Solder Paste Dispenser

Sponsor:

Dr. Arthur Weeks

Group 4 Authors:

Nathan Boucher	Mikell Alfonso	Elizar Tsymlyakov	Edward Weir
Electrical Engineering	*Electrical Engineering*	*Photonic Engineering*	*Computer Engineering*

Reviewers:

Dr. Kalpathy Sundaram	ECE	*Professor*
Dr. Sean Pang	CREOL	*Professor*
Chinwendu Enyioha	ECE	*Professor*

Advisor:

Dr. Chung Yong Chan

Chapter 1 - Executive Summary

Chapter 2 - Project Description

2.1 Motivation and Background

Printed Circuit Boards (PCBs) are fundamental in a majority of modern systems. These crucial electronic components can be seen in everything from consumer applications to complex industrial equipment. From providing power distribution, enabling connectivity, and supporting the thousands of existing Micro Controller Units (MCUs) and Integrated Circuits (ICs). These components enable the modern world of technology that society has become accustomed to. However, the tools used to produce these PCBs are often out of reach unless you are a large multi-billion-dollar corporation. That is where our senior design project comes in.

Sponsored by Dr. Weeks, our goal is to modify an Ender 3 printer to dispense solder paste onto custom blank PCBs ordered by students. Previously, students had to apply the solder paste themselves, either by using stencils from manufacturers—an additional expense that often resulted in a messy process—or by manually dispensing the paste with a small dispenser tube and magnifications lens. Our proposed system will allow students to upload their PCB design files and have the solder paste automatically dispensed. Additionally, students will be able to inspect the quality of their PCBs. This solution aims to save students valuable time in the lab.

2.2 Goals and Objectives

The primary goal of this project is to build a solder paste dispenser for prototype printed circuit boards (PCBs) using an Ender 3 3D printer for reference. The main goals and objectives are listed below:

Main Goals:

- Create a solder paste dispenser utilizing the Creality Ender 3

- Implement a schematic/Gerber file upload system using a USB port and/or SD card reader
- Determine the user's PCB placement using an L-bracket and a square as the origin
- Dispense the proper amount of solder based on the uploaded schematic's required surface mount size
- Achieve an SMD package size of 0603(imperial)/1608(metric)
- Design an optical inspection system for stereo vision and magnification.
- Assemble optical magnification modules
- Use and program the Touchscreen display to provide the user with more customizability

Advanced Goals:

- Achieve more precise SMD package sizes such as 0402(imperial)/1005(metric)
- Complete the dispensing process within around ten minutes.
- Develop image processing software to allow users to export the 3D representation of the area

Stretch Goals:

- Achieve smaller SMD package sizes such as 0201(imperial)/0603(metric) - 01005(imperial)/0402(metric)
- Implement a pick-and-place system to grab components and place them on the newly dispensed solder paste
- Set up additional sensors or camera vision to help determine the origin point and structure of more uniquely shaped PCB designs (circular, L-shaped, etc.)
- Establish Wi-Fi or Bluetooth modules for schematic upload option and 3D model exports

Objectives:

Main Goal Objectives:

Despite solder past dispensers bearing many similarities to a 3D printer, the project must be differentiated enough for it to consider all of the design requirements of Senior Design. For the main goal objectives, a custom PCB will have to be CAD-designed and printed along with custom software that must be programmed into the selected microcontroller. The custom PCB will include redesigned industry motor drivers, stepper motors, a power source, and a microcontroller. Alongside the software, there will be a schematic file upload system using an external USB port and/or an SD card reader that is connected to the microcontroller on the custom PCB. The device will be able to locate where the user has placed their own prototype PCB within the dispensing area by utilizing an L-bracket to set its origin point. Based on the user's uploaded schematic, the stepper motors will be activated to help the nozzle navigate and dispense the proper amount of solder paste. The main SMD package size that the team is trying to achieve is 0603(imperial) / 1608(metric), which equates to 1.6mm x 0.8mm. The team also seeks to prioritize the design of an optical inspection system that utilizes magnification and stereoscopy to create a 3D representation of the prototype PCB and the dispensing area. The team plans to make this controllable via a touchscreen display that will present all of this information.

Advanced Goal Objectives:

One of the more technically complex objectives that the team is planning to deliver includes achieving a smaller SMD package size of 0402(imperial) / 1005(metric), which equates to 1.0mm x 0.5mm. The dispensing time would ideally be under ten minutes, this is a task that must be tested and optimized after fulfilling the main goals and objectives. The aforementioned optical inspection system would also need software to be able to generate and export the 3D representation of the prototype PCB and dispensing area. This would be done on the same USB or SD card that the user initially inserted for the purpose of uploading their schematic.

Stretch Goal Objectives:

Upon completion of the main and advanced objectives, the stretch objectives would include achieving an even smaller SMD package size anywhere from 0201(imperial) / 0603(metric) to 01005(imperial)/0402(metric), which respectively equates to 0.6mm x 0.3mm and 0.4mm x 0.2mm. Alongside the higher precision, an additional feature that would expand the purpose of the solder paste dispenser is a pick and place system. This system would be able to utilize a pump that would pick up components that the user plans on placing on their prototype PCB. Since the schematic for the PCB would already be uploaded, the pick pump would then place the components on the newly dispensed solder paste. The stereoscopy system would also be expanded upon with additional cameras or sensors in order to determine the structure and origin points of more uniquely shaped PCB's. This would allow the solder paste dispenser to accurately operate on a wider range of PCB's. Finally, the team would attempt to utilize the Wi-Fi and Bluetooth modules on the selected microcontroller for prototype PCB schematic uploads. This would extend the user's options for uploading to include USB port, SD card reader, Wi-Fi support, and Bluetooth support. The 3D representation of the prototype PCB could also be exported to the user via Wi-Fi or Bluetooth upon realization.

The purpose of the Solder Paste Dispenser project is for this to be utilized within the Senior Design laboratory once the team has completed it. This machine will help other, future senior design students assemble their own prototype PCBs at the University of Central Florida. The team wants to provide a simple and cheap alternative for putting together PCBs through the use of precise stepper motors, rather than going through the strenuous process of applying solder paste by hand and squeegeeing out the excess amount. Ideally, the Solder Paste Dispenser would be able to dispense all the necessary solder paste within around ten minutes for a single PCB and allow students to inspect and verify the quality of their PCBs.

2.3 Features and Functionality

The SPD team aims to rebuild and modify an Ender 3D printer for the purpose of dispensing solder paste onto custom PCBs. The rebuilt printer will have a variety of features and functionalities used for operation, design inspection and verification.

2.3.1 General Operation

To operate the SPD, the user will upload a Gerber file of their custom PCB to the printer. This will be done using a USB or an SD card. The software will take the custom PCB Gerber file and convert the location information on the file into movements that will be communicated to the printer. After positioning the PCB, the user will interface with a touchscreen to command the printer to begin. Using the touchscreen, users will be able to start the printer, upload and select files, move the head of the printer manually, and export files to the connected SD card or USB stick.

To ensure the printer can determine the location of the custom PCB, PCBs will be slotted into an L-bracket. The printer's movements will all be relative to the origin established by this L-bracket.

To prevent the PCB from slipping and moving during solder dispensing, a rubber mat will be used to provide grip. This will hold the custom PCB in place and prevent errors in dispensing.

2.3.2 Design Inspection and Verification Features

For PCB design inspection and verification, the SPD will include two sensors equipped with optics mounted on the dispenser. This enables the user to check the quality of dispensing with a magnified image. This optical system will also include an image processing system to produce a stereoscopic 3D representation of the imaged area. The user can then export this file to a 3D modeler. This provides the user with the tools to inspect their custom PCBs.

2.4 Existing Products

2.4.1 Screen/Stencil Printers

The solder paste screen/stencil printer was one of the first machines in the assembly line for the Surface Mount Technology Industry creating a major impact in the commercial space. The screen printer with the use of a metal stencil enables automation of equally distributing solder paste on PCB (Printed Circuit Board) pads evenly and ready for pick and place machines which place surface components on the PCB.

The solder paste screen printers place and align a PCB and etched metal stencil with the stencil on top. Then, a squeegee comes across pushing solder paste at around a sixty-degree angle moving back and forth on top of the stencil to evenly distribute solder paste on the PCB pads. The squeegee is pulled back and the stencil is lifted off the PCB. The PCB is moved out of the way for another PCB to be printed on next.

MPM has a very accurate screen printer, the Edison II ACT Stencil Printer. Its wet print reliability is high, +/- fifteen microns and greater than or equal to 2 Cpk (Process Capability Index) at six-sigma. The printer is high-speed and has short cycle times leading to a higher output of PCBs ready for pick and place machines.

The YRP10 screen printer is made by Yamaha. The wet print reliability for the screen printer is like the Edison II ACT Stencil Printer, +/- sixteen microns and greater than or equal to 2 Cpk at six-sigma. It features a dual-lane setup as each machine has two separate parallel conveyor belts, the printing belt, and the pass-through belt. If two machines are placed with belts in line and the fronts are in opposite directions, then two printing lanes can be made to increase print production. The squeegee head's attack angle can be modified as well. It also features a stencil vacuum which presses the stencil to the PCB for a more accurate print.

The Momentum II Elite Stencil Printer is another MPM screen printer. Its wet print reliability is high, +/- twenty microns and greater than or equal to 2 Cpk (Process Capability Index) at six-sigma. This is worse than the other two mentioned, but it has many features. The printer includes triple-track processing which means that while it is processing/printing on one PCB then the previous PCB is being offloaded and another one is being loaded to increase throughput. It also has AccuCheck Print Capability Verification which is very useful as it can continuously monitor and measure the print capability of the machine. Another great feature is the vision and inspection system which verifies the printer is working accurately and that the printer is giving great results.

The process of stencil/screen printing is very effective but still has some challenging problems. Some of the difficulties include scooping, bleeding, bridging, and peaking. These issues refer to different ways solder paste is misplaced where too little or extra amounts of solder paste are left on the PCB. They come about more frequently in stencil/screen printing. The issues can be mitigated by a different solution.

2.4.2 Jet Printers

Jet printing arrived after screen printing to help make the solder paste placement process easier and faster. Jet printers take a PCB's Gerber file to make a map of the PCB's pads. Then, motors move a nozzle over each pad systematically to inject solder paste without the use of a stencil. After, the next PCB inline is printed.

Essemtec made the Archerfish which is another jet printer. It is very fast and can place solder paste dots as fast as seven hundred twenty thousand dots per hour and the minimum dot size possible is two hundred micron. The jet printer also comes with the capability of glue jetting and is its own pick-and-place machine. A system in place in the machine monitors solder paste sizing by volume and weight.

Voltera's all-in-one PCB manufacturing and assembly machine, the Voltera V-One, provides consumers with a fast way to manufacture, assemble, and prototype custom PCBs. The machine can drill vias/holes and draw traces removing the need to outsource PCB manufacturing. It also features a heat reflow bed eliminating the need to use an oven to reflow the solder after assembly. However, the V-One does not offer any functionality for design inspection and verification. 1e

2.4.3 Summary: Application of Solder

After looking at how these printers work, we will be taking more away from how jet printers work in our designs. There are features we are looking to emulate from jet printers. These features include using a Gerber file to map the PCB pads and using motors and a nozzle to dispense the solder paste. Utilizing the Gerber file makes our design user-friendly. It is user-friendly because when a PCB is designed the Gerber file is made which includes all the information a PCB manufacturer would need including the PCB's pad's locations and size. Also, dispensing solder paste from a nozzle that is controlled by motors will lead to a cheaper and cleaner process. Without this design choice, the alternative is having extra costs for the purchase of a stencil and a messy process of applying solder paste to the PCB pads.

2.4.4 Existing Optical Inspection Systems

In general, optical inspection systems are systems that include sensors, lenses and sometimes optomechanical parts for variable magnification. They are used for general inspection tasks. All these products take advantage of digital magnification and sometimes include magnification optics as well. The following paragraphs will look at three different optical inspection systems.

EVOTIS by *Vision Engineering*

EVOTIS by Vision Engineering is an optical inspection system that provides methodical inspection of critical PCBs. The system offers 3-765x magnification using optical and digital. It features a monitor for viewing. The system has a 360-

degree 3D stereo rotating viewer that can capture every detail from every angle efficiently. The system features easy switchable white and UV lights for inspections. It can handle a maximum board size of 460 mm x 460 mm. The EVOTIS system is a versatile, capable system for careful inspection of critical PCBs.

Macro Vue Eidos by *Aven Tools*

The line of Macro Vue Eidos Inspection Systems by Aven Tools are robust digital inspection systems. These systems feature a 1920 x 1080 resolution FULL HD Panasonic 1/2.8" sensor with 3.5x to 35.5x magnification. It features LED lighting with brightness control and a monitor for viewing. These systems do not feature any sort of stereo vision system. It also features a built-in SD card port for easy image capture, as well as USB for computer connectivity. The system costs $2,347.26.

W30 EasyView 4K Inspection System by *Optilia*

The W30 EasyView 4K Inspection System offers first class inspection. It features a 30x optical zoom with fast and responsive auto focus. It features a 720p sensor and comes with built in illumination. It does not come with a monitor, but as a port to connect a monitor. To maneuver the camera, the user utilizes a joystick. The system varies in price depending on optional upgrades but ranges from $5000 - $7000.

2.5 Required Specifications

Board Handling	
Maximum Board Size ($\hat{x}$ x $\hat{y}$)	8" x 8" / (203.2mm x 203.2mm)
Minimum Board Size ($\hat{x}$ x $\hat{y}$)	1" x 1" / (25.4mm x 25.4mm)
Board Securing Method	Rubber mat
Touchscreen	
Touchscreen Reactiveness	Registers 95% of light touches
Print Parameters	
Maximum Print Area ($\hat{x}$ x $\hat{y}$)	200 mm x 200 mm
Solder Dispensing Resolution*	0.2 mm
Minimum Surface Mount Size	0603 (imperial) 1608 (metric)
Dispenser Head Movement Resolution ($\hat{x}$ x $\hat{y}$ x $\hat{z}$)	0.1 mm
Optical System	
Target Magnification*	1.1x

Minimum Surface Mount Size for Imaging	0603 (imperial) 1608 (metric)
Stereoscopic Height Resolution	0.1 mm
Facilities	
Power Requirements	120V AC
Machine Dimensions ($\hat{x}$ x $\hat{y}$ x $\hat{z}$)	45 cm x 45 cm x 50 cm

Table 2.5.1 *Required Specifications*

*Demonstratable

2.6 Hardware Block Diagram

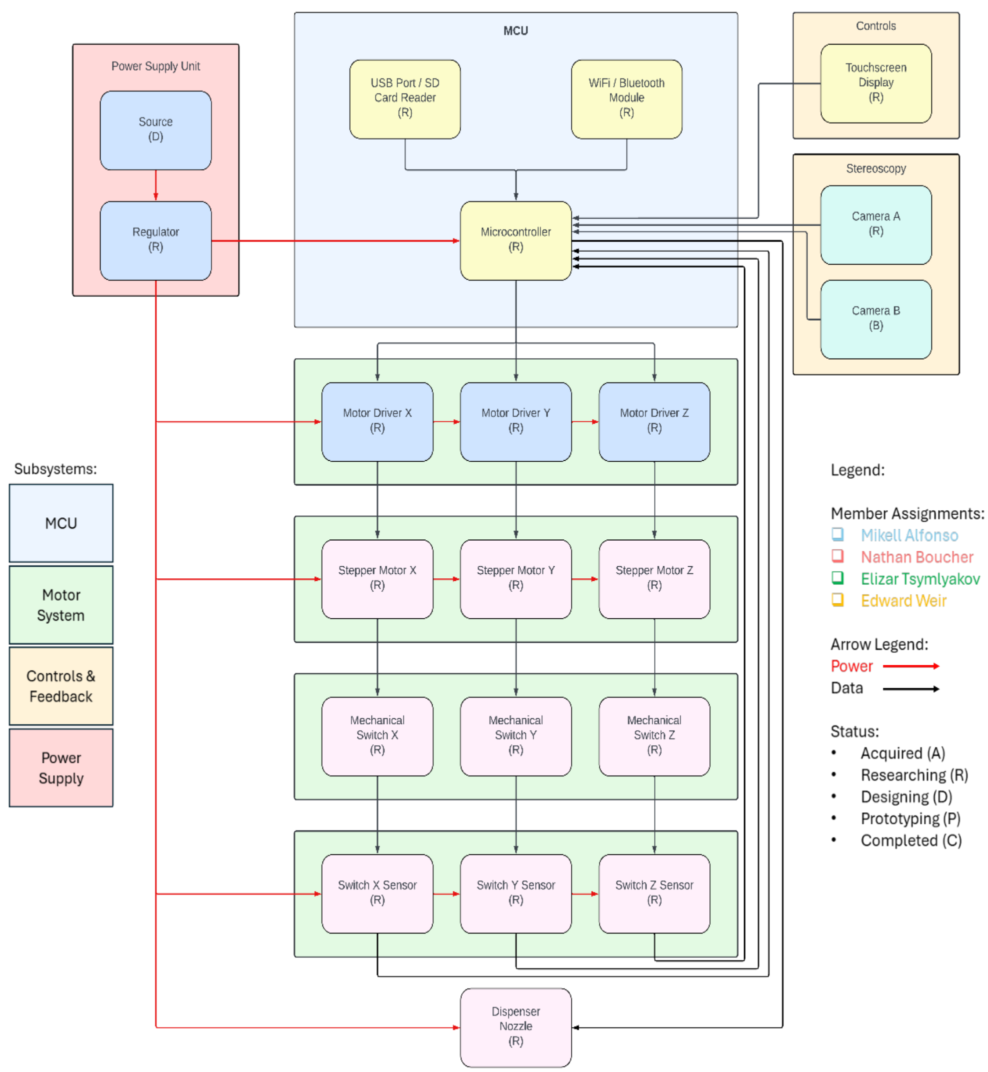

Figure 2.6.1 *Hardware Block Diagram*

2.7 Software Flowchart

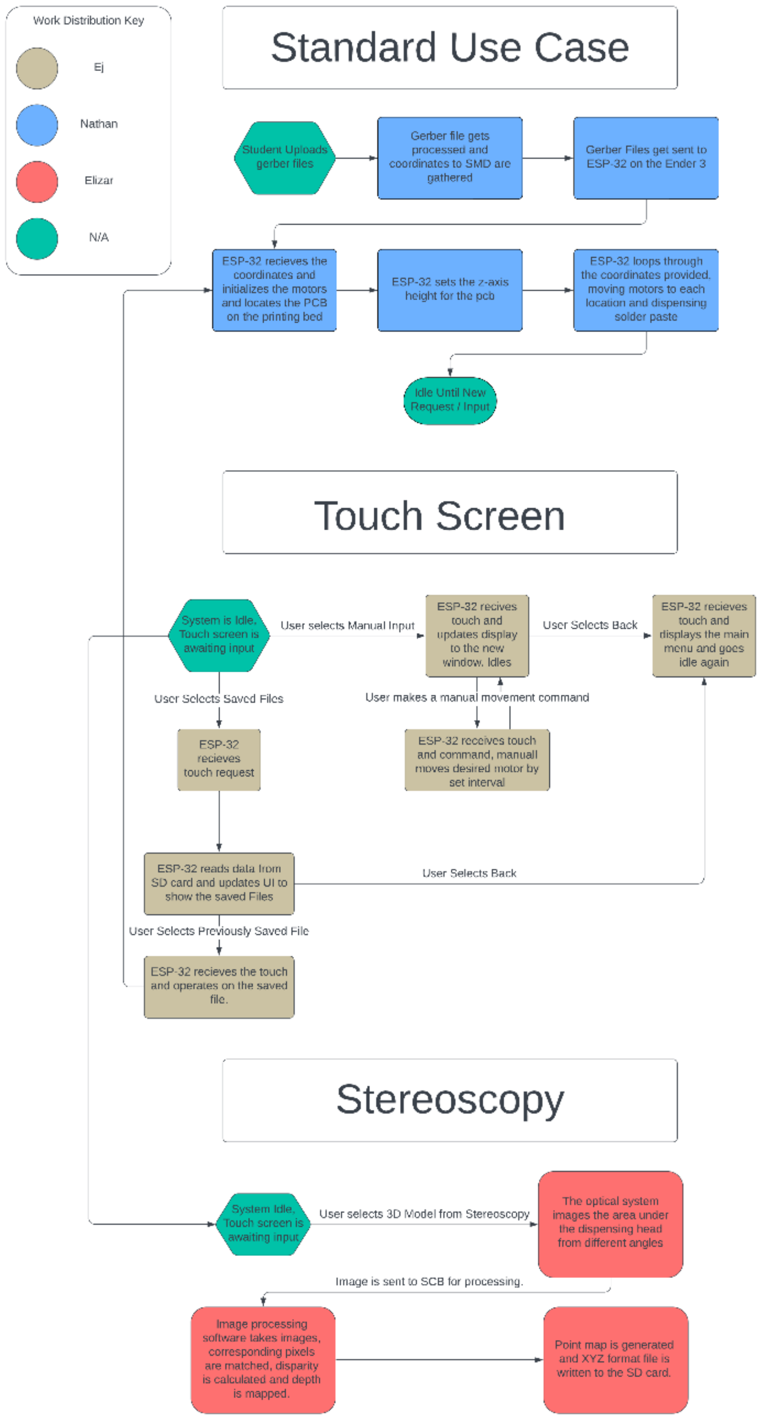

Figure 2.7.1 *Software Flowchart*

2.8 Optical Diagram and Design Requirements

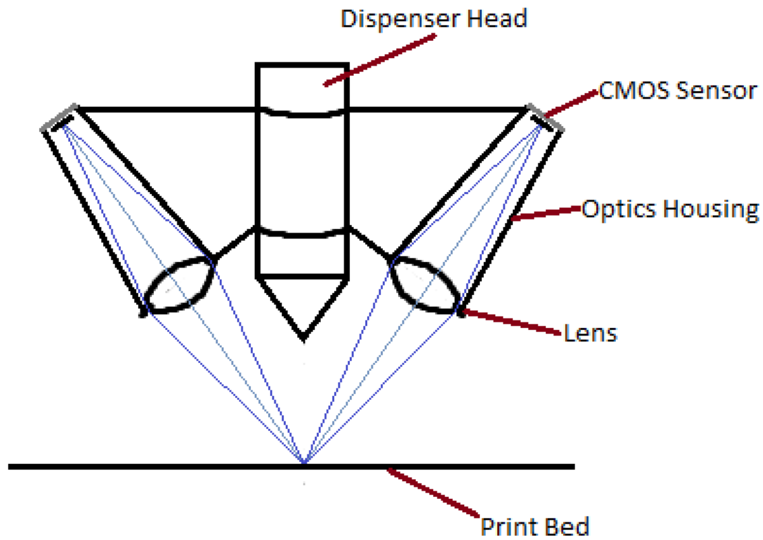

Figure 2.8.1 *General view of the optical system.*

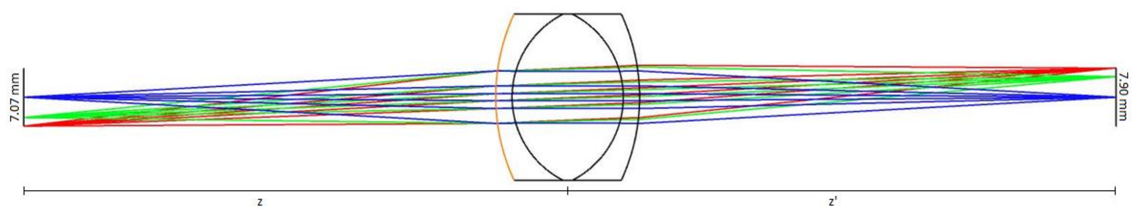

Figure 2.8.2 *Optical diagram of one assembly.*

2.8.3 Optical Design Requirements

This optical system must be designed with an image area of 5 mm x 5 mm (7.07 mm diagonal) and the proper magnification to cover the selected sensor adequately. The necessary magnification will be determined by taking the ratio of the diagonal lengths of the image area and sensor area: M = (sensor diagonal) / (image diagonal). For our current selection, we have a sensor with a diagonal of 7.9 mm. To cover the sensor adequately, we need the magnification to be ~1.1x.

To reduce cost and manufacturing complexity, imaging and magnification will be achieved using a single lens. The lens will collect and focus the light onto the sensor and the magnification obtained depends on the distance between the object and the lens (z) relative to the distance between the lens and the image (z’) where M = z’/z. So, z’ = 1.1 * z.

To achieve stereo imaging, two identical camera modules will be placed at a distance apart and at an angle such that they image the same location but from two different perspectives. The angle of viewing between the cameras, β, will be determined by the object distance and the distance between the lenses of the magnification modules, which depends on the thickness of the dispenser head. The optimal angle of the cameras relative to the baseline is 60-80 degrees.

2.9 House of Quality

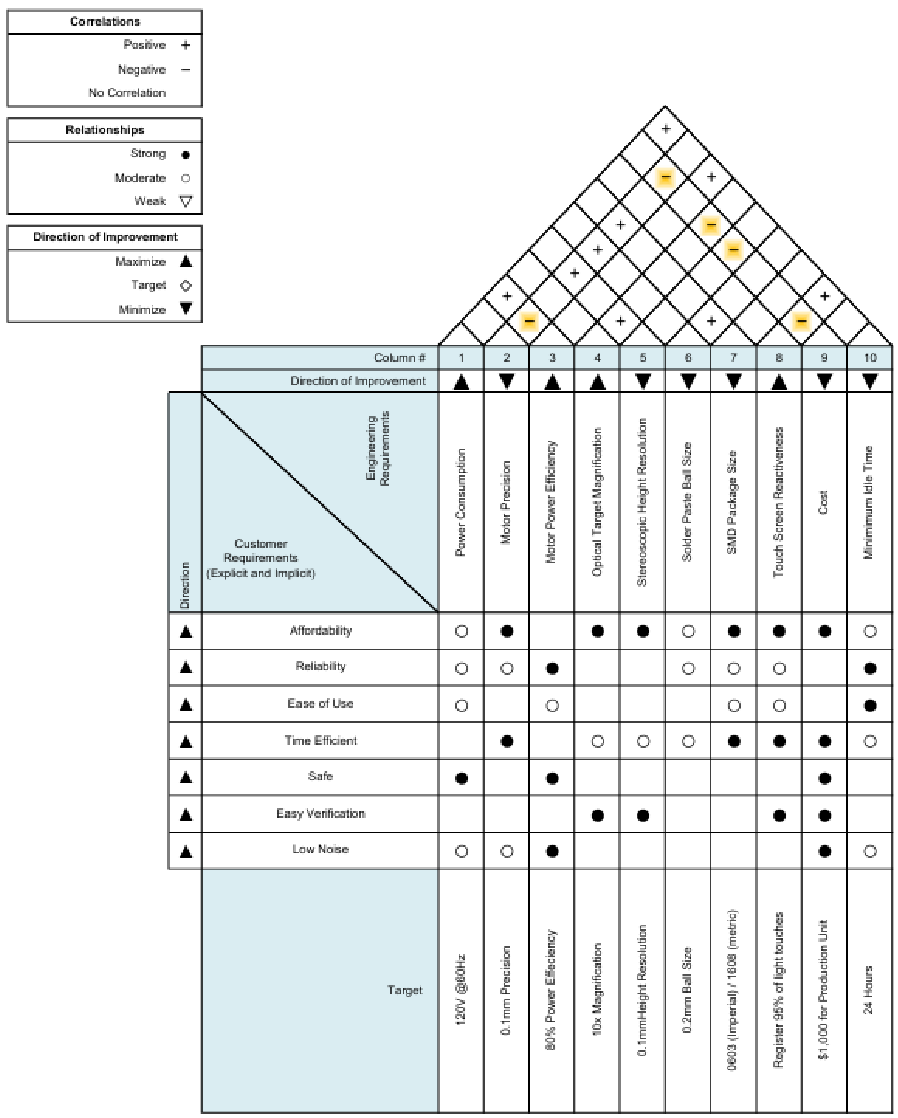

Figure 2.9.1 *House of Quality*

Chapter 3 – Research and Investigation

3.1 Technology Comparison and Selection

3.1 Displays

For the embedded system in our project, we will need some way to control the printer, select which PCB file to print solder on, and overall control the machine. Using a display is a great way to interact and control the printer. There are a multitude of considerations to look over when choosing a display.

3.1.1 Resistive vs Capacitive Touch Screen Displays

Resistive and capacitive touch screens are commonly used in embedded projects. The touch screens both have their own advantages and disadvantages. Capacitive touch screens allow for multiple touches to be registered simultaneously where only one touch can be registered for a resistive touch screen. Resistive touch screens are cheaper to make than capacitive ones so resistive ones have a lower cost. Capacitive touch screens have a glass outer layer whereas resistive touch screens have an outer layer consisting of a plastic film. A glass layer is going to last longer than a plastic layer as the glass layer is more resistant to scratches and fogging up after being used for a long time. Resistive touch screens can be used without direct conductive contact because they register touches based on force whereas a capacitive one needs conductive contact like a stylus or finger (depending on the model) for a touch to be registered.

For the uses of the project, a capacitive touch screen is going to be better than a resistive touch screen when comparing the trade-offs. The users are most likely to not be wearing something to prevent the use of a stylus or their finger from manipulating the touch screen. Also, even though the cost of the resistive touch screen is less, the price increase for the capacitive touch screen is worth it because the glass outer layer of the capacitive touch screen will allow for longer use without having to replace the screen and the multi-touch capability of a capacitive touch screen allows for more unique and seamless use of the touch screen.

3.1.2 SPI vs I2C

SPI (Serial Peripheral Interface) and I2C (Inter-Integrated Circuit) are used to allow a display to communicate with a microcontroller. Both of these communication protocols have their benefits and drawbacks.

I2C makes use of two pins, a serial data pin and a serial clock pin, to connect the microcontroller to the display and the display will be given a unique address. The unique address is used so that devices connected to the I2C bus can identify if they are the ones being communicated with by the microcontroller. So, if more than one device needs to be connected over I2C then the devices will connect to the same two pins, and each will be given a unique address for themselves. The advantage here for I2C is that only two pins are needed in this simplistic design when connecting any number of devices to the bus. Needing only two pins for I2C is an advantage because it frees up more pins on the microcontroller for other purposes and makes adding on more devices using the same protocol relatively easy to accomplish. The disadvantage of I2C is that it works in half-duplex which means lower speeds. In half-duplex, information cannot be sent both ways simultaneously. The microcontroller would have to send data to the display, then afterward the display could finally send information back to the microcontroller.

SPI uses four pins which are the MISO (Master In, Slave Out) pin, the MOSI (Master Out, Slave In) pin, the serial clock pin, and the chip select pin. The MISO pin allows one-way data transfers from the display to the microcontroller, and the MOSI pin is the opposite as it allows one-way data transfer from the microcontroller to the display. The serial clock keeps both devices that are connected synchronized and the chip select pin signals if data can be transferred between the MISO and MOSI pins. If another device is to be added there are two ways to go about it. The first way is to make each device connected to the microcontroller use the same pins except each gets an individual chip select pin, so then the microcontroller will determine which device is being communicated with. The second way is that the devices and microcontroller are connected in a daisy chain with the MISO and MOSI pins, and they all share the same chip select pin and serial clock pin. The disadvantage of SPI is the extra pins needed for communication because it takes up more resources for the microcontroller.

The SPI protocol's advantage though is that the separate one-way data pins, MISO and MOSI, mean that it is full-duplex. With full-duplex, the device and the microcontroller can communicate with each other simultaneously over the MISO and MOSI pins.

I2C works great for devices that are simple and do not require high speeds. When considering the device that will be used in the project is a display, SPI is going to be the better choice over I2C. After all, it is faster with a full-duplex design which gives speeds at ten megabits per second or more whereas I2C is limited to the usual four hundred kilobits per second or at the high end five megabits per second in Ultra Fast mode because it runs in half-duplex. The faster speeds from SPI will allow the display to refresh quicker and be much more responsive, giving users a better experience when interacting with the printer. With the high speeds of SPI, there is the downside that more pins will be used but that is a trade-off that needs to be made to give the users a user-friendly interface.

3.1.3 Display Controllers

The display controller is the most crucial part of the display. It is the middleman for the microcontroller, to control each individual pixel on the display. There are many display controllers that can be considered for the project, but that large list can be shortened by the previous two sections reviewing where capacitive and resistive touch displays are compared, and where the communication protocols SPI and I2C are compared. Also, it is important to pick the right display controller as it also determines other properties of the display module like the size of the display that can be used. The top options I believe need to be compared are the ST7789, the ILI9488, and the ILI9341.

They all have some similar characteristics. To interface with a microcontroller, they have two ways which are in parallel or serial. For the parallel bus, they use the 8080 bus type and the bus sizes possible are eight-bit, sixteen-bit, or eighteen-bit. For the serial bus, it uses SPI either on a four-wire or three-wire. Each controller also has an on-chip frame buffer which helps prevent screen tearing which is a problem where one frame will start to load before another frame is finished loading so it visually looks like the screen is tearing in two from the user's perspective.

3.1.4 ST7789

The ST7789 has a resolution of two hundred forty by three hundred twenty pixels. It supports a color depth of two hundred two thousand colors using eighteen bits per pixel.

3.1.6 ILI9341 and ILI9488

3.1.7 Display Comparison Table

	ST7789	ILI9341	ILI9488
Parallel Interface (bit)	8, 16, 18	8, 16, 18	8, 16, 18, 24
SPI Interface	Yes	Yes	Yes
Frame Buffer	Yes	Yes	Yes
Cost ($)			
Back Light Control			
Color Depth			
Resolution (pixels)			
Screen Size (inches)			

3.1.8 Summary

Compare and decide on Display.

3.2 Motor Controls

To control the motors accurately within our printer, we must make important design considerations on the motors, motor drivers, and software considerations. All these elements come together to ensure proper motor controls are required to meet our requirements. In order to move the printing nozzle as needed, our software must control outputs to pins connected to the Stepper Motor Drivers, which in return use those signals in order to control the power to the Stepper Motors themselves.

3.2.1 Stepper Motors

The Stepper Motor is the physical motor used to control the printer. These motors are designed to allow the user to control the motor's movement by sending pulses that correspond to the number of "steps" the motor should take. Stepper Motors are classified by both their size and degrees per step. This is the amount the head at the end of the motor rotates per each step. Note that many drivers are allowed to send Micro Steps to the motor. This breaks up each step into fractions allowing for more precise control.

3.2.2 Stepper Motor Drivers

Due to the nature of stepper motors requiring a large voltage (typically 8 Volts – 35 Volts) with a nominal current of at least 1 Amp, hooking up a microcontroller directly to a high volt line is not recommended. Thus, an IC or a circuit is required for the microcontroller to control the board indirectly. It is an industry standard to use specialty boards designed specifically for Stepper Motors, these are the "Stepper Motor Drivers". These specialty boards control specific ICs and other components designed specifically to control Stepper Motors. It is common for these boards to provide additional functionality such as micro stepping, sleep pins, current limits, reset pins, heat distribution, and other functionalities that are helpful for motor controls.

In this section we will look at a few of the most popular options to compare. Each board will have a brief description as well as pros and cons to ensure we are selecting the most viable driver board. Each of these boards is named based on the IC used, note that there are some different versions of each board that have some small changes.

3.2.2.1 A4988

The Allegro A4988 is a Stepper Motor Driver that has been prominent in the industry since 2019. It is a bipolar stepping motor, allowing it to use all of the coils within the stepper motor itself for efficient driving. This board offers three MicroStep resolution pins, allowing for 5 micro stepping resolutions: 1,1/2,1/4,1/8 , and 1/16. It operates the motor itself using an input voltage of 8 Volts – 35 Volts and can be rated for up to 2 Amps with proper cooling (Most manufactures include a heatsink for the IC itself). It includes a potentiometer on board allowing in order to set a maximum current. It also includes an Over-temperature thermal shutdown, under-voltage lockout, and crossover-current protection in order to increase reliability. This motor movement is controlled by two-pins, using a STEP + DIR controls in order to ensure proper movement.

3.2.2.2 DRV8825

The Texas Instruments' DRV8825 is another bipolar stepper motor that was released in January of 2021. It operates the Stepper Motor by using an input motor power supply of 8.2 Volts – 45 Volts. It supports six microstepping resolutions from 1 to 1/32 of a step, allowing for more precision. The MCU controls the microstepping resolution through 3 pins connected to the DRV8825. It contains a 4-layer 2 oz copper PCB for improved heat dissipation. It has a potentiometer used to set the maximum current and supports a maximum current of 2.2 Amps (Assuming proper cooling). It also provides Over-temperature thermal shutdown, over-current shutdown, and under-voltage lockout.

3.2.2.3 TMC2225

The Analog Devices TMC2225 is a newer Stepper motor driver that is classified as a "ultra-silent" motor driver. It is specifically optimized to be one of the quietest motor drivers on the market. It supports Microstepping of up to 1/256 by utilizing a technology called "MicroPlyer Interpolation". Which interpolates the time between two step impulses on the Step Pin, and breaks it apart into 256 equal microsteps. The TMC2225 operates on a voltage input of 4.75V-36V, and a logic high voltage of 3.3V-5V. It supports a max current of 2A per coil.

3.2.2.4 Table Comparison of Stepper Motor Drivers

	A4988	**DRV8825**	**TMC2225**
MicroStepping Resolution	1/16	1/32	1/256
GPIO Pins Required (Minimum configuration)	2 (Step + Dir)	2 (Step + Dir)	2 (Step + Dir)
Voltage Input (DC)	8V-35V	8.2V-45V	4.75V-36V
Logic Voltage Level (High)	3V-5.5V	2.2V-5.25V	3.3V-5V
Max Current	2A	2.2A	2A
Price per single unit (For the IC, not full board)	$4.25	$5.73	$5.61

3.2.3 Stepper Motor Control Libraries

One benefit of using the Arduino framework with our microcontroller is the access to a large quantity of open-source libraries. Many libraries are developed by individuals and teams and are published to be imported into projects. Many of these libraries provide a stepper motor class that allows us to initialize our GPIO pins accurately, and to control the output to those pins as needed to move the motors.

There are many design considerations to look at when selecting a library. This includes access to documentation, ease of use, functionality, and reliability. When selecting a library, we want to have access to the documentation required to efficiently write the code needed to perform the functions required.

3.2.3.1 Stepper by Arduino

This is the official Arduino Stepper Library. This library provides a single parent class containing three main methods (besides the constructors). These three methods are setSpeed, step, and stepMotor. The constructor allows for the initialization of both two and four-pin motor drivers. Allowing for control of a large variety of boards. Set Speed allows the rotation per minute (RPM) to be set for the motor. Both the stepMotor and Step functions move the motor forward or backward a specific number of steps.

This library being the official Arduino library provides some credibility. It also has a document page on the Arduino website itself including some documentation on each method. However, not all methods are covered in this site. The source code has great comments making it easy to follow and intuitively understand. However, this library is limited in functionality. It provides only the most basic methods to be used. And calibration and code would need to be written to calculate the distance moved per rotation.

3.2.3.2 StepperDriver by Laurentiu Badea

This is a commonly used library for stepper motor drivers with 4,700+ downloads on Platform IO. It offers driver specific classes that are derived from the same parent class for basic stepper motor usage. It provides controls for two-pin motors that use STEP+DIR pins to control the motors. It also has some native support for Micro Stepping pins. It does provide some documentation however, it is limited to a single readme on GitHub as well some example files showing separate use cases.

It provides a variety of methods such as move, rotate, setSpeed, startRotate, calcStepPulse, and more. It's main movement is based per step, which will require some calibration in order to get the right amount of steps/mm, in order to guarantee we can move a set distance within the margin of error from our requirements.

This library overall provides a large variety of functionality. As well as specific classes for the A4988, DRV8834, and more. This allows for full control of all pins that are needed to connect to the Driver itself.

3.2.3.3 Design a Library Ourselves

An alternative approach is to develop a custom library or set of classes tailored specifically to our requirements. This provides maximum configurability, allowing us to design functions that precisely meet our needs. For instance, we can implement movement functions that accept the required distances, enabling us to directly translate values from Gerber files and efficiently move between surface-mount devices (SMDs). Additionally, a custom library would enable better integration of motor control, allowing us to synchronize multiple motors to position the nozzle accurately during operation.

However, the downside to creating a custom library is the significant time investment required for development and debugging. While it offers the highest degree of flexibility, this approach may delay progress compared to using an existing open-source library, which provides readily available functionality and minimizes the effort required for initial implementation.

3.2.3.4 Table Comparison Between Libraries Available

	Stepper By Arduino	**StepperDriver By Badea**	**Custom Library**
Driver Specific Classes	No	Yes	N/A
#-Pin Motor Support	2 and 4 Pin Motors	2 Pin Motors	N/A
Number of methods provided	3	19+	N/A

Commented Code	Yes	Yes	N/A
Documentation	Yes	Yes	N/A

3.3 Microcontroller Unit Selection

The Microcontroller Unit (MCU) will be the brain of our project. It will control the movements of the motors, sense the edge of the printing bed from the switches, create a display on the TFT touchscreen and react to user touch, and monitor the status of each job. Without a functioning MCU there will be no functioning design, just a mechanical shell. The most important factors that are required to be researched when selecting an MCU are: number of GPIO Pins, number of ADC Pins, touch capacitive capability, amount of memory, low-power options, wireless connectivity options, CPU frequency, and the number of cores.

Having a sufficient number of GPIO pins is essential in order to control all devices, with enough of these being connected to the MCU's internal ADCs in order to read and parse data from analog signals, for example being able to sense touching on the touchscreen. Memory is another important aspect as our project has many moving parts, we need enough memory to store all of our applications data. Low-power options allows us to keep our device running efficiently, especially while in a sleep or inactive mode. Wireless connectivity will allow our design to be able to communicate to other devices easily. The CPU frequency relates to the number of clock cycles the CPU runs within a given second. Having a higher frequency allows for faster operation and processing. Likewise having multiple cores allows the MCU to run multiple options in parallel, increasing our designs computing speeds.

3.3.1 ESP32-S3-Mini-1

The ESP32-S3-Mini-1 is part of the ESP32 family of Microcontrollers by Espressif. The ESP32 series is one of the most widely renowned series of MCUs. The ESP32-S3-Mini-1 (Referred to as the S3-Mini-1) is a dual-core 32-bit processor. Having a dual-core processor allows for two processes to be run simultaneously. The S3-Mini-1 runs at a frequency of up to 240MHz and has an integrated 40MHz crystal oscillator used to provide an alternative clock cycle for peripherals. The Mini-1 version (opposed to the Mini-1U) comes with an integrated PCB antenna that supports 2.4GHz Wi-Fi (802.11 b/g/n) and Bluetooth

5 Low-Energy (LE). It supports a Wi-Fi bit rate of up to 150 Mbps and a Bluetooth speed of up to 2Mbps. It operates on voltage supply of 3.0V-3.6V.

The S3-Mini-1 comes with 39 GPIO pins supporting SPI, LCD interface, Camera interface, UART, I2C, I2S, PWM, USB 2.0, USB JTAG Controller, ADC, touch sensor, and more. This allows for a wide-variety of peripherals that can be controlled by the S3-Mini-1.

3.3.2 MSP430F6459

The MSP430F6459 is part of Texas Instrument's MSP430 series of microcontrollers. It is an ultra-low-power microcontroller with a 16-bit Reduced Instruction Set Computer (RISC) CPU. It operates on a frequency of 20MHz, and is has a single-core. The MSP430F6459 comes with 512 kBytes of non-volatile memory and 66 kBytes of traditional RAM (volatile memory). It comes with a 12-bit Successive Approximation (SAR) ADC, that has 12 channels allowing for lots of peripherals to utilize. It has 74 GPIO pins. These GPIO pins has 3 pins for UART, 3 pins for I2C, 6 pins for SPI, and 4 16-bit timers. It operates on a low supply voltage of 1.8V-3.6V, and natively supports a standby mode in order to be energy efficient while waiting for tasking. It also supports a USB serial bus, allowing for easy flashing and communication with other devices. However, it does not natively come with any support for wireless communication, an additional IC will be required to support wireless communication such as Wi-Fi and Bluetooth. At a price of $11.929 it is an affordable option.

3.3.3 RP2350B

The RP2350 is a series of microcontrollers by Raspberry Pi. Raspberry Pi is notorious for it's development boards used by engineering enthusiasts around the world. It is a dual-core, dual-architecture microcontroller. The dual-architecture allows the microcontroller to either run on RISC-V, or as an ARM processor. It operates on a frequency of 150MHz allowing for fast operations and computations. The RP2350B offers 48 GPIO pins, 8 analogue inputs (pins directed towards an ADC), and 2 MB of internal flash memory. With 520Kbytes of on-chip Static random-access memory (SRAM) it can run bulky programs. It supports a variety of peripherals including of up to 2 UART, 2 x SPI controllers, 24 Pulse-Width Modulation (PWM), 1 USB 1.1 controller, and 12 peripheral

Input/Output (PIO) state machines. The RP2350B requires a voltage input of 2.7V-5.5V which route to the internal voltage regulator within the chip. It also supports Serial Wire Debug (SWD) which is a two-pin protocol that allows debugging, pausing, and tracing through a serial interface. This requires less pins than a traditional JTAG, and offers faster debugging speeds.

3.4 MCU Software Environment

The Software Environment encompasses the process of developing, compiling, and deploying the code for the project. Having an efficient environment allows for a decrease in time associated with deploying and debugging. There are a variety of features to look for into a debugger, flashing tool, serial monitor, extensions, error checking, auto-complete (IntelliSense), and performance testing.

The two main environments that will be researched are platformIO, an extension for Visual Studio Code, and the Arduino IDE. Both of these IDEs are focused on embedded programming and provide functionality required to build an efficient project. As embedded programming requires additional tools in order flash MCUs and to be able to use a JTAG for debugging.

3.4.1 Arduino IDE 2

The official Arduino IDE 2 is a free IDE developed specifically for the purposes of embedded programming. The Arduino IDE is based upon creating “sketches”, or projects in which users can import libraries and create and flash code onto an embedded device. It offers a cloud service to save your sketches remotely. Arduino IDE 2 comes with all the necessary tools required for embedded programming including upload, verify, and debug. The verifying tools allow developers to see if their code is buildable, and to verify there are no errors while compiling the code. The upload tool will build the source code and upload it to the specified board. It does this through a serial port connected to the MCU itself (or through a JTAG). The debugger is to be used with a JTAG device to allow developers to read specific registers on the MCU for debugging purposes.

The Arduino IDE also offers a library management tool. This tool provides developers with a quick and easy way to import open-source libraries from a vast database. These libraries include functionality for a variety of peripherals that can be controlled by MCUs. Everything from camera modules, stepper motors, touchscreens, and more can easily be imported from the IDE's user interface (UI) directly. This allows for ease of use in including libraries into the sketches files to be implemented.

The Arduino IDE also comes with the Arduino Command Line Interface (CLI) tools. This enables developers to have the required functionality through CLI to build and upload their sketch. It has features for library management through the CLI itself. It offers all functionalities through the CLI to replace almost all features of the IDE's UI itself, allowing other text editors to be used.

3.4.2 PlatformIO Extension

The PlatformIO IDE is a Visual Studio Code extension that provides the functionality for embedded software development. Visual Studio Code (VS Code) is text editor released by Microsoft with the intention of having a "blank slate" for developers to create their own personalized development environment. It has a rich set of extensions available to allow VS Code to perform a wide range of software-related tasks.

The PlatformIO IDE is a very common VS Code extension among embedded engineers. With 40+ platforms supported, 20+ frameworks, and 1,500 boards natively supported, this IDE allows developers to create projects for just about any system. It comes with tools to build, upload, debug, test, clean, and a serial monitor. The build is similar to Arduino IDE's verify tool, it also the compiler to build the project in order to verify there are no build errors. The upload tool will build and upload the project through a serial port that is connected to the MCU.

The PlatformIO allows for easy configuration and changes to a projects targeted framework and board. These configurations for PlatformIO lie within a "platformio.ini" file. This allows configurations for the framework, target board, platform, library dependencies, serial port monitor speeds, and more. This INI file gives PlatformIO instructions on how to build the project itself to ensure it is properly built for your specific MCU. When changing MCU's a developer can simply change the targeted board, and then re-build and upload the project. It also comes with a UI for configuring your project. This UI includes a library management tool and configuration to target a specific board. This helps developers who are new to PlatformIO quickly and easily get a project up and run. PlatformIO also has a range of tools created for commercial development. It includes a setup for unit-testing to allow specific tests to be written. With an easy-to-use implementation developers can quickly write unit tests and check their test-coverage with the click of a button.

One major benefit of using PlatformIO is the access to all other VS Code extensions. VS Code has a rich marketplace for extensions that can be used alongside PlatformIO. Git extensions for version control can provide graphical interfaces to help manage branches and the repository. Official Microsoft C/C++ IntelliSense offers the most robust IntelliSense on the market, downloaded by over 72 million developers. This marketplace for VS Code allows developers to install extensions to save crucial time during development.

3.4.3 Table Comparison Between IDEs

	PlatformIO	**Arduino IDE 2**
Boards Supported	1,500+	50+
Frameworks Supported	20+	1
Platforms Supported	40+	1
Build Tool	Yes	Yes
Upload Tool	Yes	Yes
Debugger Tool	Yes	Yes
Library Manager	Yes	Yes
Extensions	All VS Code extensions	No
CLI Tools	Yes	Yes

3.5 ECAD Software for PCB Design

In order for the Solder Paste Dispenser to be realized, all of the electronics must be housed and connected within a custom designed printed circuit board (PCB). There are plenty of computer-aided design (CAD) software that can help with designing said PCBs. Each software program has the same core features, but with slight differences between them. When determining the CAD software of choice, there are some main considerations the team will keep in mind. The first few considerations are regarding the interior of the software itself and its main features such as the components library, the software’s compatibility, the GUI, and whether the team can collaborate on it via an online repository. The second set of considerations are regarding the exterior of the software such as the team's prior experience with the software, whether the software follows industry standards or is used widely by the industry, any extra available online resources to help navigate the software, and finally the price of getting a license to use the software.

When thinking about PCB design, there are many aspects to consider: What systems and subsystems will the team require for its design? How will the board be laid out? How is everything being powered? How many layers, and as a result, how many vias are needed to realize the design? How will the housing for the PCB be made?

3.5.1 ECAD Software Considerations

To further elaborate on the first set of considerations, it is extremely helpful to have a live components library that is constantly being updated from component market websites such as DigiKey, Mouser Electronics, Ultra Librarian, Pololu Robotics & Electronics, and more. This allows the user of the CAD software to easily implement market products from the component library into their design without the need to manually import it from the website. However, in the event that a specific product is not included in the software's pre-existing live library, it is desirable for the software to be compatible with websites that do have downloadable CAD models. These websites often have an option to download and install a component's CAD model straight to the software of choice (given that it is supported by the product market website). Another feature that could prove to be useful would be the portability of the CAD software. It would also be desirable for the software to have the feature of being able to port or upload a schematic or PCB design from one CAD software to another. The selected CAD software should also be user-friendly with quick-to-learn GUI and lots of customizability/accessibility. This would also generally include all the exclusive features and functionalities that it can perform over other CAD software. Finally, it would be ideal for the software to have a collaborative feature for multiple team members to be able to view and modify the files virtually from an online repository. The team plans to use a GitHub repository to share and store most of their files and having access to the PCB there would be convenient.

The second set of considerations are meant to cover external factors surrounding the use of the software. For example, the team's prior experience with the software is an important factor in order to hastily get accustomed to it and begin using it as soon as possible. With no prior experience, the team would require an abundance of online learning resources to help navigate the software. The availability of resources such as company-official tutorials, online forums/blogs that discuss problem-solving techniques, and company-website Q&As would help alleviate lack of prior experience. Another important factor is whether the software has features that help enforce manufacturer requirements and parameters to ensure the designed PCB can be manufactured. This is also related to whether the software is multifaceted and follows industry standards allowing for said manufacturability. With all of those factors being considered, the final consideration is the price associated with the software. There are several options for pricing offers such as free downloads, free trials, standard paid licenses, enterprise paid licenses, student discounts, and free limited student licenses.

3.5.2 Industry Used ECAD Software

Now that the criteria for choosing PCB CAD design software have been defined, there are plenty to choose and compare from. Some of the most common industry standard PCB design CAD software programs are KiCAD, OrCAD, Cadence Allegro, Flux, Autodesk Eagle, and Altium Designer.

3.5.2.1 KiCAD

Starting off with KiCAD, it is an open-source PCB CAD design software (1). It includes a built-in library alongside some official library repositories (found on GitLab) for schematic symbols, PCB footprints, 3D models, source files, and project templates for multiple versions of the software (4). The system libraries can be kept up to date by manually cloning them using Git. It also supports third-party libraries from Digi-Key, Octopart, SparkFun, SnapEDA, and PCB Libraries (3). KiCAD also supports importing schematic and PCB designs from Altium Designer, CADSTAR, EAGLE, LTSpice, Solidworks, etc. (5) KiCAD has a very simple user interface (UI) along with a schematic viewer/editor and a PCB viewer/editor. Layer views can be toggled on/off, there is a Gerber file viewer, and an integrated spice model simulator is available with customizable simulation settings (6). There are plugins, library, and color themes repositories that can be used from the KiCAD website (7). KiCAD files can be pushed to a Git repository allowing for team collaboration. The team has had little to no experience using KiCAD. However, there are plenty of official learning resources and external tools that KiCAD provides on their website (8). They also have a "Community" tab on their website that links to chats, forums, and mailing lists. Since KiCAD has a Gerber file viewer and export feature, it can be sent to manufacturers. Finally, KiCAD provides a General Public License (GNU) which means it is free software for download and distribution (2).

3.5.2.2 OrCAD

Moving on to OrCAD, it is a PCB design tool from EMA Design Automation (a Cadence partner) (10). OrCAD includes an integrated, up to date library and is also supported by Ultra Librarian and SnapEDA for component/part downloads (12). The standard version of OrCAD X supports Altium Designer, AutoDesk Eagle, and PADS translators to be able to import/export designs between these software (11). OrCAD has a plethora of extra features including allowing the user to save different versions of the same design. In addition, a design difference feature allows the user to see the differences between revisions, the "cross probing" feature lets the user see both the schematic and PCB view at once while communicating simultaneously, and a symphony collaborative feature that allows multiple users to simultaneously work on the same project at the same time (13). OrCAD also uses generative artificial intelligence (AI) for component placing, routing, etc. (18) OrCAD also has PSpice implementation. While OrCAD files can be pushed to a GitHub repository, it does not have seamless integration for the aforementioned version control feature, meaning it would have to manually be pushed every time the user seeks to update the project (14). The team has had no prior experience with OrCAD. However, there are plenty of online resources such as the Cadence community forums, EMA academy (courses and videos that teach new users), expert training, the How-To-Library, and many other forms of support (15). OrCAD can generate the necessary Gerber files to send to manufacturers and be imported from other CAD software. Lastly, for pricing there are many options to choose from. Each option has different licensing categories such as Time-based Floating License (TBL), Perpetual Floating License, and Time-based Single User License (SUL). Focusing solely on Time-based Floating License, OrCAD X Standard is unavailable (the standard package which brings OrCAD X and PSpice is $1,280.00 per year), OrCAD X Professional is $2,738.00 per year (OrCAD X Professional package brings PSpice Designer Plus, OrCAD Capture CIS, and

OrCAD PCB Designer for $5,520.00 per year), and OrCAD X Capture is $650.00 per year (23). There are also certifications, training, and workshops available that vary from being free of charge to priced (16). Despite these steep prices, there is a professional free 30-day trial and for students there is a free 6-month trial with proof of enrollment (17, 18).

3.5.2.3 Allegro

The next CAD software is Cadence Allegro, one of the more common PCB CAD software used in industry. Both OrCAD and Allegro are affiliated with Cadence and are very similar. Allegro has an up-to-date library and is compatible with most component websites just like OrCAD. It has integration of certain tools from Autodesk Fusion and Solidworks. Some of those similar features include version control, concurrent PCB design where multiple users can work on the same project at once, and generative AI techniques for PCB layout (20). Overall, Allegro has almost every feature that OrCAD has in addition to some more complex, higher-level functionalities regarding vias, layers, routing, and traces. While OrCAD is often used in simpler projects for schematic designs, Allegro is used more often for PCB layout (21). It can still be pushed onto GitHub repositories. The team has had no prior experience with Allegro. Similar to OrCAD, there are countless videos and training courses that Allegro provides (22). The price for the Allegro PCB Design package (which brings Allegro PCB Designer, Allegro System Capture, and PSpice) is $1,500.00 per month. There is also a 30-day free trial for all package types of Cadence Allegro. In addition, a student free trial can be requested which will put the user in contact with a Cadence team member to find out more information, but it is not directly downloadable (24).

3.5.2.4 Flux

A much more recently launched PCB design CAD software is Flux. This browser-based software heavily utilizes artificial intelligence (AI) for its schematic and PCB design. It has a community components library which allows parts to be shared by owners and the user can share their own parts (25). Components can be imported directly from KiCAD, Eagle, SnapEDA, and Ultra Librarian. As a result of the heavy AI usage, this CAD software has very unique features such as being able to extract and convert component information from its datasheet to be able to use it in the design (26). When designing the schematic or PCB layout, the user can ask the Flux “Copilot” AI a question to help answer questions, refer to datasheet information, perform actions on the schematic, and even navigate the UI (27). The schematic can be tested with the built-in simulator based off of LTSpice (52). It can also generate and export Gerber files along with a bill of materials (28). Flux also provides version control and projects can be shared with others for collaboration (29). Flux’s collaboration feature allows it to act as its own repository, however since it is browser-based it cannot be pushed in the team’s pre-established GitHub repository. Some members of the team have little experience with Flux, but there are many resources available on the official website. The website’s search bar also has AI implemented in it meaning that any question regarding the software can be answered and the AI will provide the source for where it received the answer if the user sought more information. In addition, if the user has not fully learned how to navigate through the software, it can simply ask Copilot for help, removing the possibility of a steep learning curve. The official website also includes some informative videos and tutorials to help prepare new users for schematic and PCB design. There are multiple plans to choose from for individuals planning to use Flux. The “Basic” free plan allows users to have 5 private projects, unlimited public projects, full design capabilities, and the AI Copilot. The “Pro” plan for $12 per month (or free for students and educators) provides unlimited private projects and unlimited editors on top of the basic plan features. The “Ultra” plan for $24 per month provides all the aforementioned features along with extra support and a private community. There are also business plans like “Organization” for $39 per month and “Enterprise” with custom pricing which include more logistical features (30).

3.5.2.5 Eagle

The next CAD software that will be evaluated is Autodesk Eagle. This electronic design automation software is integrated with Fusion which is a general CAD software platform offered by Autodesk (31, 32). Eagle supports an up-to-date, managed library, it allows users to download libraries, and users can also create their own personal libraries. Libraries can be manually refreshed within the software to automatically update any components or component information while working on a design (33). Eagle does support version control via online repositories like GitHub (35). Eagle has a Spice simulator, obstacle avoidance routing tools, generative AI capabilities, and 3D component models (36). The Eagle and Fusion integration allow for simultaneous ECAD (electronic computer-aided design) and MCAD (mechanical computer-aided design) within the software platform (34). This could speed up the process of designing the PCB through ECAD and the housing for it through MCAD. The team has had the most experience using Autodesk Eagle considering it was the University of Central Florida's ECAD of choice for the Junior Design course. The Autodesk website provides plenty of additional online resources like blogs, forums, videos, courses, and certifications for Eagle. The software is also capable of generating and exporting Gerber files for manufacturers (38). Eagle licenses cannot be purchased by themselves since Autodesk is currently in the transition of fully implementing Eagle into Fusion as a single program (37). To buy an Autodesk Fusion subscription with Eagle included it would typically be $680 per year for a single user (39). There also happens to be a Fusion 30-day free trial with all features, a Fusion for personal use (hobbyist) with limited features, and a Fusion for students that grants all features (40).

3.5.2.6 Altium Designer

The final ECAD software that will be considered is Altium Designer. Similar to Cadence Allegro, Altium is quite common throughout the industry for PCB CAD designs. Altium has an up-to-date, components library with a manufacturer part search that allows users to choose backup parts for their design (41). The library is connected to hundreds of suppliers such as Octopart and IHS Markit and components can also be downloaded from supplier websites and imported into Altium to create a personal library. Altium also has an "ActiveBOM" feature where the bill of materials is automatically updated and checks for any supply or specification issues throughout the design process. This allows parts to be replaced quickly if there is an issue with an already selected part. The BOM can also be customized with different views, groupings, or even include different suppliers (42). Altium has built-in Spice simulations with circuit analysis and customizable parameters (43). It supports integration with MCAD applications like Solidworks and Fusion (44). Auto routing, using Altium Designer's Situs feature, will help users design their PCB layout by letting the software automatically route an optimal path especially when using polygon pours (49). A similar feature called ActiveRoute performs routing for signal nets and could re-pour a polygon if needed for routing optimization (50). Altium also internally supports Git version control systems allowing the team to push source files to the repository (45, 47). The team has had some recent prior experience with Altium Designer and there are plenty of resources to help learn and navigate the software. Altium provides forums, documentation, certification/training courses, and even a practice project for new users to try out (46). Altium is capable of generating and exporting Gerber files to send out to manufacturers (48). Altium has a couple of options for pricing, there is a Perpetual License for companies starting at $11,970 and Term-Based License starting at $4,235 per year. Out of the Term-Based Licenses, there is a Standard version with basic features starting at $4,235 per year, a Professional version with more advanced features starting at $5,495 per year, and an Enterprise version with varied pricing. There are also free trials available to professionals, students, and startups. The professional free trial can last up to 30 days; however, the student free trial will last one full year upon verification of student status (51).

3.5.3 ECAD Software Comparison

Each of these ECAD applications allow the user to create schematics, run circuit simulations, create PCB layouts, place components, insert vias, and run traces/routes. All of them also have updated libraries (or can be updated) and are compatible with other CAD software to allow for importing files from one to another. In addition, they all have a feature that creates a bill of materials, they can export Gerber files, they support flat/horizontal and hierarchical designs, they have design rules checks and design for manufacturing checks (which locate any unwanted or imperative design violations), and have some type of circuit simulation (spice, thermal, etc.). Where each software seems to differ is in automation of certain features (routing or BOM), quality of life improvements, use of artificial intelligence, level of collaboration, and licenses/prices.

For the applications that may not have internally supported Git, CADLAB is a third-party site that supports Git version control for Autodesk Eagle, KiCAD, Altium, OrCAD, PADS, and more. It currently supports pushing schematic and board layout file formats with library file formats coming soon. CADLAB can connect to GitHub, GitLab, or Bitbucket even if it is already being used for version control and saving source files in an online repository. This service can also compare source file code/text between each version (53). It could be a useful tool for sharing, viewing, and annotating schematic and PCB layouts as long as it is supported by the ECAD application. CADLAB is free for individuals and free for open-source projects.

The table below shows the major features and information that was previously discussed. For reference, when the feature on the right side has “(Y/N),” the “Y” means “Yes,” and the “N” means “No/None.” The “H,” “M”, and “L” are for “High,” “Medium,” and “Low.” High on the collaboration features means that the program allows multiple users to work on the project files simultaneously; a Medium means that it only allows for version control and multiple users to view/annotate the files; a Low means it only allows users to view/annotate files. Regarding the AI feature, a High means that there is heavy usage of generative AI along with various other forms of AI support; Medium indicates there is no AI design help, but it has other automated or machine-learning features; a Low means that there are only basic auto-routing functions and active bill of materials.

3.5.4 Table Comparison Between ECAD Software

	KiCAD	EMA OrCAD	Cadence Allegro	Flux	Autodesk Eagle	Altium Designer
Live Library (Y/N)	N	Y	Y	Y	Y	Y
Download/Import Components (Y/N)	Y	Y	Y	Y	Y	Y
Integration with other CAD software (Y/N)	Y	Y	Y	Y	Y	Y
BOM (Y/N)	Y	Y	Y	Y	Y	Y
AI (H/M/L/F)	L	M	M	H	M	M
Automated Features (H/M/L)	L	M	M	H	H	H
Integrated Git Version Control Support (Y/N)	Y	N	N	N	Y	Y
Simultaneous Collaboration Features (H/M/L/F)	L	H	H	M	L	L
Prior Experience (H/M/L/F)	L	N	N	L	H	M
Available Learning Resources (H/M/L/F)	H	H	H	H	H	H

Industry-used (Y/N)	N	N	Y	N	Y	Y
Simulator (Type)	NGSpice	PSpice	PSpice	LTSpice	NGSpice	MixedSim (Spice based)
Price for Low End Version ($)	$0	$1,280/yr	$1,500/yr	$0	$680/yr	$4,235/yr
Free Trial (Length)	Unlimited	30 days	30 days	Unlimited	30 days	30 days
Student Version	Unlimited	6 months	30 days	Unlimited	1 year	1 year

Figure:

3.6 Part comparison for the Optical Stereoscopic System

3.6.1 Computers for Passive Stereoscopy

There are a wide range of computers that could be used for the stereoscopic system. The three choices in consideration are the ESP32 by Espressif Systems. The Raspberry Pi 4 and the *NVIDIA* Jetson Nano. All three vary in cost, processing power, and connectivity. The following paragraphs will compare the features of these three options, explore what is possible with these options, and discuss the suitability for application in a stereo system.

3.6.1.1 ESP32

The ESP32 is a cheap, low-power (3.3 V / 500 mA), system-on-chip that is integrated with Wi-Fi and Bluetooth capabilities. It costs less than $10. It has 520 KiB of memory, a 32-bit microprocessor at 240 MHz and only one camera serial interface (CSI) connector. It was designed and developed by Espressif Systems. The ESP32 is programmable using the Arduino IDE with a dedicated library or you can use other languages such as C/C++, Micropython, Lua, and JavaScript. It has a small form-factor making it useful for small devices. The ESP32 can be used for monitoring and controlling systems, making it useful for automation. For this reason, we will be using the ESP32 to control the solder dispensing system. If we focus on the imaging applications, the ESP32 has limited processing power and is only suitable for less intensive image processing tasks, such as motion detection. It would not be possible to run stereo vision software on the ESP32. However, the ESP32 can be used to capture images with a sensor and off-load the processing to another computer using Bluetooth or Wi-Fi. As the solder paste dispenser itself will not have any sort of monitor integrated for outputting images. It would be beneficial to the user if they could output a live feed from the camera modules to a computer so they can see where they are moving the dispenser head. This would allow users to position the stereo system precisely where they need rather than exporting the images from a computer on the printer and checking where it is looking. A live feed would also be useful for focusing the camera on an area of interest by lowering and raising the height of the head. However, it would require extra software to be developed, and it would need to be user-friendly. Overall, the ESP32 is a cost-friendly, versatile microcontroller with limited processing capabilities.

3.6.1.2 Raspberry Pi

The Raspberry Pi 4 is a platform, by Raspberry Pi, that has more processing power than the ESP32. However, the Raspberry Pi 4 consumes more power (5 V @ 3A), is larger in size and costs around $35 - $75. It features USB 3.0 and USB 2.0 connectivity, as well as, a quad-core ARM Cortex-A72 clocked at 1.8 GHz, which is around 7.5x faster than the ESP32. The Raspberry Pi 4 has a dedicated GPU and four options for memory: 1 GB, 2 GB, 4 GB, or 8 GB. It has significantly more memory than the ESP32, which also lacks a dedicated GPU. The faster processor in the Raspberry Pi 4, with the dedicated GPU, and additional memory, provides flexibility for use of processing power. Also, the Raspberry Pi 4 supports many languages including Python, C/C++, Java, JavaScript, PHP, Ruby, and more. In addition, the Raspberry Pi 4 has one CSI connector which is a problem since we require two cameras. The Raspberry Pi 4 is good for computer vision purposes but does not support two cameras so we would need extra hardware. Also, if we integrate the Raspberry Pi 4 with the camera modules on the actual frame of the dispenser, then users will be forced to use the USB ports on the board to pull data, which could make it difficult to use. It is possible that two ESP32 boards would be used to connect the cameras and off-load data remotely to a Raspberry Pi that is not integrated with the SPD. If we are to use the ESP32, we must include additional components to integrate the camera such as the ESP32-CAM.

3.6.1.3 NVIDIA Jetson Nano

The *NVIDIA* Jetson Nano is a powerful platform that is designed for AI and intensive computer vision applications. It costs around $99 and features a quad-core ARM Cortex-A57 processor at 1.43 GHz as well as 4 GB of memory. These features are comparable to the Raspberry Pi 4; however, the processing power of the Jetson Nano becomes advantageous when you look at the GPU. The Nano includes a 128-core Maxwell GPU, making it significantly more powerful for parallel processing tasks, like deep learning and intensive image processing. The interfaces on the Nano include 40-pin GPIO ports, one CSI and DSI connector, four USB 3.0 ports, ethernet and microSD. The Jetson Nano does not have built-in Wi-Fi or Bluetooth connectivity. The Jetson Nano is a larger board than the Raspberry Pi 4 and the ESP32, and it consumes more power (5 V / 4 A). Considering the computational requirements of the stereo system and cost, the Jetson Nano is overkill for the task.

3.6.1.4 Table comparison of computers for passive stereoscopy

	ESP 32	Raspberry Pi 4	NVIDIA Jetson Nano (4 GB)
Price	<$10	$35-$75	$99
Processor	Tensilica Xtensa 32-bit LX6 microprocessor.	ARM Holdings quad-core ARM Cortex-A72	ARM Holdings quad-core ARM Cortex-A57
Clock	240 MHz	1.8 GHz	1.43 Ghz
GPU	Not natively, but ESP32 can support a GPU	Broadcom VideoCore VI GPU	NVIDIA 128-core Maxwell architecture GPU
Memory	520 KiB	1 GB, 2 GB, 4GB, or 8GB options	4 GB
Ports	1x 36-pin GPIO 3x UART 2x I2C 4x SPI 18x ADC channels 2x DACs 1x SDIO	2x USB 2.0 2x USB 3.0 2x micro-HDMI 1x 40-pin GPIO 1x CSI-2 1x DSI 1x 3.5 mm AV Jack 1x USB-C power port	4 x USB 3.0 1x Ethernet 1x HDMI 2.0 1x DisplayPort 1.2 2x CSI-2 1x 40-pin GPIO 1x Micro-USB power port 1x Barrel Jack port 1x SDIO

			1x 4-pin Fan Header 1x I2C Header
Connectivity	Wi-Fi and Bluetooth	Wi-Fi and Bluetooth	Wi-Fi and Bluetooth with dongle adapter
Power Requirements	3.3 V @ 500 mA	5 V @ 3 A	5V @ 4 A

3.6.2 Software for Passive Stereoscopy

There are a variety of different computer vision software's out there and each varies in their features and complexity. The following paragraphs will consider two free options for image processing software and will discuss their capabilities and suitability for the stereo vision system.

3.6.2.1 OpenCV

OpenCV is a very popular open-source library, developed by Intel, that is used for computer vision and image processing. OpenCV is versatile across many platforms because it supports multiple programming languages, including C/C++ and Python. OpenCV has many tools for filtering, edge detection, image processing, and image transformation. It includes algorithms for object detection, for feature detection and matching, and for stereo vision and depth estimation. This library is extremely flexible and versatile. Some key features include image processing, computer vision algorithms, machine learning, video processing, and 3D reconstruction. For this reason, it is the go-to choice for many vision-based applications. For our use case, OpenCV is an attractive choice as it has various, useful tools for stereo vision applications. This includes tools for camera calibration, image rectification, creating disparity maps, and for depth estimation.

3.6.2.2 SimpleCV

SimpleCV is an open-source, Python-based framework that is based on OpenCV. It was created to provide a friendly framework for beginners to develop their own computer vision applications. SimpleCV is easier for beginners to digest as it does not dive deep into the complexities of algorithms. For this reason, SimpleCV is limited in its capabilities. SimpleCV features functionality for image capture and processing, object detection, and real-time processing. However, it does not include functionality for more advanced computer vision tasks, like 3D stereoscopic reconstructions. For these reasons, SimpleCV was not selected.

3.6.2.3 TensorFlow

TensorFlow is an open-source, machine learning platform with a large set of tools, resources and libraries. It can be used for building and deploying computer vision applications that are supported by machine learning. TensorFlow is capable of facial recognition, image classification, and object detection. However, the platform has a steep learning as it utilizes machine learning algorithms to improve the quality of imaging tasks. Using TensorFlow for our application in a stereo vision system would add unnecessary complexity as we would need to train deep learning models to work.

3.6.2.4 Table comparison of software for passive stereoscopy

	OpenCV	SimpleCV	TensorFlow
Price	Free and open-source	Free and open-source	Free and open-source
Primary Purpose	Computer vision and image processing	Simplified interface for computer vision tasks	Machine learning and deep learning
Ease of Use	Moderate, involves coding knowledge	High, easy to use and beginner friendly	Moderate to difficult, requires knowledge of machine learning
Programming Languages	C++, Python, Java, JavaScript	Python	Python, C++, JavaScript, Swift, Java
Image processing capabilities	Extensive	Basic	Limited (mostly for data preprocessing)
Stereo vision capabilities	Stereo vision and depth maps	Basic	Limited
Video processing	Real-time video and image processing	Basic video support	Limited, other libraries necessary for integration

3.6.3 CMOS Sensors for Passive Stereoscopy

There are many kinds of Complementary Metal Oxide Sensors (CMOS) out on the market, at an affordable price. For this reason, the stereo vision system will utilize a CMOS sensor. Most CMOS sensors, under $100, utilize a camera serial interface connector. This works considering our options for computers, which all feature at least one CSI connector. The sensor that is selected must have enough resolution to be able to adequately image a 7.07 mm radius.

3.6.3.1 Raspberry Pi HQ Camera

The Raspberry Pi HQ Camera features a 1/2.3" (Sony IMX447) sensor with a pixel count of 12.3 MP. Each pixel being 1.55 micron by 1.55 micron. The camera features a 22-pin CSI-2 connector and was designed to be used with a Raspberry Pi computer board. It has a price of around $50 and the sensor has a diagonal length of 7.9 mm. The sensor comes with an IR filter and can be easily integrated with a lens tube using the thread that is attached to the sensor. The Raspberry Pi HQ camera comes with only a sensor, no lens attached.

3.6.3.2 Arducam OV2640

The Arducam OV2640 is a compact camera module and lens assembly that features a sensor of 1600 x 1200 pixels (2 MP) with each pixel being a square with length 2.2 micron. The sensor in the Arducam OV2640 was produced by OmniVision. The sensor has a diagonal length of 4.5 mm and a price of $10-$15. The camera is connected using a standard 15-pin CSI connector making it compatible with platforms like the ESP32. The camera already comes with a lens installed which would need to be removed to attach other optics.

3.6.3.3 Arducam IMX230

The Arducam IMX230 features a Sony IMX230 sensor that has 5344 x 4016 pixels (21 MP) with each pixel being 1.12 micron by 1.12 micron. The sensor has a diagonal length of 8.4 mm and can output 30 FPS at the largest resolution and 120 FPS at a resolution of 1080p. This camera module runs from $80-$90. It features a CSI-2 connector strip making it compatible with platforms like the

Raspberry Pi. The camera comes with an integrated lens that will have to be removed if we decide to use this sensor.

3.6.3.4 Table comparison of sensors for passive stereoscopy

	Raspberry Pi HQ Camera	Arducam OV2640	Arducam IMX 230
Price	$50	$10-$15	$80-$90
Removeable Lens	Yes	Yes	Yes
Sensor size (pixels)	4056 x 3040	1600 x 1200	5472 x 3648
Sensor size (MP)	12.3 MP	2 MP	21 MP
Pixel Size	1.55 μm x 1.55 μm	1.75 μm x 1.75 μm	1.13 μm (w) x 1.25 μm (h)
Sensor size (mm)	7.44 mm x 5.96 mm	4.6 mm x 3.4 mm	6.17 mm x 4.55 mm
Diagonal Length	7.9 mm	4.5 mm	7.76 mm
Connector	CSI-2 interface	CSI-2 interface	CSI-2 interface

3.6.4 Lenses for Passive Stereoscopy

The following paragraphs will discuss options for lenses for the stereo vision camera modules. When selecting a lens for our individual camera modules, we must consider what our requirements are. We need a biconvex lens. The lens should not be too small in diameter as this would make it difficult to work with when assembling the camera modules, but it should not be too large where we lose depth of field in the image. An adjustable aperture would allow us to restrict the diameter of the lens to achieve a lower NA and as a result higher depth of field. However, including an adjustable aperture may create additional disparity in the quality of the images so if we are considering adding an aperture, it must be fixed. The focal length of the lens selected must not be higher than 50 mm to ensure that the entire optical system can function when installed on the solder paste dispenser. We will be considering lenses with a focal length of 40 mm. This allows us to maintain a higher depth of field while ensuring the modules will be short enough to fit. The lens we select must have sufficient transmission and minimal aberrations.

3.6.4.1 Thorlabs LB1378-A (Bi-Convex N-BK7 Lens)

The Thorlabs LB1378-A is a bi-convex, spherical lens made of SCHOTT N-BK7 glass. The glass has a refractive index (n) of 1.517 at 588 nm. The diameter of the lens is 12.7 mm (1/2 inch) and it has a focal length of 40 mm. The lens is coated with a 350 nm – 700 nm anti-reflection coating ensuring high transmission. The lens has a transmission of around 90%. The finished surface quality of the lens is 40-20 scratch-dig, so it has a good surface finish. A mounted Thorlabs LB1378-A-ML lens costs $52.28. For analysis, figures below, created using Ansys ZEMAX OpticStudio, are shown. These figures contain information about the minimum spot size, the Seidel coefficients and a general layout of the optical system with the lens.

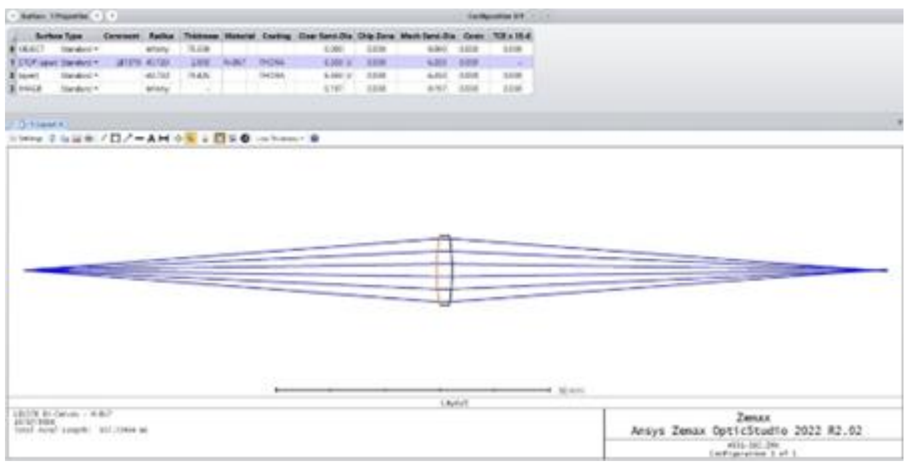

Figure 1: Thorlabs LB1378-A optical configuration in Ansys ZEMAX OpticStudio.

```
Title: LB1378 Bi-Convex - N-BK7
Date : 10/17/2024

Wavelength                       :          0.5876 µm
Chief Ray Slope, Object Space    :          0.0000
Chief Ray Slope, Image Space     :          0.0000
Marginal Ray Slope, Object Space:           0.0757
Marginal Ray Slope, Image Space :          -0.0694
Petzval radius                   :          Infinity
Optical Invariant                :          0.0000

Seidel Aberration Coefficients:

Surf    SPHA  S1     COMA  S2     ASTI  S3     FCUR  S4     DIST  S5     CLA (CL)     CTR (CT)
STO     0.019825     0.000000     0.000000     0.000000     0.000000    -0.006559    -0.000000    LB1378
  2     0.017855    -0.000000     0.000000     0.000000    -0.000000    -0.006380     0.000000
IMA     0.000000     0.000000     0.000000     0.000000     0.000000     0.000000     0.000000
TOT     0.037680     0.000000     0.000000     0.000000     0.000000    -0.012938     0.000000
```

Figure 2: Seidel coefficients

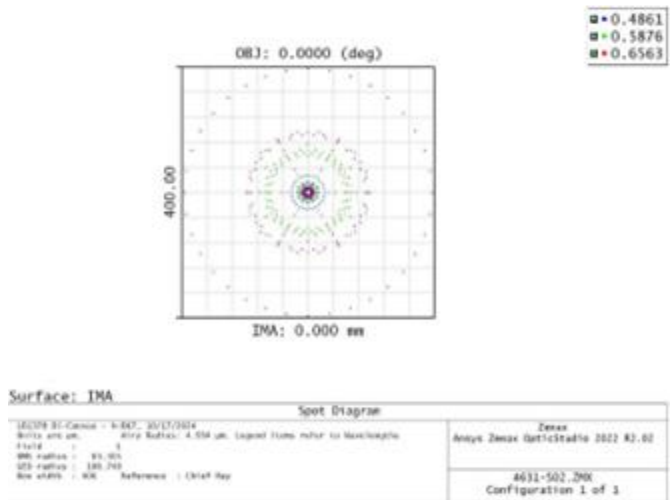

Figure 3: Standard spot size diagram

3.6.4.2 Thorlabs TRH254-040-A

The Thorlabs TRH254-040-A is a Hastings cemented triplet, achromatic lens that is biconvex on the outer edges. The triplet contains a biconvex, low-index center lens, and the exterior lenses are high-index, convex-concave lenses. The lens has a diameter of 1” (25.4 mm), a focal length of 40 mm, and a working distance of 32.3 mm. The lens is made of N-F2 and N-K5 glass manufactured by SCHOTT. Their respective refractive indices (@ 588 nm) are 1.486 and 1.522. The lens is coated with an anti-reflection coating for 400 nm – 700 nm for high transmission of visible light. The finished surface quality is 40-20 Scratch-Dig. This lens is optimized for infinite conjugate ratios and is useful for magnification. This lens is also designed to compensate for spherical and chromatic aberrations. It also has good on-axis and off-axis performance. A mounted Thorlabs TRH254-040-A-ML costs $111.38.

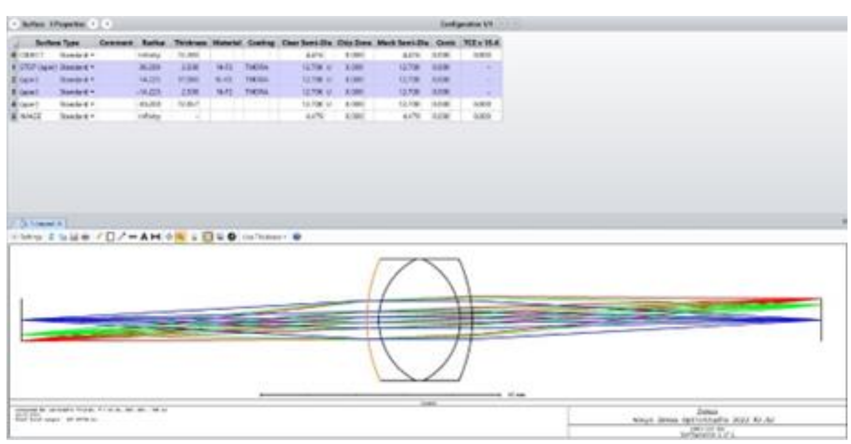

Figure 4: Thorlabs TRH254-040-A optical configuration in Ansys ZEMAX OpticStudio.

```
Title: Unmounted Ø1" Achromatic Triplet, f = 40 mm, ARC: 400 - 700 nm
Date : 10/17/2024

Wavelength                      :        0.5876 µm
Chief Ray Slope, Object Space   :        0.0612
Chief Ray Slope, Image Space    :        0.0490
Marginal Ray Slope, Object Space:        0.0554
Marginal Ray Slope, Image Space :       -0.0546
Petzval radius                  :      -50.5444
Optical Invariant               :        0.2447

Seidel Aberration Coefficients:
```

Surf	SPHA S1	COMA S2	ASTI S3	FCUR S4	DIST S5	CLA (CL)	CTR (CT)
STO	0.009257	0.003014	0.000981	0.000759	0.000566	-0.007894	-0.002570
2	-0.007386	-0.001252	-0.000212	-0.000166	-0.000064	0.007954	0.001348
3	-0.007361	-0.000385	-0.000020	-0.000166	-0.000010	0.007957	0.000416
4	0.009156	-0.000955	0.000100	0.000759	-0.000090	-0.007883	0.000823
IMA	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
TOT	0.003667	0.000422	0.000849	0.001184	0.000403	0.000134	0.000017

Figure 5: Seidel coefficients

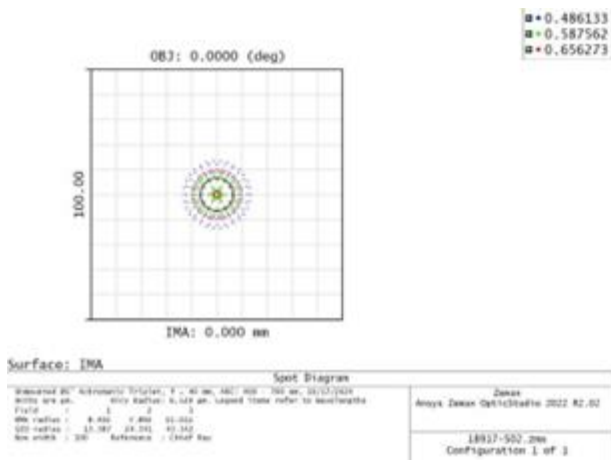

Figure 6: Standard spot size diagram

3.6.4.3 Thorlabs TRS254-040-A

The Thorlabs TRS254-040-A is a cemented Steinheil triplet achromatic lens optimized for finite conjugate ratios, making it useful for 1:1 imaging. The lens is made of a low index, biconvex center lens with two identical, higher-index, convex-concave lenses on the outside. The lens features excellent aberration compensation, and the lenses coated with anti-reflection at 400 nm – 700 nm (R_{avg} <0.5%). The surface quality is 40-20 Scratch-Dig. The inner and outer material are, respectively, N-F2 and N-K5 glass, manufactured by SCHOTT. The lens has a focal length of 40 mm and a working distance of 68.2 mm. The diameter of the lens is 1” (25.4 mm). The price for a mounted version of the lens runs $117.31. For analysis, the lens was imported into Ansys ZEMAX OpticStudio and simulated for our use case. The figures are shown below.

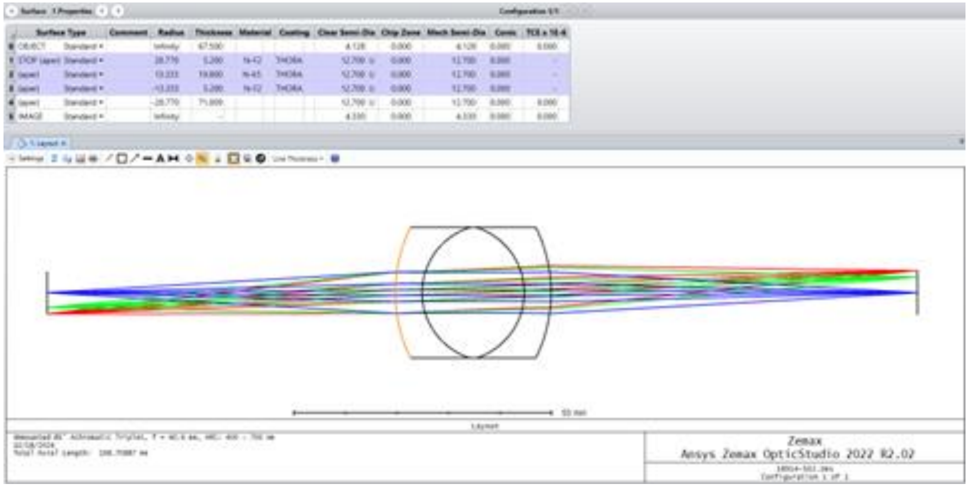

Figure 7: Thorlabs TRS254-040-A optical configuration in Ansys ZEMAX OpticStudio.

```
Title: Unmounted Ø1" Achromatic Triplet, f = 40.6 mm, ARC: 400 - 700 nm
Date : 10/18/2024


Wavelength                          :          0.5876 µm
Chief Ray Slope, Object Space       :          0.0612
Chief Ray Slope, Image Space        :          0.0434
Marginal Ray Slope, Object Space:              0.0593
Marginal Ray Slope, Image Space :             -0.0564
Petzval radius                      :         -48.3720
Optical Invariant                   :          0.2447

Seidel Aberration Coefficients:

Surf     SPHA  S1      COMA  S2      ASTI  S3      FCUR  S4      DIST  S5      CLA (CL)      CTR (CT)
STO      0.010935      0.003373      0.001040      0.000796      0.000566     -0.008333     -0.002570
  2     -0.008659     -0.001641     -0.000311     -0.000178     -0.000093      0.008315      0.001576
  3     -0.008588     -0.001012     -0.000119     -0.000178     -0.000035      0.008345      0.000984
  4      0.010613     -0.000024      0.000000      0.000796     -0.000002     -0.008332      0.000019
IMA      0.000000      0.000000      0.000000      0.000000      0.000000      0.000000      0.000000
TOT      0.004301      0.000695      0.000610      0.001237      0.000437     -0.000005      0.000008
```

Figure 8: Seidel Coefficients for Thorlabs TRS254-040-A

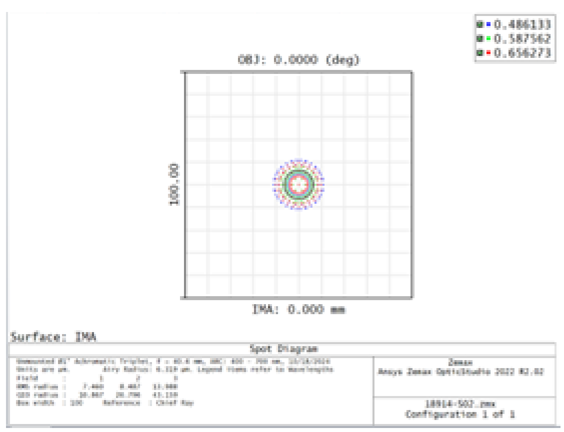

Figure 8: Standard spot size diagram for Thorlabs TRS254-040-A

3.6.4.4 Analysis of Lens Options

All the 40 mm lens options were configured, in the figures above, to achieve 1.05x magnification or slightly higher. All simulated configurations have an acceptable length regarding the design requirements.

Seidel coefficients represent the magnitude of optical aberrations as a fraction of the wavelength of light used in a system. Aberration becomes significant and noticeable when the Seidel coefficients start to reach 0.25 or 0.5, a quarter or half of the wavelength of light in an optical system. For the Seidel coefficient values for spherical aberration at 587.6 nm, the LB1378 has a coefficient value of 0.0377, the TRH-040-A Hastings triplet has a coefficient value of 0.00367, and the TRS-040-A Steinheil triplet has a coefficient value of 0.00430. We see a significant improvement in reducing spherical aberrations using triplets rather than the singlet; However, overall, none of the lenses have significant aberrations.

The standard spot size diagram shows the focused spot size at the image plane and provides information like root-mean squared (RMS) spot size and airy radius. To minimize blur in our image, it's important to reduce the RMS spot size so it is close to the airy radius. The LB1378, in its configuration, has an RMS spot size radius of 83.3 micron and an airy radius of 4.9 micron. The TRH-040-A Hastings triplet, in its configuration, has an RMS spot size radius of 8.4 micron and an airy radius of 6.5 micron. The TRS-040-A Steinheil triplet, in its configuration, has an RMS spot size radius of 7.5 micron and an airy radius of 6.3 micron. The triplet lenses offer much better optical performance than the singlet lens.

3.6.4.5 Table comparison of lenses for passive stereoscopy

	Thorlabs LB1378-ML	Thorlabs TRH-040-A-ML	Thorlabs TRS-040-A-ML
Price	$52.28	$111.38	$117.31
Working Distance	40 mm	68.2 mm	68.2 mm
Focal Length	40 mm	40 mm	40 mm
Diameter	12.7 mm	25.4 mm	25.4 mm
Type	Singlet	Hastings triplet	Steinheil triplet

3.7 Power Supply

A power supply is necessary to provide power for all systems within the Solder Paste Dispenser. For example, power must be distributed to the custom PCB which houses the microcontroller, stepper motor drivers, stepper motors, switches, touchscreen display, stereoscopy system, and the dispenser nozzle. Designing a power supply from the ground-up requires extensive knowledge on rectification, filtering, regulation, and safety methods. Instead, it would be more cost-effective and time-efficient to research and adapt the project's design to a commercial off-the-shelf (COTS) power supply.

Before looking into the specifications and power ratings of the Ender-3, there are many different types of power supplies. Alongside the multiple power supply types, there are various terms and definitions to cover before reading a PSU datasheet. The main two types of power supplies are linear power supplies and switched mode power supplies.

3.7.1 Linear Power Supplies

Linear power supplies convert AC voltage into a steady DC output voltage with relatively low ripple and noise. Below is a figure provided by Rohde & Schwarz to describe the design principles of the linear power supply. There are two stages of circuits seen in the image below, the primary circuitry is the AC input stage seen on the left. The transformer separates the two stages, stepping down the AC input voltage and isolating them from each other. The beginning of the secondary stage rectifies the AC into DC through the rectifier. The actuator acts like a switch to provide control over the output. This is managed by the analog control (output) amplifier, which when controlled by the reference voltage, acts like a buffer (90). As the buffer detects a difference between the positive and negative terminals, it tries to match the values seen in the terminals and turns on the actuator, thus providing output voltage from the rectifier output. In addition, two buffer capacitors are placed to help decrease ripple and increase stabilization of the DC signal.

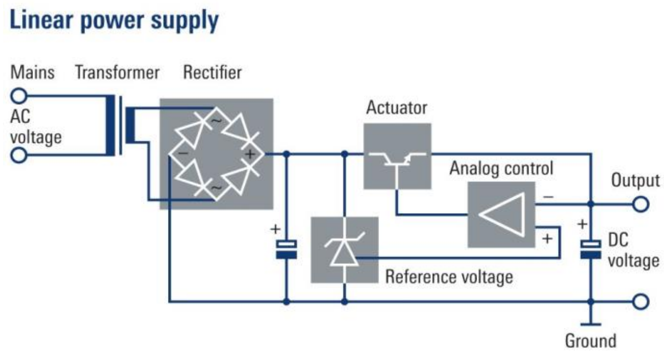

Figure:

Generally, this is how a linear power supply operates. For example, Matsusada Precision provides a diagram showcasing a very similar way to achieve the operation of a linear power supply. Similar to Rohde & Schwarz where the circuit is split up into an input stage and a output stage, the AC input goes right into a step down transformer and then into a rectifier. The “smooth” capacitor performs the same function as the buffer capacitors from the previous design, where it is used to reduce ripple and keep a constant DC signal. Despite this design providing less details, the series regulator here is basically the combination of the voltage reference, actuator, and analog control amplifier from the previous design (91). According to Monolithic Power Systems (MPS), voltage regulators use four main components: pass transistors, error amplifiers, voltage references, and a resistor feedback network (92). This in combination with the low pass filter (which adds a capacitor between the positive and negative terminals of the output) matches very closely to the above design.

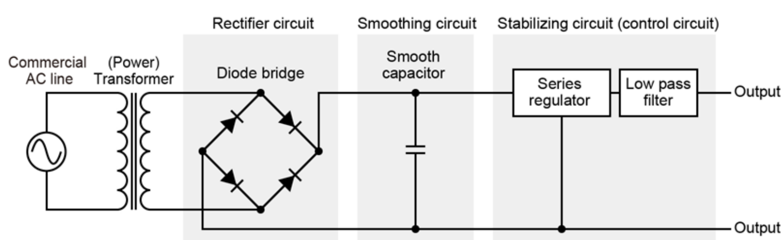

Figure:

Linear power supplies require a transformer, rectifier, buffer, and filter. The smoothing or buffer capacitor and the stabilizing circuit ensures that the positive sinusoidal waves coming out of the rectifier are leveled out to keep it at a stable DC. However, circuits like this require cooling methods or large heat sinks as this linear power supply generates heat.

3.7.2 Switched-Mode Power Supply

Switching over to switched-mode power supplies, one of the main differences is the order of circuitry when compared to linear power supplies. Using another circuit diagram provided by Rohde & Schwarz, it can be seen that the first step is to rectify the input AC voltage into DC. This voltage is then smoothened out by that capacitor connected to ground and any high frequency voltage is clipped. The switching transistor is meant to emulate AC by switching on and off very rapidly, as the voltage is then fed into a high frequency transformer. After it is stepped down using the transformer, a rectifier and low pass filter is used to stabilize and level off the DC voltage (90). In addition, a control component is placed to regulate the switching transistor by changing its duty cycle (a percentage representing the period that a signal is high/low).

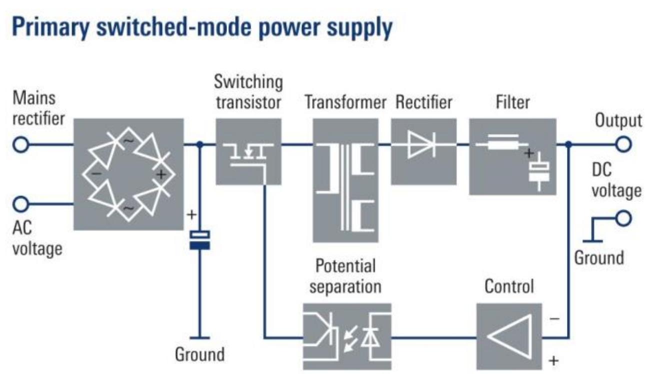

Figure:

Similarly, the MPS shows switched-mode power supplies to start off with a rectifier circuit, followed by a smoothing capacitor. The stepped down voltage through the high frequency transformer is induced and controlled by the switching device and control circuit. Then, it is rectified again and filtered to become DC output voltage (91). The switching device acts as a “chopper” which is a type of DC-to-DC converter used to step up/down DC power (93). It changes fixed DC power to variable DC power with a series of high frequency pulses.

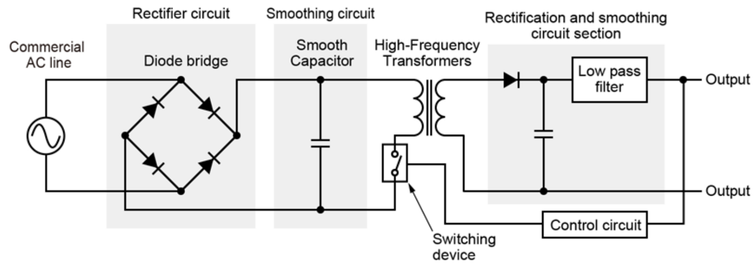

Figure:

Switched-mode power supplies basically utilize this DC-to-DC conversion strategy to emulate AC with DC pulses; this process is typically referred to as pulse width modulation (PWM), producing analog signals with DC signals and using it to control a signal (94). They require two rectifications (one at the input and another after the transformer), a switching transistor, a high-frequency transformer, a control circuit, and a low pass filter.

3.7.4 Comparison between Linear and Switched-Mode

When comparing the two main types of power supplies, there are a few key differences worth noting. Switched-mode power supplies produce more noise over linear power supplies because of the high-frequency switching transistor. The switched-mode power supply is smaller in size than the linear power supply because the high-frequency transformer is smaller than typical low-frequency transformers (as a result it also weighs less). Due to the switching transistor, the switched-mode power supply is more efficient because it is constantly being turned on and off. Meanwhile, the linear power supply is always on and wastes more energy via heat resulting in lower efficiency. Linear power supplies respond faster to changes in the load because it responds using its voltage regulator rather than the switched-mode's entire control circuit. When it comes to the cost of either one, it depends on the application and how much power is going to be used. For example, linear power supplies can typically be cheaper in low-power applications, but switched-mode can be cheaper in high-power applications (91).

3.7.5 Other Types of Power Supplies

Despite linear and switched-mode being the most common types of power supplies found in electronics, there are various other forms of power supplies use for several other applications. For example, there are uninterruptible power supplies (UPS), battery power supplies, programmable power supplies, power over ethernet (PoE), solar power supplies, etc. However, these power supplies are not necessarily useful for the application of this project. An uninterruptible power supply provides power in emergency situations when the main power source fails or is interrupted. Although losing power during a long dispensing session might be worrisome, it certainly is not an emergency that is worth the price of a UPS. A battery power supply would not be of much use considering the Solder Paste Dispenser must remain on for lengthy periods of time and is not portable, justifying the lack of necessity. Programmable power supplies like the ones seen in circuits laboratories are simply too vague and versatile for this application. The programmable power supply in and of itself is its own consumer product that is not specifically used to power machines; it is more for powering and testing systems. Power over ethernet is simply delivering power through ethernet cables into a device. The main issue with this is the low power rating and current being delivered within the milliamp range. Finally, the use of solar power is just extremely unnecessary and unfeasible for a Solder Paste Dispenser that is meant to sit inside of a room-temperature or cooled room.

Now that some of the other types of power supplies have been listed off and described, the topic returns to linear versus switched-mode power supplies. It is evident that the switched-mode power supply has a greater complexity than that of the linear power supply. For the purpose of this project, it appears that a switched-mode power supply is the better option. It is smaller and more efficient than the linear power supply and noise is not too big of a factor for this application.

3.7.6 Datasheet Common Specifications and Conditions

Now that the power supply types have been narrowed down, there are multiple conditions and parameters to consider when choosing a power supply and reading its datasheet. Using the Mean Well LRS-350-24 datasheet as an example (further elaborated on later), there are several output parameters such as DC voltage, rated current, current range, rated power, ripple & noise, voltage adjustment range, voltage tolerance, line and load regulation, setup time, rise time, and holdup time. DC voltage and rated power are both basic output voltage and output power specifications. Rated current is the maximum continuous DC current that the PSU can output, and current range describes the minimum and maximum current values that it provides. Ripple (measured in millivolts peak-to-peak) is often seen as a periodic AC component at the DC output, meanwhile noise consists of various frequency spikes in the voltage of the output. The combination of both of these tests is referred to as periodic and random deviations (PARD). The voltage adjustment range in this case applies to the terminal on the switched-mode power supplies that can be oftentimes adjusted via a screwdriver to change the range of output voltage while maintaining other output characteristics. Line and load regulation are shown as percentages that describe the PSU's ability to keep its specified output voltage when a change occurs in the input line voltage or in the load. Voltage tolerance is the combined tolerance of both of these test specifications. Setup time is the time it takes for the PSU to become functional and begin outputting voltage. Rise time is the time it takes for the PSU's output to reach steady state, which is usually right after the setup time finishes. Finally, holdup time is the amount of time it takes the PSU to recover back to a continuous output voltage after loss of input power. All three of the past specifications regarding time usually depend on the load.

Moving on to the input specifications, there is voltage range, frequency range, efficiency, AC current, inrush current, and leakage current. Voltage range simply describes the acceptable range of input voltage that the PSU operates within (considering this is a switched-mode power supply it can sometimes be either an AC or DC voltage range since they act like DC-to-DC converters). The frequency range is the range of acceptable input frequencies that the PSU operates in (many times it will be house 50 Hz or 60 Hz). Efficiency describes the ratio of output power to input power for the PSU (many times the efficiency in switched-mode power supplies is significantly higher than that of linear power supplies). AC current is the allowed input current from an AC source into the power supply. Inrush current is the current that occurs right after input voltage is applied to the power supply. Finally, leakage current is a safety concern for power supplies as it is current that flows from the input neutral wire or input live wire to the metal grounding casing.

There are various protections in place for these power supplies such as overload (overcurrent), overvoltage, over temperature, over power, short circuit, and under voltage protection. Overload protection protects the circuit from high levels of current by latching off or entering a recovery mode. Similarly, short circuit protection prevents a surge of current from occurring caused by a short circuit in the power supply. Over power protection also attempts to stop the power supply from allowing more current flow than its power rating allows for. The main difference is that overpower protection is placed on the primary side where a rectifier circuit is, while overcurrent protection is placed on the secondary side. Overvoltage protection is meant to prevent a surge of voltage from affecting the rest of the internal circuitry, meanwhile undervoltage protection is meant to prevent power loss and some components from being damaged. In addition to these protection features, power supplies also require a method of cooling down. Some manufacturers choose to cool down their power supplies via convection while others need forced cooling using a DC fan.

There are also environmental factors that affect the efficiency and operation of power supplies such as working temperature, working humidity, storage temperature, storage humidity, temperature coefficient, vibration, and over voltage category. Working temperature and humidity simply state what the acceptable temperature range and humidity levels are for the device to operate in. The same goes for storage temperature and humidity where it describes the environment that the device should be stored in when it is not operating. Temperature coefficient refers to the percentage change in the output voltage per 1°C change in temperature. The vibration specification is the power supply's resistance to vibration, showcasing its mechanical strength. Finally, the over voltage category describes the maximum overvoltage that the power supply can handle if the power supply fails. The category ranges from I to IV, each one inversely indicating the minimum number of protective devices in place between the device and the sub-station transformer that delivers the power.

Alongside all of the specifications regarding voltage, current, power, temperature, and more, there are also safety standards that many power supplies are required to follow. Some of the safety specifications include safety standards, withstand voltage, isolation resistance, and electromagnetic compatibility (EMC). Safety standards are often set by organizations such as IEEE and specific ones may be referenced to show that a power supply abides by said standards. The withstand voltage is a rating for the insulation and voltage that a power supply can handle without failing between two points such as the input and output. Isolation resistance is similar in the sense that it describes the resistance between two points on the power supply like the input and output. EMC Emission and Immunity determine the power supply's intended environment of operation based on the emissions it releases and the immunity it has towards electromagnetic fields (EMF) or radiation. There are also a few extra things to consider like the “mean time between failures” (MTBF) which represents the length of time a PSU should operate reliably for and “mean time to failure” (MTTF) which is a more accurate measurement of how long it would actually take for it to fail. Alongside this, datasheets typically include size dimensions and weight of the device.

The specifications listed were just some of the many that can be found in a power supply’s datasheet. Some of these are more important factors to consider than others when it comes to selecting the part that is suitable for this project. There are other specifications that were not listed off, but still might show up depending on the manufacturer/designer.

There are also many safety considerations (IEEE paper)

3.7.7 COTS Power Supplies

To determine the necessary power supply needed for all of these components, we can first take a look at the required power supply specifications in the Crealty Ender-3 V2 Neo. This is the model of the Ender 3 that the team plans on modifying into a solder paste dispenser. The Ender-3 V2 Neo plugs into an AC wall socket via a wall plug, its rated input voltage is 100-120V AC (6.8A), 200-240V AC (3.4A) at 50/60 Hz (54). Its rated output voltage is 24V (~14.6A) and its rated power is 350 W. This information can be found on the official Crealty website. The Ender-3 V2 Neo’s specifications and power/voltage ratings match the ratings of the majority of the 3D printers within Creality’s Ender Series (with the few exceptions being the Ender-3 (270W), Ender-3 Pro (270W), Ender-6 (360W), Ender-5 Pro (270W), and Ender-5 Plus (550W)). The Ender-3 V2 Neo has a sleeker design compared to other Ender Series 3D printers by hiding away its power supply underneath the printing bed. For example, the Ender-3, Ender-3 Pro, and Ender-3 Max all have an exterior power supply sticking outside of the device (55).

3.7.7.1 Creality CMS 350-24

There are a few power supplies that match the power ratings for the Ender-3 V2 Neo such as the CMS 350-24 Switch Power Supply. The CMS 350-24 is a

Creality made power supply unit (PSU) that supplies 24V DC at 14.5A (in the USA) with an input of 100-120/200-240VAC (6.8/3.4A) at 50/60Hz. This model has one output voltage regulation terminal, three positive output terminals, three negative output terminals, one ground wire terminal, one neutral line terminal, and one live wire terminal. The three positive and three negative output terminals are what provide the 24V DC for the device that this PSU is meant to provide power to. The ground wire, neutral line, and live wire terminals are meant to be the input of the PSU from an AC power source (wall outlet). The CMS-350-24 also provides safety features such as short-circuit protection, overvoltage protection, overload protection, and over temperature protection. Other notable features include its operating temperature range of -20°C ~ +70°C. Its rated power is 350.4W with an output voltage of 24V. The PSU has size dimensions of 215 x 115 x 30 mm (8.46 x 4.53 x 1.18 inches) and a weight of 0.63 kg (~1.39 lbs) (56).

3.7.7.2 Mean Well LRS-350-24

Creality's Ender-3 V2 3D Printer uses a similar rated power supply by Mean Well called the LRS-350-24 (57). The Mean Well LRS-350 Series is a set of 350W Switching Power Supply with single outputs that are rated for various voltage/current outputs/inputs. The LRS-350-24 is the 24V output model which delivers a current range anywhere from 0 - 14.6A. It is rated for exactly 350.4W and has a maximum ripple and noise of 150mVp-p. The input voltage range begins at around 90 ~ 132VAC or 180 ~ 264VAC at the frequency range of around 47 ~ 63Hz with an efficiency of 88%. The input stage AC current allows for 6.8A to flow at 115VAC meanwhile 3.4A at 230VAC. Similar to the CMS 350-24, it has short circuit protection, overload protection, over voltage protection, and over temperature protection. In the datasheet, overload is considered to be 110 ~ 140% of the rated output power, in this case being 350W (58). Upon reaching this overload condition, the power supply will enter “Hiccup mode” to ensure that the condition is removed. Hiccup mode is a safety feature on switch-mode power supplies that basically turns off the power converter when an overload is recognized, restarts the converter, and checks again for overload (59). In general, overloads could be due to low loads resulting in overcurrent or overvoltage. Moving on to the over voltage protection, the LRS-350-24 considers the range 28.8 ~ 33.6V to be over voltage. Depending on the severity of this condition being met, the power supply could enter into Hiccup mode or Latch off mode. Finally, the over-temperature protection conditions are similar in the sense that if the working temperature of -25°C ~ +70°C is surpassed, then the Hiccup mode or even the Latch off mode will activate. It shares the same terminal types as the CMS-350 with one output voltage regulation terminal, three positive output terminals, three negative output terminals, one ground wire terminal, one neutral line terminal, and one live wire terminal. On top of those features, it is also capable of enduring an input surge of 300V AC for about 5 seconds. Similar to the CMS-350-24, the LRS-350-24's size dimensions are 215 x 115 x 30mm (8.46 x 4.53 x 1.18 inches) and has a packaging weight of 0.76 kg (~1.68 lbs).

3.7.7.3 Mean Well S35024

The next PSU that will be looked at is the Mean Well S35024. This power supply has not been used in an Ender-3 3D printer but bears very similar specifications to the voltage and power ratings of the Ender-3 V2 Neo. For starters, it is another single output switching power supply and a part of Mean Well's S-350 Series of PSUs. The S-350-24 is the 24V output model rated for output current range from 0 – 14.6A and rated power of 350.4W. Just like the LRS-350-24, it has a maximum ripple and noise voltage of 150mVp-p. The input voltage range is 90 ~ 132VAC or 180 ~ 264VAC with a frequency range of 47 ~ 63Hz and an efficiency of 81%. The input stage AC current is lower than that of the LRS-350 series, allowing for 6.5A to flow at 115VAC meanwhile 4A at 230VAC. Some of the main differences between the two series is that the S-350 series lacks over temperature protection and cannot withstand a high surge input. Despite the lack of over temperature protection, the working temperature range is -10°C ~ +60°C. As a result, the S-350 series is a lower cost, power supply than the LRS-350 series. The S-350 still has overload protection which is labeled as 105 ~ 135% of the rated output power. However, it does not have hiccup mode nor latch off mode; instead, it constantly monitors and limits current levels until there is no longer overcurrent. The over voltage protection defines over voltage to be 27.6 ~ 32.4V with hiccup mode available. The S35024 has ten terminals: one for voltage adjustment, three for positive output voltage, three for negative output voltage, one for ground wire, one for the neutral line, and one for the live wire. The size dimensions are 215 x 115 x 50 mm (8.46 x 4.53 x 1.97 inches) with a packaging weight of 1.07 kg (~2.36 lbs) (61).

3.7.7.4 Mean Well UHP-350-24

Another similar power supply from Mean Well is the UHP-350-24. This is another switching power supply, but instead it is part of the UHP-350 series. The UHP-

350-24 supplies 24V DC, 14.6A, and is rated as 350.4W. The maximum ripple and noise voltage is 240mVp-p, which is considerably higher than that of the previous PSUs. The input voltage range is 90 ~ 264VAC with frequency range of 47 ~ 63Hz and efficiency of 94%. The AC input current is 4A at 115VAC and 2A at 230VAC. The primary difference from the previous two Mean Well PSUs includes the UHP-350-24 having an active power factor correction (PFC) circuit, which prevents phase delays between the voltage and current. This function reduces current distortion and adjusts the power factor to have a higher ratio of real power to apparent power (64). The UHP-350-24 also has short circuit protection and brings back the ability to withstand a 300VAC surge input for 5 seconds, similar to the LRS-350-24. Its overload protection categorizes overload to be 110 ~ 140% of the rated output power and it uses hiccup mode to fix the condition. Overvoltage protection will shut down the output voltage when it reaches the range of 26.4 ~ 31.2V (it will not automatically turn back on, user must manually re-power). This PSU also has over temperature protection where it shuts down output voltage when it surpasses working temperature range of -30°C ~ +70°C (power supply will recover on its own upon temperature decreasing). On top of having the largest range for working temperature, the UHP-350-24 does not utilize DC fans for cooling but rather it just uses convection; this results in a less noisy operation. Finally, it has a significantly slimmer design with size dimensions of 220 x 62 x 31 mm (8.66 x 2.44 x 1.22 inches) and has a packaging weight of 0.68kg (~1.50 lbs) (63).

3.7.7.5 Delta PMT-24V350W1AK

Stepping away from Mean Well PSUs, there is a panel mount, switch power supply made by Delta called the PMT-24V350W1AK. This power supply is part of the PMT series and supplies the usual 24V DC, 14.6A, and rated for 350.4W. The output can be adjusted anywhere from 20.0V DC to 26.4V DC. Since this is a switching power supply, it can be selected for it to either input 100-120V AC or 200-240V AC (with a range of 90-132V AC or 180-264V AC singe phase). The nominal input frequency sits between 50Hz to 60Hz with a frequency range of 47Hz to 63Hz. The AC input current at 115V AC is 7A meanwhile at 230V AC it is 4A with an efficiency of 87.0% at 230V AC and 100% load. It has a ripple and noise voltage of less than 150mVpp. In addition to these electrical characteristics, it has overvoltage protection, overload (overcurrent) protection, over temperature protection, short circuit protection, shock protection, and an internal fuse. Overvoltage for this PSU is defined as above 32.4V (it will automatically shut off if reaches higher) and any voltages below this threshold are considered safety extra low voltage (SELV). The device can also handle up to 25A of rated load current, anymore beyond that will make the PSU enter Hiccup mode and will automatically turn back on once it reaches below threshold again. The same Hiccup mode safety features will be used when the power supply reaches a temperature above it's operating temperature of -10°C ~ +70°C. The short circuit protection has hiccup mode, and the shock protection is done by having a connection to Earth. Like most other power supplies discussed earlier, it is air cooled via a DC fan. The size dimensions for this device are 215 x 115 x 50 mm (8.46 x 4.53 x 1.97 inches) and has a unit weight of 0.82 kg (~1.81 lbs) (66).

3.7.7.6 Cosel WMA350H-24

The final switching power supply that will be looked at is the Cosel WMA350H-24. As part of the WM series, it is a single output switching power supply that provides a maximum output wattage of 350.4W with 24V and 14.6A. It has an input voltage range from either 85-132V AC or 170-264V AC (single phase) with an input AC current of 6A at 115V or 3.3A at 230V. It operates at 50/60Hz and has a frequency range of 47-63Hz. The device has an efficiency of 87% when running at 115V AC and 88% when running at 230V AC. With a 100% load, the power supply has ripple noise of up to 150mVp-p. It only has overcurrent and overvoltage protection. The PSU can operate up to 105% of its rating, and the overcurrent protection seems to implement a hiccup mode that allows the device to recover automatically. The overvoltage protection kicks in somewhere between the voltage range of 27.6V to 33.6V, but it is not clear whether it is hiccup or latch. Its operating temperature range is from -20°C ~ +70°C using an internal fan for forced cooling. The dimensions for this device are 115 x 30 x 215 mm (4.53 x 1.18 x 8.46 inches) and weighs 800g (~1.76 lbs) (70).

3.7.7.7 RS PRO 233-6892

The final switching power supply being considered is the RS PRO Embedded Switch Mode Power Supply Model 233-6892. This power supply is meant to be used for medical and industrial purposes, but it matches the requirements needed for our device. For example, it has an input voltage range from 90-264V AC with a frequency range of 47-63 Hz. At 115V AC it takes 4A and at 230V AC it takes 2A. It outputs 24V DC at 14.6A for a rated power of 350W with an efficiency of 93%. It also has 150mVpp maximum ripple and noise voltage. It has a few protections in place such as overvoltage, which it defines as being above

30V. When the over 30V condition is met, the PSU will turn off output voltage and will have to be manually re-powered for it to recover. Overcurrent protection allows it to self-recover when the output current goes beyond 110% of its rated output current. Finally, short circuit protection also has a self-recover mode. The power supply has no overtemperature protection, but it is fan cooled with an operating temperature is -40°C ~ +70°C. Finally, it has size dimensions of 130 x 86 x 35 mm (5.12 x 3.34 x 1.38 inches) and weighs 430g (~0.95 lbs) (81).

3.7.7.8 Power Supply Unit Comparison

Now that plenty of power supplies have been covered, it is obvious that many of them have striking similarities with only a few minute differences. For example, each of these all have the same ten terminals layout: one voltage adjustment/regulation terminal, three positive DC output terminals, three negative DC output terminals, one AC ground wire terminal, one AC neutral line terminal, and one AC live wire terminal. Due to the specifications of the Ender-3 V2 Neo, all of the aforementioned power supplies have a general range of input AC voltages that allow house 100-120V AC or 200-240V AC at 50/60 Hz. Each of them outputs 24V at 14.6A which gives them a 350.4W power rating. Many of them have some assortment of protections for either overvoltage, overload, overcurrent, overtemperature, or short circuits. The areas that they each mainly differ in are the number of protections they have, the operating temperatures, the efficiency of the power supplies, leakage or ripple/noise, sizes, and weights. Some of the more important factors include efficiency, protection, and size of the PSU. Ideally, the power supply wastes the least amount of power possible, has the most circuit protections in place for safety reasons, and is as compact as possible to fit within the frame of the Ender-3 V2 Neo's housing space. Below is a table comparing the various specifications of each of these power supplies.

3.7.7.9 Table Comparison Between Power Supply Units

	CMS 350-24	LRS-350-24	S35024	UHP-350-24	PMT-24V350W1AK	WMA350H-24	233-6892
Manufacturer	Creality	Mean Well	Mean Well	Mean Well	Delta	Cosel	RS PRO

Type of PSU							
Rated Output Voltage							
Rated Output Current							
Rated Power							
Input Voltage							
Input Current							
Efficiency							
Frequency							
Ripple and Noise							
Leakage							
Operating Temperature							
Cooling Method							
Hours of Operation							
Protections							
Method of Protection							
Safety Class							
Dimensions							
Weight							
Cost							

3.8 Solder Paste

Solder paste will be dispensed on all the PCB boards from the dispenser. There are different types of solder paste depending on a variety of parameters including alloy, flux, and size. For the best results then one of the solder paste types needs to be chosen to be used within the dispenser.

First and foremost, before solder paste is made, there is just solder powder made from an alloy. The most common alloys are SAC305 or eutectic. Eutectic is an alloy comprised of tin and lead. SAC305 is an alloy combination of tin, silver, and copper. Both eutectic and SAC305 consist mostly of tin because it has a relatively low melting point of five hundred-five Kelvin and in other terms two hundred thirty-one Celsius. Since lead is hazardous, eutectic alloys have been mainly pushed aside and SAC305 is mainly used in the surface mount technology industry. The copper in SAC305 helps lower the melting point of the alloy and the silver helps by adding extra mechanical strength to the alloy. Other metals that are included in other less commonly used alloys include nickel, indium, antimony, and bismuth.

The next component of solder paste is the flux which helps turn the solder powder alloy into the paste that is well known. The flux is primarily used to clean the surface to solder on and allow the solder powder to have wetting which makes it spreadable and able to come out of a dispenser smoothly. There are three types of flux which are water-soluble flux, no-clean flux, and rosin-flux.

Rosin-flux is a mildly aggressive cleaning agent and good for wetting. The rosin-flux does have a downside when it comes to cleaning the leftover residue after the soldering process. Special solvents need to be used to remove unwanted residue to prevent corrosion.

Another type of flux is water-soluble flux. It is great for removing oxide layers which clean the surface to solder on and is a more aggressive cleaning agent than rosin-flux. Water-soluble flux is problematic because it does not burn off well which means it gets left behind on the PCB and all the flux needs to be removed to prevent corrosion. Corrosion can occur on the PCB if the leftover water-soluble flux residue is left. An advantage over rosin-flux is that for the cleaning process, only water is needed to clean the water-soluble flux off.

A flux that does not need excessive cleaning was the next development which brought no-clean flux. There was a trade-off made in the development to not need cleaning. No-clean flux does not clean the surface to the same level as water-soluble flux because it is not as aggressive as a cleaning agent. There are also combinations of no-clean flux and rosin-flux that need little cleaning and have a better cleaning agent than no-clean flux alone.

The particle size is the last main component of solder paste. The particle sizes in each solder paste are identified by the type number of the solder paste which describes the particle size of the solder power alloy. The range of types is one to eight with type one having the largest solder paste particle sizes to type eight which has the smallest particle sizes. IPC is the standard that determines the size to type for the solder powder particles.

The process of using a spray to atomize molten solder powder and then sifting the particles in a series of meshes allows for the collection and organization of the different-sized solder powder particles for solder paste. The type number also refers to mesh size as well as the particle size.

The most common type sizes to be used are type three and type four, which range with particle sizes from twenty-five to forty-five microns and twenty to thirty-eight microns respectively, as they are the most applicable size for most applications. As electronics have become smaller and smaller overtime, the types with smaller particle sizes have increased in popularity. The best type to use for our project is going to be type three as it is commonly available and based on the expected PCBs that will use the project, they are not going to require ultra small particle sizes.

IPC Category	Powder Size (microns)	Minimum Aperture Size (mil)	Min inner diameter for needle/nozzle (mm)
Type 1	150-75μ	30	1.50
Type 2	75-45μ	15	0.75
Type 3	45-25μ	9	0.45
Type 4	38-20μ	7.5	0.38
Type 5	25-15μ	5	0.25
Type 6	15-5μ	3	0.15
Type 7	11-2μ	2.5	0.11
Type 8	8-2μ	2	0.08

Chapter 4 – Standards and Design Constraints

4.1 Related Standards

The following standards are relevant to the extent of the Solder Paste Dispenser. Despite not having the parts selected, these standards generally cover the current specific needs of this project. Once the parts have been finalized, much greater detail will be provided, and more standards will be described below.

4.1.1 Universal Serial Bus (USB) 3.2

Universal Serial Bus (USB) 3.2 is a set of standards that was released in 2017. USB 3.2 supports a max transfer speed of up to 20 Gbits per second, this is possible by using two-lines with a maximum speed of 10Gbits in parallel. USB 3.2 is the specific standard for how data transfers. The physical connections themselves supported in USB 3.2 are the Standard-A connector, Standard-B, Micro-A, Micro-AB, Micro-B, and the newer Type-C.

4.1.2 ISO 45001

The ISO 45001 standard covers occupational health and safety requirements. These standards provide a strategic management framework which is designed to integrate safety into the workplace. The standards provide guidelines for companies to ensure that the workplace is safe. It provides guidelines for hazard identification and risk assessment. It also focuses on facilitating improvements on safety, not just reducing risk of injury. Considering the likelihood of utilizing laboratories to develop our systems, ISO 45001 is applicable to the development of this system.

4.1.3 ISO 10110

The ISO 10110 standard are the standards used for specifying optical elements. It encompasses design drawings and table specifications. ISO 10110 drawings are typically divided into four main parts – the drawing of the optical component itself, and three columns below it that describe the left and right surfaces, as well as the material. By standardizing the layout of optical drawings for designers, manufacturers and users; they can easily find the information they need from a specific optical drawing, and this makes it much easier for different disciplines that support the product to understand what is going on. The right column and left column describe the shape and specifications of the surface of the optic. The center column describes the material the optic is made of and its specifications. The specifications for the left, center, and right columns are standardized as well. There are 13 specification types, and they can either be specified or left empty on the drawing if irrelevant or not important. These specification types include general remarks, material stress birefringence, material bubbles and inclusions, material inhomogeneity and striae, surface form tolerance, centering tolerance, surface imperfection tolerance, surface texture, surface treatment and coating, data of lens element, non-toleranced data, aspheric surface detail, and laser induced damage threshold.

4.14 EMVA 1288

The EMVA 1288 standard is a standard created by the European Machine Vision Association. It is a widely recognized guideline that standardizes the measurement and reporting of camera and image sensor performance for machine vision systems. This standard is used by camera manufacturers and exists to ensure that cameras and sensors are tested with consistency and comparability. This allows consumers to compare different sensors and cameras reliably. Measurements of key parameters like quantum efficiency, signal-to-noise ratio, dynamic range, and saturation capacity are all standardized.

4.1.5 IEC 62368-1

The IEC 62368-1 standard was introduced by International Electro technical Commission (IEC) and enforced on December 20th, 2020. It is a safety standard dedicated to identifying energy sources and proposing safeguards against them. It should reduce injuries and damage for a wide range of technology products such as computers, networks, consumer electronics, displays, audio/video equipment, communications products, office appliances, and power supplies. It was initially introduced to supersede prior safety standards such as the IEC 60950-1 (ICT) and the IEC 60065 (AV). It is a standard in the U.S., Canada, and the EU. Some of the safety concerns that the latest 4th edition brings up are electrically caused injuries and fires, along with thermal burn injuries by making changes to touch temperature limits allowed on certain products. Regarding switched-mode power supplies, it specifies that prior to supplying power it is required to use proper loads with specific characteristics for output voltage, current, or power to be measured. This standard can be found in many of the referenced switched-mode power supply datasheets.

4.1.6 IEC 60601-1-2:2014

The IEC 60601-1-2:2014 standard was introduced by IEC as a safety standard to reduce the emission of electromagnetic disturbances in devices that might be commonly used for Medical Equipment (ME). It specifies the necessary EMC Immunity test level that a device must abide by depending on its environment of intended use. It also provides clarification on how to test for and determine a device's immunity level depending on its intended use. The standard also elaborates on the criteria for what is considered a pass or a failure for EMC immunity. The fourth edition of this standard comes as a revision to replace the previous third edition. This standard was made for enforcement in the U.S. and the EU. However, it does not only apply to medical equipment as some of the referenced power supplies abide by these standards.

4.2 Economic Constraints

There is a huge economic constraint when it comes to making this project. Personalized solder paste dispensers typically range in the several hundred to several thousands of dollars to purchase one. For example, those sold by IntelliSpense can cost anywhere from $7,700 to $12,100. For high-end solder paste dispensing, this price can be justified as this is a very niche market and target audience that this product would be sold to. The alternative that the team is providing is still expensive, but significantly cheaper than those sold in the automatic solder paste dispenser industry.

The main economic constraint is simply funding for this type of project. Despite it being cheaper than commercial off the shelf products, it still requires a few hundred dollars to achieve, on top of the time it takes to put it together. For starters, the Ender-3 V2 Neo that the team is basing the design off of must be purchased in order for us to use its mechanical structure. The Ender-3 V2 Neo currently costs $299.00 which is a requirement for this project to be realized. The downside to purchasing this 3D printer is that most of the money spent on it will be for a complete package that the user will plan to dismantle and not utilize. Many of the parts that the printer comes with will be rendered useless in order to adapt it into a solder paste dispenser. These parts include the display, PCB, power supply, motor drivers, stepper motors, heating bed, and nozzle for dispensing.

Now that the user has purchased the Ender-3 V2 Neo and understands what components will not be used, they will then need to spend an estimated ~$280 extra as mentioned later in Chapter 10.1 Budget and Financing. The team's design includes implementing a new MCU capable of delivering all the features needed, a new touchscreen display with a fresh UI, different stepper motors that grants higher precision, different motor drivers, a new power supply with regulators, and the cameras and optics system.

Now that the whole picture has been painted, it is clear to see that this project will cost upwards of around $500-$600. Luckily, the project has been sponsored by Dr. Arthur Weeks which grants the team the ability to design a more complex and intricate solder paste dispenser. It is a relatively expensive system to make and variables such as price or component availability might complicate the process further. For the current design and path of development, the team's solder paste dispenser will be as efficient, cost-effective, and reliable as possible.

4.3 Time Constraints

In order to create and/or replicate the design of this solder paste dispenser, it would take not only a lot of money, but a lot of time and effort. One would need to purchase the pre-existing structure of the Ender-3 V2 Neo and then implement the rest of the team's design on their own. The time constraints are mainly within the building aspects of it rather than any other types of constraints.

The team must meet their milestones and soft deadlines earlier than the actual due dates. Missing milestones would result in a snowball effect that leads the team to progressively fall even farther behind schedule. When it comes to senior design as a course in each team member's degrees, it is of utmost importance that each member puts all of their effort into this project to ensure it works. If the project were to be unsuccessful, it would result in repeating an extra two semesters prior to being able to graduate. This is a huge time constraint as senior design only offers two semesters for students to plan, prepare, design, and implement their projects. Senior Design I is meant to cover the planning and preparation phase when all of the report deadlines are due. Senior Design II covers more of the design and implementation phase when the actual constructing of the physical device occurs. By the end of Senior Design II, it is expected to have a fully functional and reliable automatic Solder Paste Dispenser.

The team is fortunate enough to work under the guidance of Dr. Arthur Weeks, who has a general idea of the end result of this project. This helped the scheduling of our milestones since Dr. Weeks laid the groundwork for what results are expected of the team. The goals and objectives that were set in the original Divide and Conquer document were inspired by Dr. Weeks original concept of the solder paste dispenser.

Considering the grand importance of this project, it is in the best interest of each team member to ramp up production and put as much time and effort into this. Not only will this project be a success through our efforts, but it will be and has been a great learning and researching experience.

4.4 Equipment Constraints

4.5 Safety Constraints

The solder paste dispenser is comparable to a 3D printer regarding safety. Maybe even safer as we do not require any heating elements to dispense the solder paste. To ensure we have a safe and reliable device, we must have reliable, isolated electrical connections. This is important to reduce the risk of short-circuiting which could cause harm or fire. For safe operation, users should avoid placing their hands in the motors or in the region of dispensing during operation. When modifying the dispenser, the dispenser should be off.

4.6 Environmental Constraints

4.7 Manufacturability Constraints

When it comes to the manufacturability of the Solder Paste Dispenser, there are a lot of factors to consider. As previously mentioned, the 3D printer that this solder paste dispenser is being built upon is only being used for its mechanical structure. The other components of the printer are simply inspiration for what the team seeks to achieve. The mechanical structure of the printer does not need to be manually manufactured, just simply purchased. This includes other design requirements like the power supply, stepper motors, etc. The optical system that is currently still being researched and developed will require a certain level of assembling to achieve. The lenses and cameras themselves will not be manufactured by the team, they will simply be purchased and put together.

On the other hand, the PCB is the main component that requires actual manufacturing to be outsourced. The PCB houses a plethora of components from microcontrollers to active components like op-amps to basic passive components like resistors, capacitors, and inductors. As a result, one of the biggest constraints regarding manufacturability is the availability of the necessary components. There are plenty of replacements for components in the event that any of them are unavailable to have long lead times, however the user would need to communicate with the PCB manufacturer to resolve this issue. The cost of making the PCB could range anywhere from a few tens of dollars to about one hundred dollars.

All of the ECAD software that have been discussed in prior chapters are capable of creating the necessary Gerber files to submit to manufacturers for them to begin building it. However, each manufacturer has different design constraints that must be discussed prior to designing the PCB for this project. For example, traces and vias might have a strict minimum size that the manufacturer requires the designer to abide by in order to ensure it is manufactured correctly. This is due to the fact that different manufacturers have different industrial machines with different precision and tolerances. Of course, as the design of the PCB becomes more complicated/smaller, that results in stricter economic constraints to fully realize the design.

The PCB design should also be simple to install and connect with the other components of the solder paste dispenser. It must be taken into account that different users with varying levels of experience might seek to replicate or handle this device. Thus, the manufacturing constraints are a very important aspect of the solder paste dispenser.

4.8 Ethical Constraints

This section will discuss the various ethical constraints associated with the design, development, and use of the solder paste dispenser project. This section is important to understand and ensure legality and responsible use of technology. We will discuss intellectual property concerns that are necessary to ensure that the solder paste dispenser project respects intellectual property rules.

When utilizing software or hardware for a project, it is important to review the legal requirements and ensure proper credit where necessary. Some hardware and software are open-source, while others are proprietary. With open-source, it may be as simple as providing credit. With proprietary, hardware and software typically require licensing agreements. Providing credit is always important; however, since we do not currently plan to commercialize our product, the restrictions are slightly relaxed. To ensure best ethics, we will provide credit where necessary.

4.9 Sustainability Constraints

Chapter 5 – Comparison of ChatGPT

5.1 Introduction

ChatGPT is a very useful artificial intelligence (AI) tool developed by OpenAI that is designed to interact with users in a “conversational way” (OpenAI). It is a generative language model that is trained to perform tasks such as answering questions, generating text, processing audio, and much more. The approach used to train this model is called reinforcement learning from human feedback (RLHF). This was achieved by feeding prompts to ChatGPT and having groups of humans pick their preferred response provided by the AI model (Technology Review). This process helped clean up the model to try to avoid responding with mistakes, false claims, and other erroneous material. However, this AI model is still being worked on as it is currently in version GPT-4 and it still has plenty of limitations.

According to OpenAI, ChatGPT may respond with incorrect answers since there is no objective “source of truth” that the model was trained to grab information from. In addition, if OpenAI was to make the model more conservative with its responses, it might lead to not responding to a question all together. The model currently might provide different responses based on the way the prompt is worded by the user. With that in mind, ChatGPT might take some freedoms and assume what the user is asking without clarifying it with further questions. On top of all of those limitations, OpenAI is trying to optimize the model as much as possible to prevent it from utilizing biased data, behaviors, and responses in order to provide the most comprehensive replies (OpenAI/index).

5.2 Power Supplies Example

With that being said, there are some ways in which ChatGPT can prove to be useful for engineering projects such as this Solder Paste Dispenser. For example, the team asked ChatGPT to provide various other commercial off-the-shelf power supplies that are similar in specifications to the one that is used in the Ender-3 V2 Neo along with some resources to find more information on them. The response it provided was very well-informed as it listed off five different power supplies, some “key features” that the user should consider when choosing a power supply that fits their needs, and some links to popular electronic components marketplace websites. It first described the type of input the Ender-3 V2 Neo uses along with the type of power supply (switch-mode power supply) that it is. It also follows a format for the list starting with the input voltage, output voltage, power rating, frequency, features, and where it is available for purchase.

However, a few issues arose when it began to list off different power supplies. Out of the five power supplies it provided, only three of them were useful and/or unique. The list consists of the Mean Well LRS-350-24, RS PRO 24V DC 350W, S-350-24 Power Supply, Mean Well RSP-320-24, and the BTF-Lighting LRS-350-24. The first three aforementioned power supplies were good recommendations from ChatGPT upon further researching the parts, but the final two were not. The Mean Well RSP-320-24, while being a real power supply, does not match the power rating (350W) of the Ender-3 V2 Neo that even ChatGPT acknowledges in the conversation's following paragraph. It closely matches the specifications, but the output current rating and output power rating do not match the requirements for the 3D printer. Then, the fifth and final recommendation of the BTF-Lighting LRS-350-24 is simultaneously erroneous and a duplicate of the first power supply made by Mean Well which was suggested. BTF-Lighting is mainly a lighting and LED company that sells multiple LED products ranging from matrix displays, modules, pixel strips, chips, and controllers (BTF-Lighting). They do happen to sell power supplies, but they are not manufactured nor designed by BTF-Lighting (rather they are made by JSPower). There is one power supply that is sold on the BTF-Lighting website that is capable of surpassing the power rating, but again it is not made by them. In addition, the power supply is also not called the LRS-350-24.

After listing off the power supplies, ChatGPT provides a section discussing the main features to focus on when looking for a power supply. It includes the required input voltage range, output voltage, power rating, protection features, form factor, and method of cooling. After this, it provides a few links to marketplace websites for electronic components to help steer the user in the right direction looking for more parts (ChatGPT Convo).

Overall, ChatGPT was able to help steer the team in the right direction and provide a reference of what the type of power supply is and where to find them. For example, ChatGPT helped locate Mean Well, which makes multiple different 350W switch-mode power supplies that meet the requirements for the Ender-3 V2 Neo. The features section also gave the team an idea of what to look for in these power supplies. There are multiple factors when choosing one, but ChatGPT provides a good start for users that might be new to the power supply industry.

5.3 Code Example

5.4 Conclusion

Nonetheless, ChatGPT can provide good suggestions meanwhile spewing out nonsensical results or data. It is up to the user to research further based on the general ideas given by the AI model's response. In addition, users who seek more detailed responses must ask more questions or even challenge the model by giving it even more prompts.

Chapter 6 – Hardware Design

Chapter 7 – Software Design

Chapter 8 – System Prototype Construction

Chapter 9 – System Testing and Evaluation

Chapter 10 – Administrative Content

10.1 Budget and Financing

Component Description	Quantity	Cost per component	Cost Sum
ESP 32 MCU	1	$8	$8
Touchscreen Display	1	$25	$25
Stepper Motors	3	$20	$60
Motor Drivers	3	$10	$30
Power Supply	1	$25	$25
PS Regulator	1	$12	$12
Cameras	2	$15	$30
Optics	2	$45	$90
PCB	1	TBD	TBD
		Total Cost:	$280

Table 10.1.1 *Budget and Financing*

*The 3D printer which the internal circuitry needs to be rebuilt completely has been donated to the team for this specific project. The cost is not provided in the table above.

10.2 Project Milestones

The milestones mark important objectives that our team needs to reach to complete this project on time. Staying on target with persistent planning and work will keep us on track. We plan to hit the ground running by starting to test and prototype earlier than needed to run into unknown issues and solve them sooner rather than later.

Initialization Phase				
Milestone	**Description**	**Start Date**	**End Date**	**Duration**
Group Formation	Bring the group together and meet our project sponsor	08/19/24	08/26/24	1 Week
Communication Tools	Group meeting to decide on tools to track tasks and stay organized	08/26/24	09/02/24	1 Week
Committee Formation	Reach out to faculty to form our committee	08/26/24	09/06/24	2 Weeks
D&C Paper	Complete the first 10 pages of the paper	08/26/24	09/06/24	2 Weeks
60 Page Paper	Complete the first half of the paper	09/06/24	10/25/24	7 Weeks
Final Paper	Finish and finalize the entire paper	10/25/24	11/26/24	5 Weeks

Table 10.2.1 *Initialization Phase Milestones*

Production Phase				
Milestone	**Description**	**Start Date**	**End Date**	**Duration**

Component Selection	Determine components for the project	09/09/24	TBD	TBD
Gerber file software	TBD	TBD	TBD	TBD
Stepper Motor Software	TBD	TBD	TBD	TBD
Screen GUI software	TBD	TBD	TBD	TBD
PCB Design	TBD	TBD	TBD	TBD
Optical Inspection System Design	Design and assemble optical inspection system.	TBD	TBD	TBD
Optical Stereoscopy System	Program image processing to produce 3D representations of target areas.	TBD	TBD	TBD
Integrate and Test	TBD	TBD	TBD	TBD
Final Design	TBD	TBD		TBD

Table 10.2.2 *Production Phase Milestones*

10.3 Work Distributions

Work Distributions	
Name	**Tasks for Project**
Nathan Boucher	Code to take XYZ coordinates and translate to stepper motors movement and dispensing, Part of Code to convert Gerber Files
Mikell Alfonso	PCB design and creation, PCB design for stepper motors
Elizar Tsymlyakov	Optical System Design and Image Analysis
Edward Weir	Code for Display GUI, Part of Code to convert Gerber Files to usable information for SPD

Table 10.3.1 *Work Distributions*

Chapter 11 – Conclusion

Appendix A – References

[1] “Products-creality 3D printer,” creality, https://www.creality.com/pages/products?collection=Ender%2BSeries&spm=..product_242cbae6-d639-4293-a537-e4e37310fa67.header_1.1&spm_prev=..product_6f26c47a-4f19-44d2-8e0a-a98315510cae.nav_link_store_1.1 (accessed Oct. 24, 2024).

[2] “Ender-3 V2 neo 3D printer,” creality, https://www.creality.com/products/ender-3-v2-neo-3d-printer?spm=..page_1967279.products_display_1.1&spm_prev=..product_ce00868d-efe2-4fa8-9168-240e7c3b3cd1.header_1.1 (accessed Oct. 24, 2024).

[3] “Mouser,” SFE_WMA-3398293, https://www.mouser.com/datasheet/2/622/SFE_WMA-3398293.pdf (accessed Oct. 24, 2024).

[4] “Deltapsu,” PMT-24V350W1AX, https://www.deltapsu.com/en/products/download/Datasheet/PMT-24V350W1AK (accessed Oct. 24, 2024).

[5] “Improve power converter reliability using hiccup-mode ...,” Improve Power Converter Reliability Using Hiccup-Mode Current Limiting, https://www.ti.com/lit/an/snva604/snva604.pdf (accessed Oct. 24, 2024).

[6] LRS-350-MEAN WELL Switching Power Supply Manufacturer, https://www.meanwell.com/productPdf.aspx?i=459 (accessed Oct. 24, 2024).

[7] Creality VIP Mall, https://mvip.creality.com/en/goods/goodsDetail/945 (accessed Oct. 24, 2024).

[8] “Products-creality 3D printer,” creality, https://www.creality.com/pages/products?collection=Ender%2BSeries&spm=..product_242cbae6-d639-4293-a537-e4e37310fa67.header_1.1&spm_prev=..product_6f26c47a-4f19-44d2-8e0a-a98315510cae.nav_link_store_1.1 (accessed Oct. 24, 2024).

[9] “Ender-3 V2 neo 3D printer,” creality, https://www.creality.com/products/ender-3-v2-neo-3d-printer?spm=..page_1967279.products_display_1.1&spm_prev=..product_ce00868d-efe2-4fa8-9168-240e7c3b3cd1.header_1.1 (accessed Oct. 24, 2024).

[10] “OrCAD PCB design software,” EMA Design Automation, https://www.ema-eda.com/products/cadence-orcad/why-orcad (accessed Oct. 24, 2024).

[11] R. Pöschl, “How to create a bill of Materials (Bom)?,” KiCad.info Forums, https://forum.kicad.info/t/how-to-create-a-bill-of-materials-bom/12346 (accessed Oct. 24, 2024).

[12] “About KiCad,” KiCad EDA, https://www.kicad.org/about/kicad/ (accessed Oct. 24, 2024).

[13] “Visual collaboration and Version Control Platform for YOUR PCB,” CADLAB.io I Visual collaboration and version control platform for your PCB, https://cadlab.io/ (accessed Oct. 24, 2024).

[14] Altium Education, https://education.altium.com/courses/ (accessed Oct. 24, 2024).

[15] “Transforming the electronics industry with innovative PCB design software,” Altium, https://www.altium.com/ (accessed Oct. 24, 2024).

[16] “What is autodesk fusion?,” Autodesk, https://www.autodesk.com/solutions/what-is-fusion-360 (accessed Oct. 24, 2024).

[17] “Eagle / Autodesk Fusion Software: Get Prices & Buy Official,” Autodesk, https://www.autodesk.com/products/eagle/overview?term=1-YEAR&tab=subscription&plc=FSN (accessed Oct. 24, 2024).

[18] “Reference I Flux,” Docs.flux.ai, https://docs.flux.ai/reference (accessed Oct. 24, 2024).

[19] “A better way to build PCBS,” Flux, https://www.flux.ai/p (accessed Oct. 24, 2024).

[20] “PCB Design I cadence,” Cadence, https://www.cadence.com/en_US/home/training/pcb_design.html (accessed Oct. 24, 2024).

[21] “Matrix,” Parallel Systems, https://www.parallel-systems.co.uk/matrix/ (accessed Oct. 24, 2024).

[22] “Allegro X design platform | PCB & system design | cadence,” Cadence, https://www.cadence.com/en_US/home/tools/pcb-design-and-analysis/allegro-x-design-platform.html#allegro-x-pcb-designer (accessed Oct. 24, 2024).

[23] “OrCAD PCB design software,” EMA Design Automation, https://www.ema-eda.com/products/cadence-orcad/why-orcad (accessed Oct. 24, 2024).

[24] R. Pöschl, “How to create a bill of Materials (Bom)?,” KiCad.info Forums, https://forum.kicad.info/t/how-to-create-a-bill-of-materials-bom/12346 (accessed Oct. 24, 2024).

[25] “About KiCad,” KiCad EDA, https://www.kicad.org/about/kicad/ (accessed Oct. 24, 2024).

[26] “Accelstepper,” AccelStepper - Arduino Reference, https://reference.arduino.cc/reference/en/libraries/accelstepper/ (accessed Oct. 11, 2024).

[27] “Stepperdriver,” StepperDriver - Arduino Reference, https://reference.arduino.cc/reference/en/libraries/stepperdriver/ (accessed Oct. 11, 2024).

[28] “Arduino documentation,” docs.arduino.cc, https://docs.arduino.cc/libraries/st (accessed Oct. 11, 2024).

[29] When your project involves interfacing peripherals with a microcontroller, “SPI vs I2C protocols - pros and cons,” Arrow.com, https://www.arrow.com/en/research-and-events/articles/spi-vs-i2c-protocols-pros-and-cons (accessed Oct. 11, 2024).

[30] Editor, “FAQ: Capacitive or resistive touch?,” Crystalfontz LCD Blog, https://www.crystalfontz.com/blog/faq-what-is-the-difference-between-a-resistive-and-a-capacitive-touch-screen/ (accessed Oct. 10, 2024).

[31] “Crystalfontz glossary - I2C,” Crystalfontz LCD Blog, https://www.crystalfontz.com/blog/glossary/i2c/ (accessed Oct. 10, 2024).

[32] “Unique solution for electronic production,” Solder Paste Jet Printing Solution | Essemtec AG, https://essemtec.com/en/products/dispensing/solder-paste-jet-printing/ (accessed Sep. 19, 2024).

[33] “Tech specs - compare our products: Voltera,” Voltera Inc., https://www.voltera.io/tech-specs (accessed Sep. 19, 2024).

[34] “V-one - A desktop PCB printer: Voltera,” Voltera Inc., https://www.voltera.io/v-one (accessed Sep. 19, 2024).

[35] “Premium printer yrp10 Overview,” Yamaha Motor Co., Ltd., https://global.yamaha-motor.com/business/smt/printer/yrp10/ (accessed Sep. 19, 2024).

[36] “Edison II Act Stencil printer: ITW EAE,” Edison II ACT Stencil Printer I ITW EAE, https://www.itweae.com/product/mpm-printers/edison-ii-act-stencil-printer (accessed Sep. 19, 2024).

[37] “Solder paste perfection at Jet Speed - how jet printing is gainin...,” Evertiq, https://evertiq.com/nanews/45650 (accessed Sep. 19, 2024).

[38] “Solder paste printing process,” SURFACE MOUNT PROCESS, https://www.surfacemountprocess.com/solder-paste-printing-process.html (accessed Sep. 19, 2024).

[39] “Essential technical knowledge of solder paste printing Machi,” I.C.T is the Provider of Reflow Oven,Pick and Place Machine,SMT Machine, https://www.smt11.com/blog/SMT-Field/Essential-technical-knowledge-of-solder-paste-printing-machi-5378.html (accessed Sep. 19, 2024).

Appendix B – Copyright Permission

Appendix C – Acronyms

Abbreviation	Definition
IC	Integrated Circuit
PCB	Printed Circuit Board
LED	Light-Emitting Diode
I2C	Inter-Integrated Circuit
SPI	Serial Peripheral Interface
SPD	Solder Paste Dispenser
USB	Universal Serial Bus
SD	Secure Digital
GPIO	General Purpose Input Output
I/O	Input / Output
CSI	Camera Serial Interface
RMS	Root-mean squared
SNR	Signal-to-noise ratio