technology to keep pace with the rapidly changing landscape of wireless communication.[68]

One significant milestone in Bluetooth's evolution was the introduction of Bluetooth 4.0. This version marked a pivotal moment in the history of Bluetooth with the introduction of Bluetooth Low Energy (BLE). BLE is a low-power communication mode designed for devices with stringent power constraints. It revolutionized the world of wireless connectivity, making it possible for a wide range of devices to communicate with minimal energy consumption.

BLE quickly gained widespread adoption and has become the preferred communication mode for numerous applications, particularly in the realm of the Internet of Things (IoT). It enabled devices like fitness trackers, smartwatches, and various sensors to operate on small batteries for extended periods, making them highly practical for everyday use.

As Bluetooth standards continue to evolve, the Bluetooth SIG remains at the forefront of development, introducing new features and enhancements to meet the demands of modern wireless communication. The constant expansion and refinement of Bluetooth standards reflect the technology's adaptability and its role in connecting and enabling an increasingly interconnected world.[69]

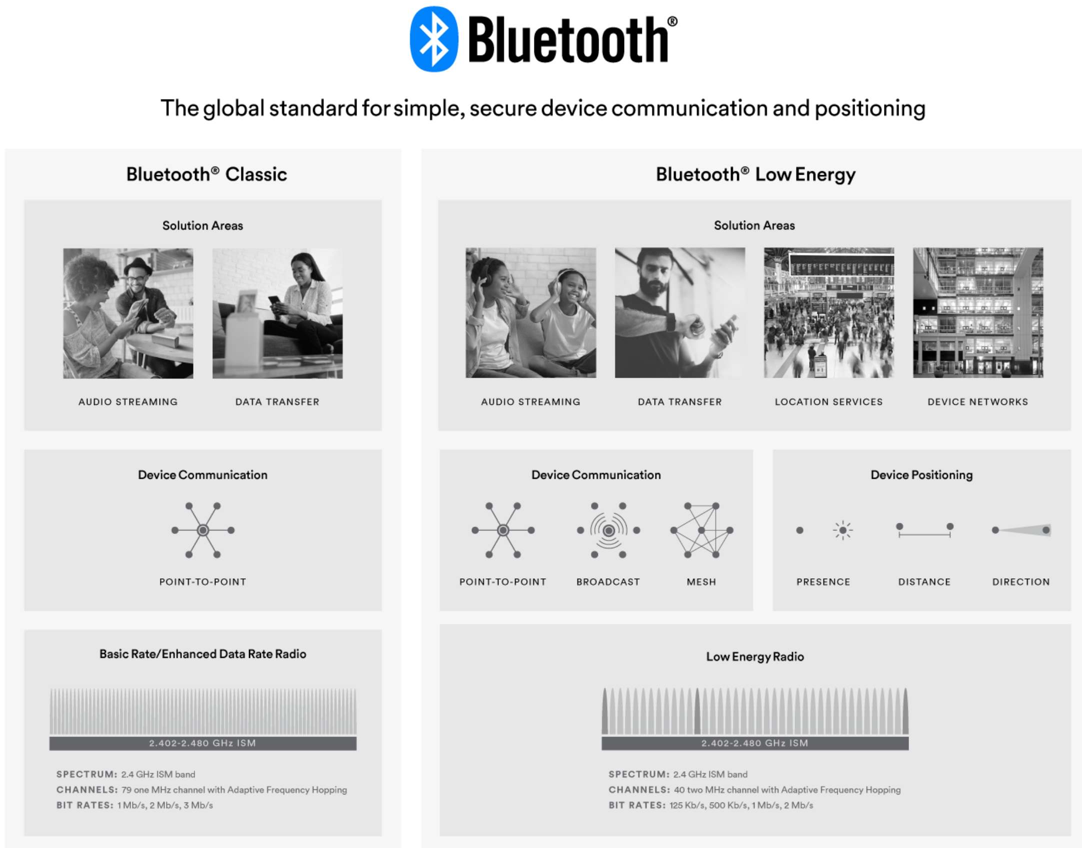


Figure 30. Bluetooth Module

4.1.3 Power Supply Standards

Power supply standards are important guidelines and specifications that ensure the safe, efficient, and compatible delivery of electricity to devices and systems These standards vary around the world, but are objective one such as security, energy efficiency and collaboration. Key components of power supply standards include voltage levels, frequency, connectors, and efficiency ratings.

Voltage and frequency standards vary around the world, with common examples being 120V at 60 Hz in the United States and 230V at 50 Hz in many European countries. These standards specify electricity supplied to homes, businesses, and industries. Connectors and plugs are standardized to ensure safe and reliable connections between appliances and power sources. For example, NEMA 5-15 outlets in the US. has a specific design, while countries in Europe tend to use Type C and Type F plugs.

Energy efficiency standards such as 80 PLUS for computer power supplies aim to reduce energy consumption, reducing operating costs by allocating electricity based on their energy consumption use it properly Power supply standards are essential to ensure safe and continuous supply of electricity across a wide range of applications. These standards not only protect users from electrical hazards but also promote energy efficiency and compatibility between devices and systems, contributing to electricity overall energy consumption is sustainable Manufacturers, governments and international organizations work together to establish and update these standards which are continuously updated to reflect advances in technology and energy demand, making it the cornerstone of the modern energy system

4.1.3.1 NEMA 5-15 Outlet Standards

NEMA 5-15 is the most widely recognized electrical outlet standard in the United States, playing a significant role in everyday electrical systems in homes, offices, and commercial buildings It has a unique design of two thin parallel tubes resembles having a small a slot and a large grounding hole. The 15 outlets provide a voltage of 120 volts, with a maximum current rating of 15 amps, making it suitable for a wide range of electrical tools and appliances for widespread use This standard is typically used for appliances such as computers, televisions, lamps, chargers, and small kitchen appliances. The design of NEMA 5-15 ensures compatibility with a wide range of electrical cables and plugs, providing flexibility and versatility for consumers and manufacturers. It is an integral part of the North American electrical system. It provides safe and reliable power to many everyday electrical appliances.

4.1.3.2 USB (Universal Serial Bus) Standards

USB (Universal Serial Bus) standards play a key role in connecting and powering a wide range of electronic devices. The USB standard is developed and maintained by the USB Implementation Forum (USB-IF), a group of industry leaders responsible for defining and promoting USB technology. Several USB standards have emerged over the years, most notably USB 1.0, USB 2.0, USB 3.0, USB 3.1, and USB 3.2. Each standard brings improvements in data transfer, power delivery, and connections.

Earlier in this report, we discussed USB technologies and connector types. Among the different technologies of USB, we chose USB 3.2 Gen1 with the connector USB connector type-B. This allows the user to deliver power at a current of 5A and voltage of 20V.

4.1.3.3 PCB Standards

IPC-2221, also known as the IPC-2221 Generic Standard on Printed Board Design, is a crucial industry document that sets the standards and guidelines for designing printed circuit boards (PCBs). Developed by the Association Connecting Electronics Industries (IPC), this standard is used by engineers, designers, and manufacturers in the electronics industry to ensure that PCBs are designed with reliability and performance in mind. IPC-2221 covers a wide range of topics, including board materials, conductor widths and spacings, via design, thermal considerations, and much more. It provides essential information for creating PCBs that meet the electrical and mechanical requirements of various applications, from consumer electronics to aerospace and defense systems. By adhering to IPC-2221, designers can improve the quality and manufacturability of their PCBs, reducing the likelihood of errors, failures, and the need for costly revisions in the production process.

IPC-2221 has undergone several revisions to keep up with advancements in technology and materials, with the most recent revision as of my last knowledge update in 2022 being IPC-2221E. This document serves as a valuable reference for professionals involved in PCB design and manufacturing, offering detailed guidance on trace thickness, clearances, and other critical factors that influence the performance and reliability of electronic assemblies. PCB designers and manufacturers rely on IPC-2221 to ensure the industry-wide consistency of PCB designs, leading to products that are more robust and better able to meet the demands of today's fast-paced and technology-driven world.

4.2 Design Constraints

There are several constraints that are important to consider in the design of the StepQuest device. Many of these constraints are tied to the physical constraints of a wearable device. These constraints are important to consider and implement in order to better improve the overall design of the StepQuest device. Below are the descriptions of the constraints acting on the device.

4.2.1 Social Design Constraints

Social design constraints are constraints that are imposed due to the outside expectations of people and society at large. These typically include factors such as ease of use and overall appeal to the target audience which considers things such as design and cost. These types of constraints are important because failure to meet them may result in the failure of the product once it reaches the market. Without meeting these constraints, consumers are less likely to buy, use, and recommend the product.

4.2.1.1 Comfort

StepQuests' main social constraint is the overall comfort of the device. This has to do with both the weight and size of the finished product. As StepQuest is meant to be a wearable wrist-watch device, a big factor of whether or not consumers will want to use it is whether or not the device is comfortable and convenient to use.

The weight of the device is important as a watch that is too heavy may tire out or hurt the consumers wrist. This can make the overall product experience uncomfortable which may impact how often the consumer uses StepQuest. As StepQuests' purpose is to be used on a daily basis in order to improve the fitness and health of the user, failure to meet this constraint would be detrimental to the project's goal.

In the case of weight, there is no worry about a device being 'too light' so only the upper bound of weight is considered. Similar fitness related watches on the market typically range from 28g to 42g so the constraint that the weight shall not exceed 38g should be applied to the project.

The size of the device is just as important, if not more important in regards to comfort. Unlike with weight, there is concern about the device being either too small or too large. A device that is too large will feel bulky on the wrist, making it stand out too much for those who may be more fashion conscious, preventing use.

Furthermore, it may make it difficult to wear items such as jackets and overall makes it seem like a nuisance to the user. However, a device that is too small is also problematic, particularly for those who suffer from poor eyesight. A small device may make it too difficult to interact with the device as intended, also limiting use.

It is important for the watch to fit entirely on the wrist to avoid the perception of bulkiness but also for the watch to be easily visible to the user for ease of use. Most fitness watches on the market are within 38mm to 45mm in terms of size and similarly, StepQuest should be constrained to a size between 38mm to 43mm to ensure the comfort of consumers.

The size and weight constraints applied to the project affect what components can and should be purchased. The size and weight of each component must be carefully considered in order to ensure that these bounds are met. Furthermore, due to other constraints working alongside comfort, some sensors may even have to be set aside entirely if the sensors available would not fit in the reduced size or if they are simply too heavy.

4.2.2 Manufacturing Constraints

4.2.2.1 PCB Constraints

Designing and manufacturing a digital watch that is both comfortable to wear and capable of several functions faces a formidable constraint. The human wrist does not have a large surface area, requiring the device, and therefore the PCB, allowing the device to slightly exceed the width of the wrist. The small dimensions of the human wrist introduce several constraints on the PCB design. The overall design is required to be small, and the constraints forced on the design of the PCB are important to consider. The constraints include form factor, placement of components, power capabilities, and functionality.

<u>Form Factor</u>

The small dimensions of the human wrist will have a large impact on the form factor and size of the PCB. The PCB must fit within the small size that is required to a device that is worn on the wrist. This will ensure that the PCB can fit within the case of the watch and the device is comfortable to wear, regardless of the amount of time worn and activities that the user is participating in. The PCB must be small in dimensions, while accommodating the electronic components such as the display, input buttons, power source, etc. It must be smaller than the designed case, allowing the PCB to fit within the case. It can only slightly exceed the width of the average sized wrist. The PCB must also be lightweight. These factors will make the watch more comfortable to wear on the wrist.

Functionality

The device must be capable of not only basic functionality, but it must also be capable of the unique fitness RPG features. To create this functionality, various components need to be used, such as a display, inputs, microcontroller, etc. The dimensional constraints put on the PCB limit the components that can be put on the PCB, which in turn limits the number of functions that the device is capable of. While basic watch features such as time keeping, changing the time, etc., do not require many components, the same cannot be said for the unique features that this device is capable of. The foundational aspect of the design of the device is to collect biometric data of the user as they wear the watch, and then use the collected data as a basis for the game, powering the in-game features. Several biometric components are required, and the size constraints on the PCB limit the number of biometric components that can be added, therefore limiting the number and capabilities of the features within the game.

Power Capabilities

The device must have a long battery life, ensuring that it can be used throughout the day. This can be a difficult task, as the constraints on the PCB restrict the size and weight of the battery that can be implemented. The battery used must be small to accommodate the small size of the PCB and the watchcase, and it must be lightweight, to ensure that the device is not heavy and that it is comfortable to wear, especially for longer periods of time and during physical activity. This battery must therefore be efficient in its power delivery. Features can also be added to reduce the power consumption of the battery, such as turning the display off if the user is not looking at it or if the device has not been used after a certain amount of time. Other features of the circuit design will also aid in the power efficiency of the battery, such as efficiently designed voltage regulators and utilizing electronic components that do not consume a lot of power. These measures will allow the watch to be powered for extended periods of time, allowing usage throughout the day. The user will also not have to charge the device as often, further adding to the ease of use of the watch.

Placement of Components

The restricted dimensions put on the PCB limit several factors regarding the components on the PCB. The number of electronic components that can be soldered onto the PCB is constrained, affecting the functionality and capabilities of the device. The components must be selected with caution, prioritizing the components that are most important to the core functionality of the device, such as biometric and input components. These components must also be carefully placed, to reduce the density of placed components, making sure that they do not interfere, and that heat expenditure can be reduced. There must be no wasted space on the PCB. This will ensure that the placement of the components is as efficient as possible, while taking the previously stated factors into consideration.

4.2.3 Economic Constraints

Economic design constraints are constraints which limit what can be achieved by the final project due to factors outside of the team's control. This commonly includes factors such as time and budget. These constraints are important because they inform the team of what is feasible and what is impossible for the project to achieve. Knowledge of these constraints allows the team to make the appropriate decisions in terms of scope, components, and overall goals of the project.

4.2.3.1 Time

Time is the largest economic design constraint that StepQuest faces. While there may be some leeway on other economic constraints as the factors are within the control of the team themselves, the same cannot be said about time. A time limit of only two semesters or thirty weeks is available to complete the engineering design process. This process has many steps including defining the problem, brainstorming solutions, planning, prototyping, testing, and improving. Having to rush through these steps in this limited time will determine what the team is able and unable to achieve.

As it stands, the team has one semester or fifteen weeks to define the problem, brainstorm solutions, and plan. Already the problem has been defined, solutions found, and the current project solution, StepQuest, chosen. The entirety of this document serves to plan for the project. However, planning for a project is time consuming and there are many aspects to prepare for to ensure preparedness when the time to prototype arrives.

During this short time period, the team must research and determine, standards, constraints, components, goals, objectives, milestone plans, and more. Furthermore, after these determinations are made, with consideration to how much time is allowed to prototype and test the project, components must be ordered and tested, PCB must be fully designed, printed, and tested, and software flows must be determined in advanced.

All this must occur in a short time frame with consideration that each team member is an individual attending college at UCF, possibly working a part-time job, and has family and extracurricular obligations. All of this combined serves as a constraint to what can be achieved in terms of sensors that can be implemented, game components, and the overall neatness and goals of the project.

4.2.3.2 Budget

Budget is another economic constraint that Stepquest must consider. The project team received no outside funding for the project and as such, are fully responsible for the costs of the project themselves. This impacts what technologies and sensors can be applied to the project. Currently, a roughly two-hundred-dollar budget is allocated for the project, allowing each team member to only be responsible for fifty dollars overall. However, this budget comes with complications.

StepQuest as a project requires many components and sensors. As it is a fitness wearable project, it is expected to obtain measurements such as step-count and possibly even heart rate. However, these sensors, alongside all the other components such as screens, batteries, and PCB all have their own respective cost. The imposed budget may result in components that aren't the most ideal being chosen for the project to stay within budget. Furthermore, given the cost of some sensors, particularly the heartrate monitor, it may wind up being scrapped as a feature entirely due to this constraint.

Aside from the original cost of the sensors, it must also be considered that multiple of each component are needed. Each component must be tested and the prototype, if assembled on a bread board as currently planned, will require different test-device versions of the component. This only adds to the cost of the project and makes staying within the budget a larger concern.

However, the budget isn't as harsh of a constraint as the time constraint imposed by the very nature of the project. As the budget is determined by the team itself, it would be possible to increase the budget but this comes with its own problems and complications. Not all of the students in the group have income during the year, some relying on family, federal grants, or summer internship money. As a result, increasing the budget, though it would allow for a better overall project, may not be feasible given the circumstances.

Overall, the self-imposed budget constraint will affect what components will be purchased for the project. This may lead to buying components that require more work or effort to get to the desired state. While some of this can be circumvented by adding more to the budget, this may cause unnecessary duress to team members and should be avoided unless it is absolutely necessary for the good of the project and team as a whole.

5.0 Comparison of ChatGPT

In the ever-changing modern education environment, the utilization of state-of-the-art technologies has become an integral part of the learning experience for students. One technology stands out amongst the rest. This technology is artificial intelligence, specifically chatbots. There are many artificial intelligence driven chatbots available to users, but the most common artificial intelligence chatbot amongst students and professionals, regardless of discipline, is ChatGPT. These AI driven chatbots have become a powerful tool for many people, especially students. Not only do they enhance a student's experience, for better or for worse, they allow students to do things that they have never been able to do before. While AI driven chatbots seem like science fiction, they do have their limitations. Not only in relation to students and the education environment, but also as technology. There are also several pros and cons to consider when assessing students using AI chatbots. Some that could drastically change the educational experience for students.

AI chatbots utilize the science of natural language processing and machine learning to allow for a collaborative and instructional experience. This is typically facilitated via a back-and-forth chat on a particular platform. Conversations are had with the chatbot, in which the user provides some kind of input prompt, and the AI chatbot provides some kind of output answer. These conversations are text-based conversations. For most AI chatbots, files, pictures, etc. typically are not valid inputs. The AI chatbot provides its output response in real-time, allowing for a human-like conversation. AI chatbots are capable of conversating about and teaching a wide array of topics. AI chatbots can talk about anything from technical subjects to creative analysis. Its main purpose is to output knowledge, data, and support to users, making it comparable to the world's smartest assistant.

AI chatbot platforms are a strong and versatile tool for students. AI chatbots are capable of teaching students about nearly any topic that they want to learn about. An input prompt is provided, typically in the form of a question or command, and once the AI chatbot provides its output response, the student can ask it a question about its response, a student could conduct further questioning on the topic, they could switch topics entirely, the functionality of AI chatbots are extensive. AI chatbots are also capable of basic visual output, utilizing ASCII characters to produce visuals such as graphs, diagrams, etc. A very important factor to a student's educational experience is there personal learning preferences and preferred teaching style. If the student asks the AI chatbot to respond in a certain style or manner, the AI chatbot can tailor its output responses according to the student's personal specifications.

Limitations

AI and AI chatbots have quickly flooded schools and universities, being utilized by many students around the globe. While AI chatbots can help students during their educational journey, one must identify the limitations of this technology, especially how it pertains to education. There are many restrictions and problems linked to students using AI during their education. The world of AI and AI chatbots is ever evolving and is rapidly growing, so it is not only important for students to recognize the limitations of AI chatbots, but it is also critical that teachers and institutions do too. There are several limitations of these AI chatbot platforms that are crucial to recognize. Some of which include how AI chatbots may lack depth in their output responses, students may develop a dependance on these AI chatbot platforms, they may not have the proper contextual understanding, the potential for misinformation, they may limit a student's critical thinking development, they provide limited feedback and guidance, the numerous ethical and academic integrity concerns, technical issues, and an AI chatbot’s lack of emotional intelligence.

The science behind how AI chatbots function is complex, but in broad terms, they create their output responses utilizing patterns learned from provided training data. Due to this fact, an AI chatbot cannot be relied on to produce in-depth responses. This is particularly true in complex topics. Because of this lack of depth in an AI chatbot’s output response, this could possibly negatively affect students and their education. If a student is relying on these AI chatbot platforms, possibly as their primary source of educational support, they may not be able to get in-depth answers to questions they have on a particular topic, especially if it is in a complex or specialized topic. If an AI chatbot cannot deliver, then the student would be unable to gain the specialized knowledge that they otherwise would be able to if they used more traditional education support systems, such as professors or tutors.

With the growing use of AI chatbots, especially for students, they may develop a dependance on AI chatbots as a source of education, and this can have unfortunate consequences for some students. By developing a dependance on these AI chatbot platforms for educational support, a student’s problem solving and critical thinking abilities can be negatively affected. Due to the easy accessibility and widespread use of these AI chatbot platforms, students are likely to use them, and if not used responsibly, then may develop a dependance on them. They may not realize it while they are doing it, but the AI chatbot is doing all the difficult thinking and research for them, and by not developing and growing their problem solving and critical thinking skills, these skills may considerably atrophy with time. This can be especially problematic in younger students. A younger student has had less time to train and grow their cognitive abilities, so if they are robbed of using them by using an AI chatbot, they may never gain the necessary cognitive skills that are required in higher education.

The science behind how AI chatbots work can limit their overall contextual understanding. They are limited in their circumstantial comprehension and abilities, making some received output responses low quality and irrelevant. At times, when an AI chatbot lacks a proper grasp on the contextual information that pertains to the user's subject in question, the output that the AI chatbot provides can be less than inadequate. The problem lies in the fact that the AI chatbot does not know that its response is irrelevant. Even worse, the student may not know, and the AI chatbot’s response can feed them the improper information, further hindering the student's education. If the student does not know how to fact check the specific information that the AI chatbot provides, then the student has done themselves a disservice. They will be learning and researching data that is irrelevant to the subject that they originally had questions about. This can make their educational experience more complex and cumbersome when they must make sure that the AI chatbot’s response is relevant to the subject that the student asked it about.

Current AI chatbots depend on already existing information. This can lead to AI chatbots providing incorrect or outdated data. This leads to several problems. For a student that is familiar with the subject, they may be able to fact check the AI chatbot’s output, and make sure that it is correct. If it is not correct, they likely have the necessary knowledge to figure out how to find the correct answer. For a student who is new or unfamiliar with a subject, they will probably lack the requisite background knowledge to fact check the AI chatbot. This will lead to the student receiving incorrect information, information that the student does not know is incorrect. This can bog down a student who is trying to learn about a new subject. It can make their learning and educational process slow and filled with errors. Another problem is when an AI chatbot uses outdated information as a basis for generating its response. For a student who is knowledgeable about the subject, they would likely be able to recognize that the AI chatbot’s response is outdated, but for a student who is not familiar with the subject and is new to it, they will likely not have this luxury. This can lead to gaps in a student's knowledge of a subject, gaps that they do not know are a problem.

<u>Pros</u>

AI chatbots are a relatively new subject for students. When compared to more traditional educational support methods, AI chatbots are quite immature. Regardless of this, they are a potent tool for students in their educational careers. If used properly and responsibly, AI chatbots such as ChatGPT and other similar platforms can be an important tool in a student's toolbelt. They have impressive functions and abilities that no other technology or tool provides quite like AI chatbots do. While fundamentally different, in some ways, AI chatbots are far superior to traditional educational support tools such as tutors or the internet. AI chatbots allow students to do things that they have never been able to do, providing an invaluable educational source.

One of the most impressive aspects of modern AI chatbots is the array of their knowledge. Modern AI chatbot platforms such as ChatGPT, were trained on an extensive collection of information from the internet. AI chatbots have internalized and collected information from a wide variety of sources, providing students with a way to tap into a portion of the internet's collective knowledge. AI chatbot platforms act almost as a comprehensive source of data, being some students singular source for information and education. They offer such a diverse range of information that for many students, they could learn nearly any subject they desire. Modern AI chatbots can teach students about topics about virtually any subject or topic, ranging from STEM to the arts. Access to an educational tool this powerful is extremely beneficial for students who are researching a particular subject or collecting data on a wide array of topics, where they can then utilize the information that an AI chatbot provides to both support and enhance their educational experience.

An integral part of a student's educational experience is their preferred learning and teaching style. In more traditional learning environments, a professor cannot accommodate every student's preferred learning style, as this would be impossible with even moderately sized classes, filled with diverse students. Tutors may also have this problem, if a student does not tell them or the tutor is unable to recognize what a particular student's preferred learning style is, then the student may not be learning in the ideal way. AI chatbots do have this ability to offer a learning environment that is custom to the student and can accommodate any kind of learning style, provided that the student informs the AI chatbot about their preferred learning style. An AI chatbot can adjust to a student's educational needs and preferences. This can be beneficial for students who have a unique learning style or prefer to learn in more unconventional ways. It can offer a custom set of information, delivered in a way that is tailored to an individual student's needs and preferences, making their learning experience not only more efficient for them, but also more effective.

Cons

While AI chatbots are incredibly valuable to today's students and offer a lot of advantages, they also come with several disadvantages. AI chatbots are an incredibly complex technology, and many do not properly understand the weight of damage that they can do to students, especially when used improperly or irresponsibly. One tends to hear more about the advantages of AI chatbots regarding students and their education, and they disadvantages are typically overshadowed. This is dangerous, as the disadvantages must be properly recognized, not only by students but by educators and institutions.

One of the most damaging aspects of AI chatbots is the fact that it can generate gaps in student’s knowledge and knowledge that is ultimately incorrect. Due to how AI chatbots are trained and how they gain their impressive knowledge base, they are susceptible to providing incorrect or incomplete information. The AI chatbot does not know that this is the case, it simply regurgitates information that it gathered from its training data. If a student is relying on AI chatbots as their sole source of education and learning, then they could be at a serious disadvantage. They may gain wrong information that they think is correct, have incomplete knowledge, etc. This may not be detrimental in the short term, but in the long term, it can be. If a student’s foundational information on a subject is fundamentally flawed in some way, they will not be able to properly build on top of that knowledge foundation. For a student's experience with the subject, they may not have this problem, but for a student that is not familiar with the subject, they may be unable to recognize that their foundation of knowledge is flawed. They will not know that there is a problem, and they will continue to build on a flawed foundation of knowledge, which will ultimately negatively affect their education in the long term.

An often-overlooked disadvantage of AI chatbots is for them to operate optimally, one must be skilled in prompt engineering. This is a relatively new skill, one that was introduced when AI chatbots became mainstream. Prompt engineering is the practice of forming and crafting inputs to provide AI chatbots to ensure the most optimal output. Due to the capabilities of modern AI chatbots, the input prompt must be very detailed, consisting of a particular structure to ensure that the AI recognizes the provided system instructions and exactly what the user wants. If a student is not skilled in prompt engineering, their experience with AI chatbots may be subpar, resulting in a negative association with such a powerful and valuable tool. They may be less apt to use it to support their education and learning, causing them to neglect a powerful learning tool, since other students may be utilizing AI chatbots properly and getting the upmost benefits from them.

Examples

One incredibly common use of AI chatbot platforms is to aid in programming. During senior design, students are required to create an electronic device, from start to finish, and this device is required to have a microcontroller on board. This microcontroller must be programmed in the specified programming language for the microcontroller. To program the entire repository necessary for the device to function as intended is a difficult task. It will take a long time, there will be many errors to find and fix, etc. To program this entire repository manually, using only the internet and documentation, would be a daunting task. By using an AI chatbot platform to aid in the programming process, one can make this task less daunting. Using the AI chatbot to generate small functions, find errors in a chunk of code, etc. Does not harm one's learning experience. It benefits it by allowing one to focus on the most important aspects of the project, opposed to the nuances that slow them down and impede the progress of the project.

Another usage for AI chatbot platforms is to use it to help with idea generation. This can be especially useful and beneficial for report writing. During senior design, a lengthy report needs to be written by all group members. Writing this report is a learning experience, allowing group members to better understand and internalize the project they are doing. Technical and creative writing does not come as easily to some as it does others. This can make the report writing experience quite difficult for some. By using an AI chatbot platform to aid in idea generation for report writing, the writing experience for people that have a difficult time with writing reports can be less difficult. It is unwise and unethical to copy and paste the output of these AI chatbot platforms, but to use them as a helpful guide and idea generator is a useful tool during senior design. It allows one to focus on the bigger picture of what one is writing about, instead of getting lost in the weeds and being unfocused on what pertains to what one needs to learn and understand. This therefore provides them with a better understanding of their project and a better learning experience.

Conclusions

During senior design, one will have to research many new subjects that pertain to the project they are working on. It is inevitable that one will run into a subject that they have a hard time grasping and learning about. This could lead to a lot of wasted time and energy, time and energy that could be used to research other topics, or work on other aspects of the project. By using an AI chatbot platform to aid in the researching and learning process, one can avoid this pitfall. One can use an AI chatbot to explain a topic from a different perspective, or simply explain it in a different manner, possibly one that is more tailored to them. This will benefit them by saving time and energy, and they may be able to learn more about the subject they are researching, giving them an enhanced learning experience during senior design.

10.0 Administrative Content

Below are the descriptions and accompanying tables of the administrative content that are associated with the overall research and development of the StepQuest device throughout Senior Design.

10.1 Budget

Currently, due to the scale of the project the group will be splitting the finances evenly. At this time, we do not plan to seek sponsors, but as we proceed, we may adjust this decision. Prices for items are purely for estimation purposes since we are still in the research process of which hardware we would like to go with, chip prices, PCB manufacturers, etc. Quantity currently also reflects items needed for research, and items that have not been eliminated from the realm of being used, so they will also be under continued evaluation. These quantities reflect having 2 prototypes that can be split among the group as needed. Most PCB houses require a minimum purchase of 4 boards, so some items are listed with this in mind. Tax and shipping are also not estimated, and the prices are rounded down.

Item	**Cost Per Item**	**Quantity**	**Total cost $ USD**
Microcontroller	**$10**	**2**	**20**
OLED Display	**$25**	**2**	**50**
Accelerometer	**$2**	**4**	**8**
Heart Rate Sensor	**$2.5**	**4**	**10**
LIPO Battery	**$10**	**2**	**20**
3d printer materials	**$25**	**1**	**25**
Watch band material	**$10**	**2**	**20**

Various resistors and minor components	**$5**	**1**	**5**
PCB Manufacturing	**$30**	**1**	**30**
			$188 **188/ 4 = $47 per member**

Table 21. Estimated Budget

10.2 Milestones

Senior Design 1 – Fall Semester 2023

The milestones for Senior Design 1 have been listed below, broken down into weeks as shown in Table 3.

Week #	Dates	Milestones
1	08/20 - 08/26	Form Project Group
2	08/27 - 09/02	First Group Meeting
		Determine Project Idea
3	09/03 - 09/09	Senior Design Bootcamp (09/05)
		Begin Work on Divide & Conquer
4	09/10 - 09/16	Finalize and Submit Divide & Conquer (09/14)
5	09/17 - 09/23	Attend Meeting with Dr. Wei at 4:30 PM (09/18)
		Begin Work on 60 Pages
6-10	09/24 - 10/28	Work on 60 Pages
11	10/29 - 11/04	Receive Feedback on 60 Pages
		Finalize and Submit 60 Pages (11/02)
		Purchase Necessary Materials
12	11/05 - 11/11	Begin Work on remaining 60 Pages
13-15	11/12 - 12/02	Work on Remaining 60 Pages
		Begin Testing Components
16	12/03 - 12/09	Receive Feedback on 120 Pages

		Finalize and Submit 120 pages (12/04)

Table 22. Senior Design 1 Milestones

Senior Design 2 – Spring Semester

Though the milestones for Senior Design 2 still have much to be determined, the known milestones have been broken down as shown in Table 4.

Week #	Dates	Milestones
1	01/07 - 01/13	All Necessary Materials Received
		Test Any Remaining Components
TBD	TBD	Work on Creating Prototype Device
		Work on Creating Prototype Game
TBD	TBD	Meet with Committee Members as Necessary for Revisions to Design, Requirement Specifications, etc.
TBD	TBD	Work on Final Device
		Work on Final Game
TBD	TBD	Test Device
		Test Game
TBD	TBD	Prepare for Final Presentation
TBD	TBD	Present and Conclude Project

Table 23. Senior Design 2 Milestones

10.3 Work Distributions

The work distributions for Senior Design 1 have been listed below, broken down into weeks as shown in the table below.

Responsibility	Primary Responsibility	Secondary Responsibility
Heartbeat Sensor	Spenser	Mohamed
Inputs	Mohamed	Spenser
MCU	Spenser	Mohamed

Accelerometer	Spenser	Mohamed
LCD Display	Mohamed	Spenser
Power Switch	Mohamed	Spenser
Vibration Module	Spenser	Mohamed
Battery	Mohamed	Spenser
Step Counting Algorithm	Jacey	William
Home Screen	Jacey	William
Update of Game Mechanics	William	Jacey
Accomplishment Checks	William	Jacey
Get Time	William	Jacey
ActivePoints Calculations	Jacey	William
Main Menu Features	William	Jacey
Dungeon Features	William	Jacey
Town Features	Jacey	William
Travelling Mechanics	Jacey	William

Table 24. Work Distributions

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