PIN ART PRO

ECE 445 Design Document

3/2/2021

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1. Introduction

1.1 Objective

When it comes to art, both artists and art enthusiasts strive to create and find unique pieces that invoke human emotion. For this reason, the role of technology in art is largely focused on computer assistance in creating art as opposed to generating pieces based solely on algorithmic means [1]. In the medium of pin art, technology such as image processing is used to create on-the-spot contours of live image feeds. This style of pin art is limited by a lack of readily available and easy-to-use machinery to automatically generate contours of static images. Artists who wish to create amazing pieces of pin art that amaze crowds must spend many hours or dollars overcoming a technical knowledge barrier that prevents mechanical pin-art masterpieces from becoming a mainstream art medium.

Our solution is a pin-art board that uses a motorized pin-displacer to take static digital images using file formats such as PNG and JPG to create pin-art contours using the grayscale equivalents of those images that are then turned into edge data files using OpenCV. The displacer allows artists to focus on the pin material and color rather than mechanical engineering issues, and the physical contour also has the side effect of allowing visually impaired persons to use the pin-art to get an idea of what the image may have looked like.

1.2 Background

The idea of the “Pin Art Pro”, a pin-displacing physical display, has existed and been worked on before in different forms with varying degrees of success. Stanford has created a high tech and expensive version which is used to quickly give side views of objects from files representing 3-dimensional objects [2]. Designer Sean Follmer has created a table top with a pin display used to show 3 dimensional math formals and gives people the ability to interact with objects by having a camera feedback loop that tracks the displacements of objects in front of the camera [3]. Even though pin-displacing physical displays exist there are some major drawbacks with those that exist.

Both pin displays described above designed by others are used to represent 3 dimensional objects in 2.5 dimensions (like 3D, but only gives a side view and doesn’t show all sides of the object at the same time). These displays allow blind people to easily create 3 dimensional objects by allowing them to see all sides of an object before they print it on 3D printers. Right now, however, it is still hard for blind people to see 2D art. Most 2D art is used to represent 3D objects. With our apparatus, we can add an extra half dimension to give depth to 2 dimensional works so they can see the art by feeling it. Our project will work as one step in that direction. We do not lock the pins in place at the moment so feeling the pins may push them back. Our project will still be cheaper as instead of moving each pin individually as done in the other designs we are pushing groups of pins at a time, which will be slower but significantly cheaper.

1.3 Visual Aid

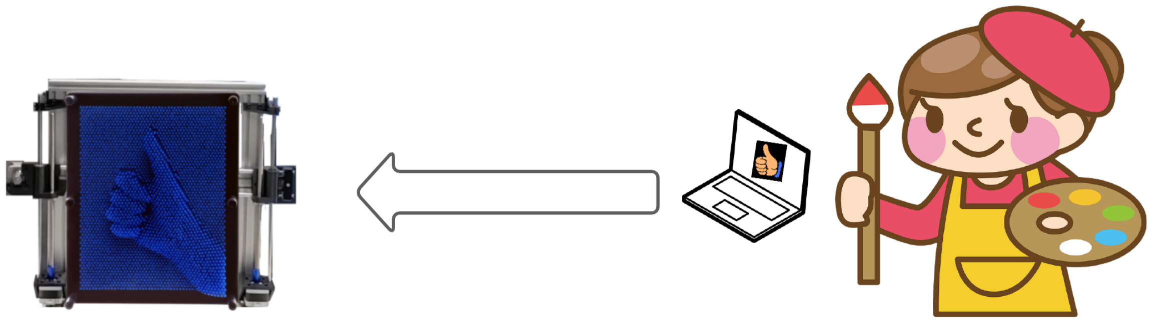

Fig. 1. Visual representation of Pin Art Pro use case.

1.4 High-Level Requirements

- Using our computer program to interface with the Pin Art Pro device, the user should be able to see a visually recreated image on the pin art board at a lowered resolution of 16x20 pixels.

- Given a digital image of arbitrary resolution, our image analyzer should output a motor controller data file of size 3.5KB or less to fit onto the Pin Art Pro device memory.

- Our motor hardware should be able to align our linear actuator to any 0.5in x 0.5in. region of the board within a tolerance of +/- 0.1in and push pins on the board using the actuator by an adjustable distance between a range of 0in - 2.3in.

2. Design

2.1 Physical Design

On the very back of our product there is the pin pusher, which is given power through the regulated wall outlet and has its movements managed through our PCB. This is behind the actual pin art board which gets pushed by a linear actuator that can move in the Z and Y axis. The full design with both the pin art display and the pin pusher behind it is shown in Figure 2.

Fig. 2. Physical view of the front of the Pin Art Pro.

For our *Physical Design* the pin art board [4] was taken from the actual pin art board we bought for this project. The *Pin Pusher*, behind the pin art board on Figure 2 and all of Figure 3 was edited from Maker Mashup's 3D Printer [5].

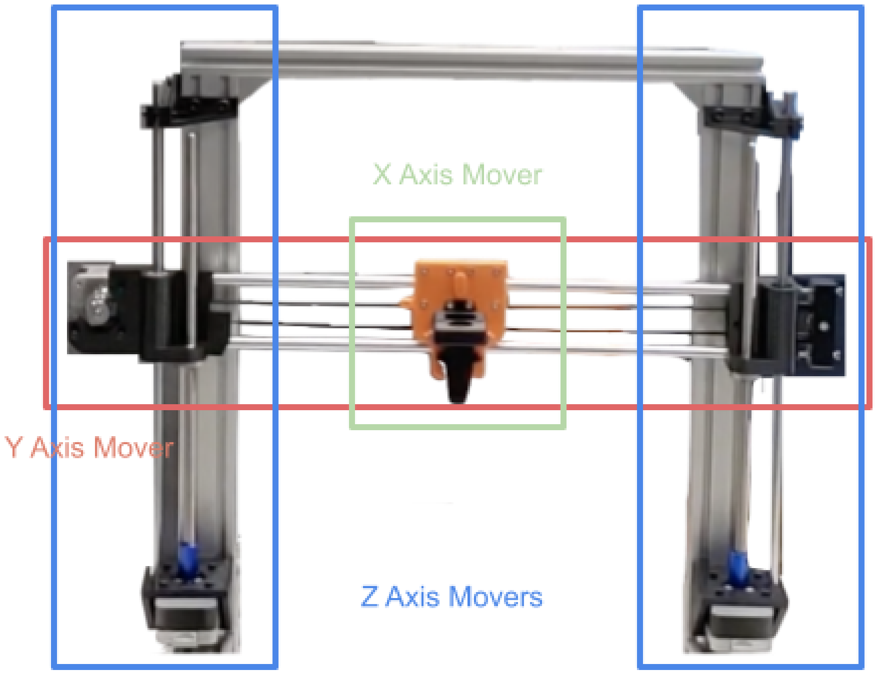

Fig. 3. Physical design of the Pin Pusher component.

Figure 3 shows the Pin Pusher which moves the linear actuator along the Z and Y axis. The linear actuator on the X Axis mover pushes the pins pack.

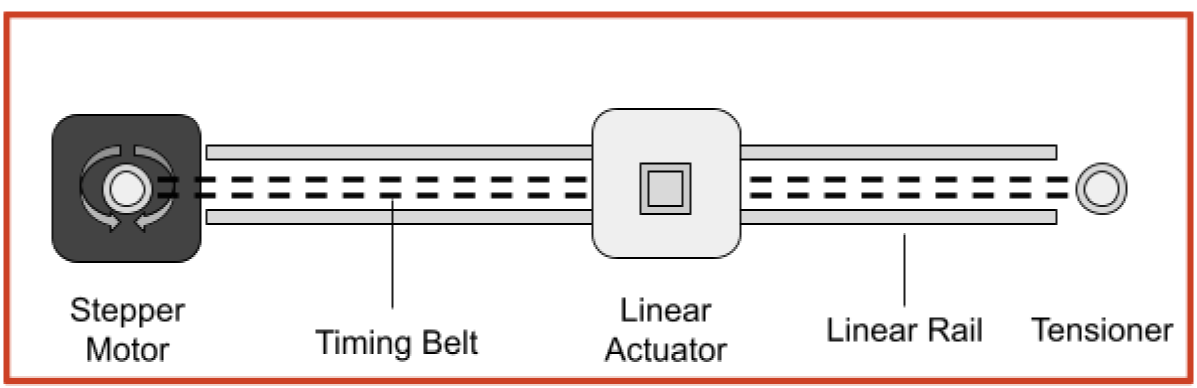

Fig. 4. Y-Axis Mover front view diagram.

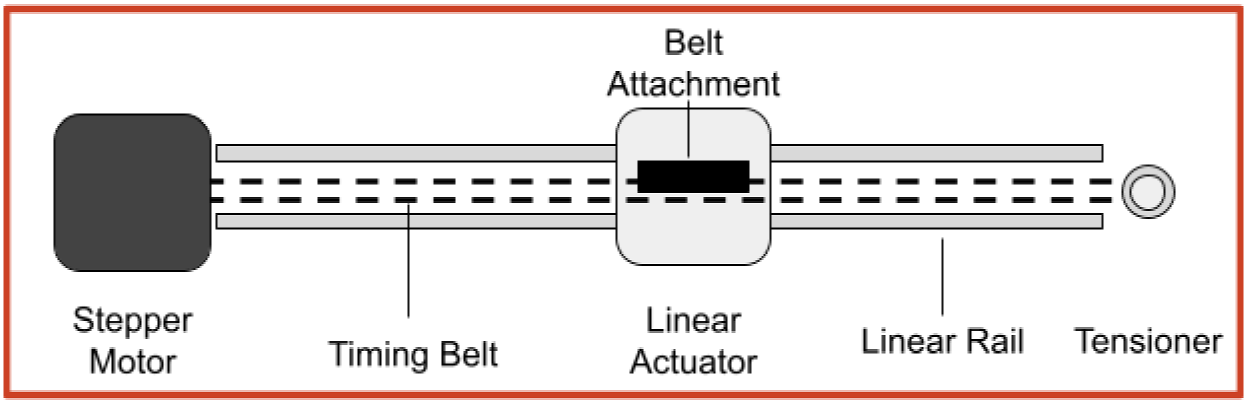

Fig. 5. Y-Axis Mover back view diagram.

Figures 4 and 5 shows the Y Axis Mover moves the linear actuator along the Y axis by attaching it to a timing belt that gets moved by the stepper motor.

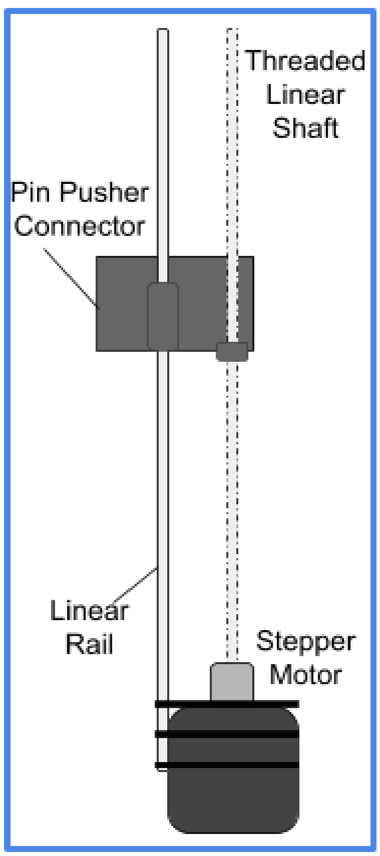

Fig. 6. Diagram representing design of left Z-Axis Mover.

Figure 6 shows the Z axis mover which moves the entire *Y Axis Mover* along the Z axis (up and down) by rotating its threaded linear shaft using a stepper motor.

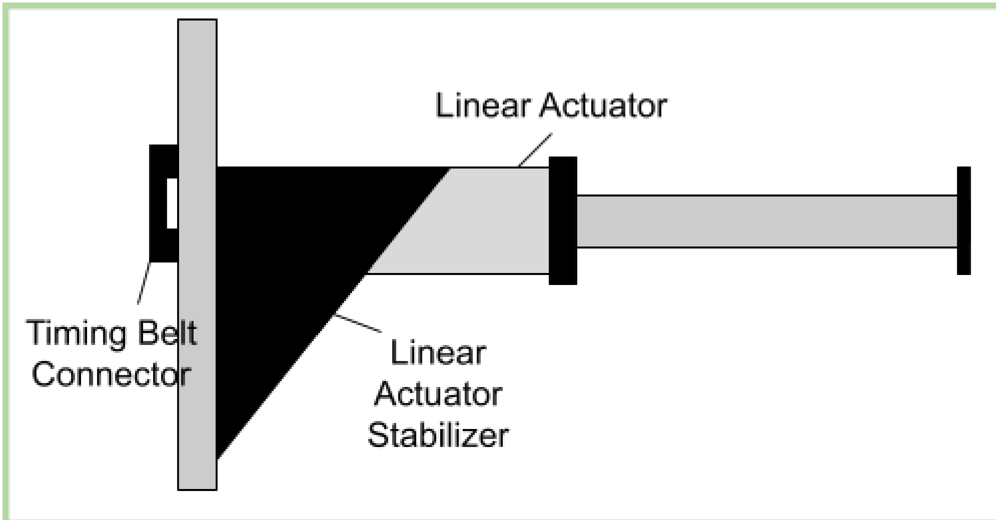

Fig. 7. X-Axis Mover side view diagram.

Figure 7 shows the side view of the X axis mover, which displaces the pins which are in the pin art board in which would be in front of the linear actuator as shown back in figure 2.

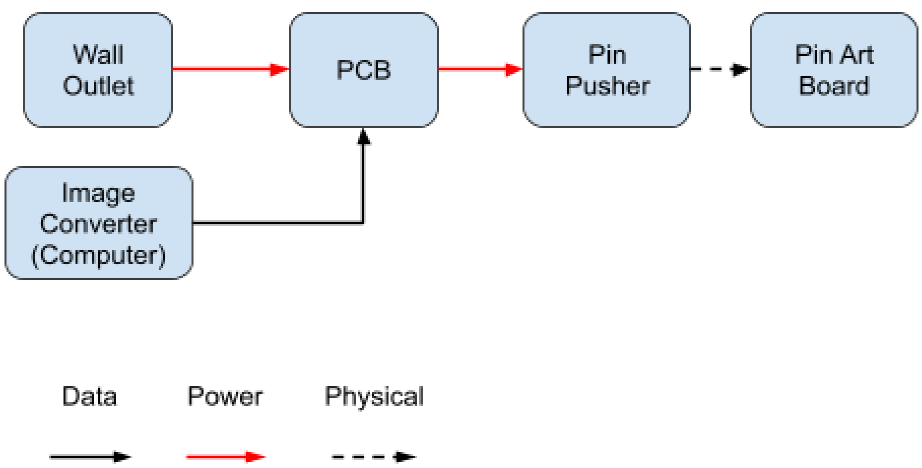

Fig. 8. High-level design diagram.

Figure 8 shows a high level system overview and how the pin pusher gets its power and information on how much to move in each direction and when.

2.2 Block Diagram

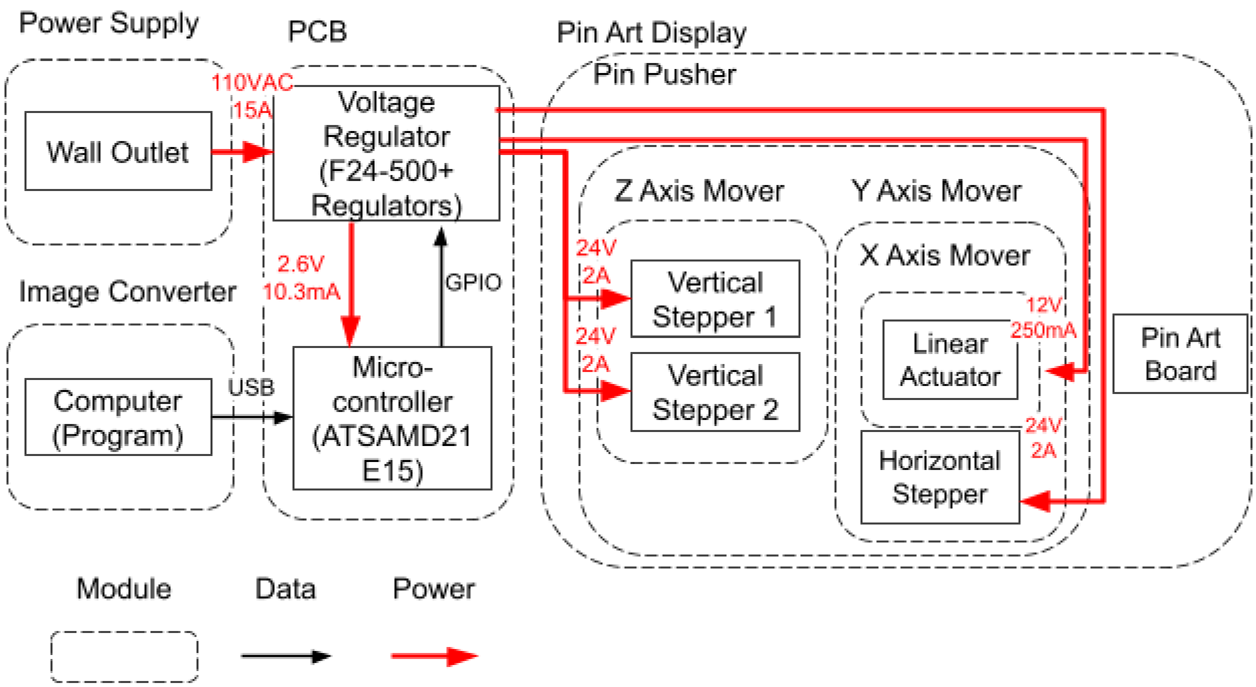

Fig. 9. System block diagram.

Figure 9 shows the breakdown of how we go from image to 2.5D rendering via our pin art display. First, we need enough regulated power to power 3 stepper motors, one linear actuator, and 1 microcontroller, which comes from the wall outlet. Then we need the image which our computer program would convert into a displacement map. That map would be saved into the microcontroller as an array of integers. The microcontroller would next tell the motors and actuator how much to move to correctly displace each group of pins the correct amount.

2.3 Functional Overview

2.3.1 Power Supply

Supplies everything that needs power with power.

- *Wall Outlet:* Connects to the electricity from the regular US Wall Outlets. This sends the voltage to the computer and our PCB separately, we will manipulate the power from this energy source to move the motors.

2.3.2 Image Converter

External module that assigns displacements based on an image to push the pins.

Computer (Program): Takes in a digital image on the user's computer and converts it to a displacement mapping data file by using the OpenCV library to denoise and find edges inside of the digital image. Using that edge data, we sample the averages based on the pin pusher control resolution of 16x20 regions to produce percentile displacements for each pixel region. This data is then sent via USB connection to our microcontroller, which receives the data and uses it as its basis for motor control.

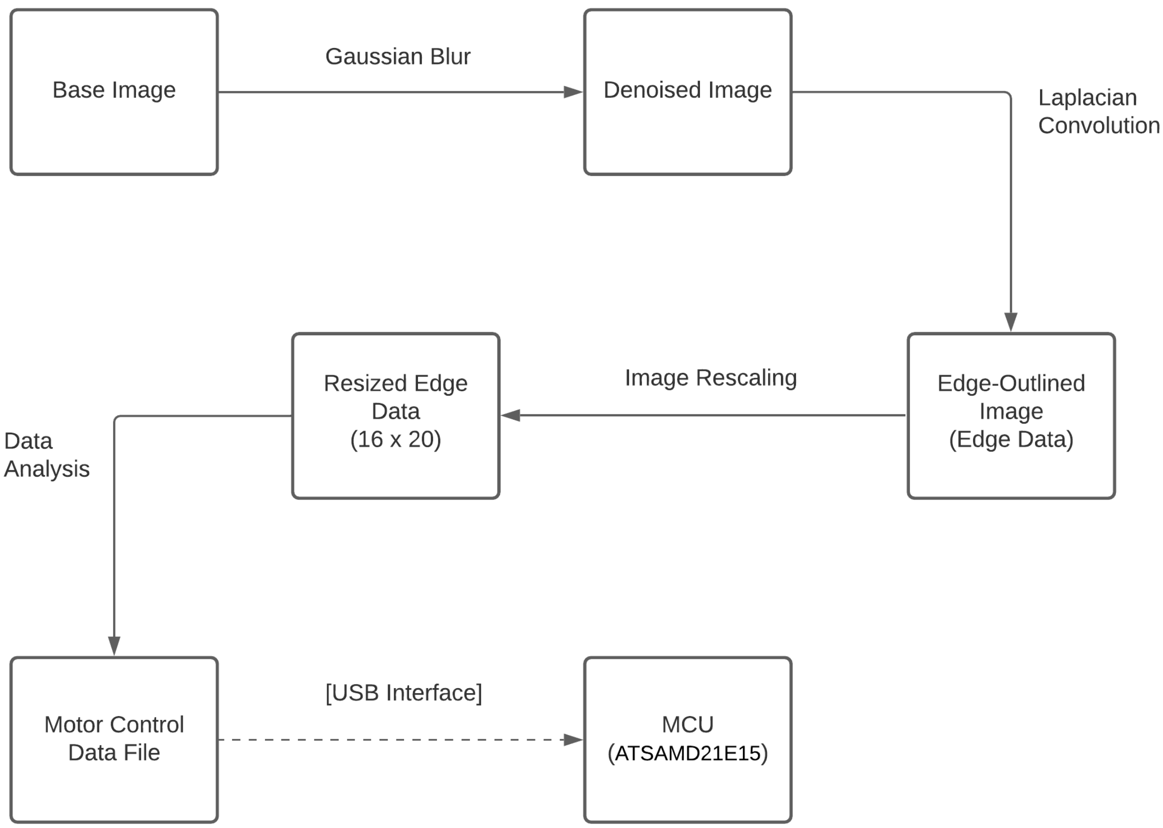

Fig. 10. Image processing pipeline using OpenCV.

2.3.3 PCB

- *Voltage regulator*: Makes sure each electrical component is supplied with the correct power as to not break our project and operate it safely. It is used to give consistent voltage to the motors, not the modulated power which moves the motors.

- *Microcontroller (ATSAMD21E15)*: Holds the displacement values of each square group of pins as integers and gives the correct modulated power outputs to the X, Y, and Z axis movers on the pin pusher module to move the motors the correct amount. It also has stored and runs the program for said motor controls.

2.3.4 Pin Art

Physically moving subsystem and pin art board that creates final 2.5D rendering of the image.

● Pin Art Board: Array of pins to be pushed to create final rendering.

○ Pin Pusher: Moves the X axis mover as shown in figure 7 in the Z and Y axis to push all of the pins to the correct displacements. The entire pin pusher physical design module is shown in figure 3.

■ Z Axis Mover: Moves the Y Axis Mover in the Z Axis. Physically shown in figure 6.

● *Vertical Stepper (1 & 2)*: Uses the threaded pole to move the X axis mover up and down since the Is given power from the voltage regulator and the data on how much to offset the pins by the microcontroller.

■ Y Axis Mover: Moves the X Axis Mover in the Y Axis. Physically shown in figures 4 and 5.

● *Horizontal stepper*: Connects to a belt to move the pin pusher left and right. Is given power from the voltage regulator and the data on how much to offset the pins by the microcontroller.

● X Axis Mover: Holds the linear actuator in place

○ *Linear Actuator*: Physically offsets a group of pins at a time to the correct displacement as given by the microcontroller.

3. Requirements & Verification

3.1 Power Supply

Requirement	Verification
1. Needs to be able to supply our entire system with all the voltage it needs (at least 24V and 7A) and be stable.	1. The voltage and current outputs will be checked with a multimeter to ensure that they are equal to the required values. Test the voltage signal with an oscilloscope to see if it is stable.

3.2 Image Converter

Requirement	Verification
1. Any image must be divided into 320 sub-square sections, as shown in figure 11, and assign a depth (between 0 and 2.3 rounded to the nearest .1) to each sub square based on the image data. Background color must be set to have a depth value of 0.	1. Look at a resized output edge-outlined image where each of the 320 pixels of the image are colored in greyscale, where a depth of 0 is black and 2.3 is white to see if the image is recognizable. A super simplified example is shown in Figure 12.

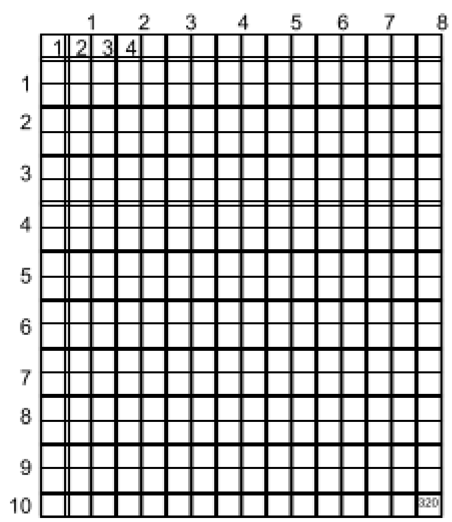

Fig. 11. 320 Sub-Square regions.

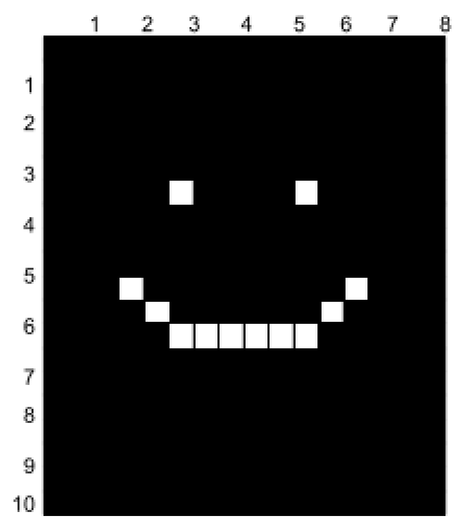

Fig. 12. Smiley Face Example.

3.3 Control Logic Unit

3.3.1 Voltage Regulator

Requirement	Verification
1. Converts AC to DC. 2. Supplies the microcontroller, the 3 stepper motors and a linear actuator with the correct amount of power (shown in the block diagram) within their tolerances. 3. Should not be supplying voltage to the X axis mover while moving in either the Z or Y axis (may damage the pins if the actuator is out) or vice versa.	1. Use an oscilloscope to make sure the current is not oscillating 2. Using an oscilloscope by connecting one end to the output of the voltage regulator and the other to ground make sure the voltage supplied to each part is correct as shown in black diagram 3. Wait for voltage to go to 0 a second time (it reaches 0 when reversing polarity, so we need to wait for the one after) for the linear actuator. Can be done with a not gate.

3.3.2 Microcontroller (ATSAMD21E15)

Requirement	Verification
1. Program code for converting motor control data into actual outputs the motors can read and controlling USB communication must fit into programmable memory of our MCU. 2. Need to be able to receive data via USB from a computer. 3. Motor control data must fit in the on-chip memory of our MCU.	1. Successful flashing of program code onto microcontroller unit. 2. Connect the microcontroller to your laptop via USB and upload the displacement map, try reading it after. If it can’t either read or write restart the microcontroller. 3. Successful storage and reading of motor control data in SoC program.

3.4 Pin Art Display

3.4.1 Pin Art Board

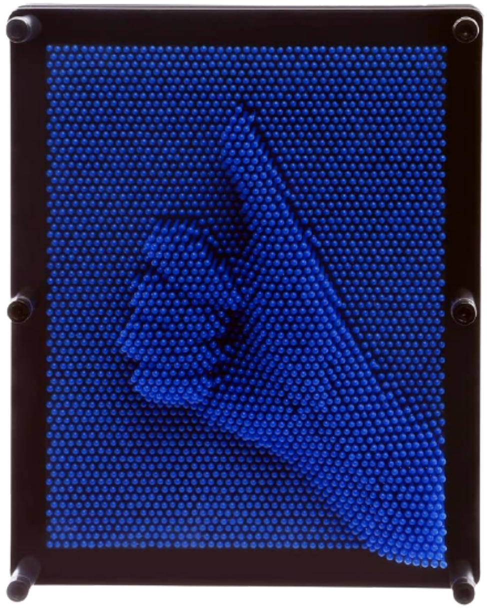

Fig. 13. Pin Art Board.

Figure 10 shows the physical design of the pin art board by itself, after a completed more detailed displacement map was pushed onto it.

Requirement	Verification
1. Needs to be reachable by 2D mover and fit within its bounds; in our case, that is 10 in by 8 in by 2.3 in. 2. Must be able to correctly display our displacement map such that every pin can move effortlessly, otherwise it might take significantly longer for our actuator to push the pins.	1. Measure with a ruler. 2. Push and pull all of the pins to make sure that none of them are stuck or get stuck part of the way through. If one does make sure to lubricate it or take out that one pin.

3.4.2 Pin Pusher

3.4.2.1 Y Axis Mover

Requirement	Verification
1. Needs to be able to move the entire width of the pin art board; in this case, 8in. 2. Needs to be able to supply enough torque to move the linear actuator and the parts that hold it into place.	1. Measure with a ruler 2. Find the torque needed using the following equation $T = \frac{(\mu F + mg)}{2} * \frac{D}{1}$, shown in tolerance analysis under Figure 16.

3.4.2.2 Z Axis Mover

Requirement	Verification
1. Needs to be able to move the entire height of the pin art board; in this case, 10in. 2. Needs to be able to supply enough torque to move the linear actuator and the parts that hold it into place.	1. Measure with Ruler 2. Find the torque needed using the following equation $T = \frac{FP}{2\pi\eta} + \frac{\mu F \circ P}{2\pi}$, shown in tolerance analysis under Figure 15.

3.4.2.3 X Axis Mover

Requirement	Verification
1. Needs to be able to move the entire depth of the pin art board in this case 2.3in as well as have some space between it and the pin board. 2. Needs to be able to push a small enough grouping of pins to be able to display the art with a great enough accuracy. 3. Needs to be able to supply enough force to push the pins. The analysis is shown in figure 19 and described	1. Connect the linear actuator to power, if it can be fully displaced without stalling the full 3 inches there and back then it works, measured with a ruler. 2. Split the dimensions up so that the image would still be recognizable or effectively showcase your image (figure 11), keeping in mind the thickness of the linear actuator's pusher (what actually touches the

above and below that figure.	pins). For us the part that touches the pins is approximately .5in by .5in so to split up the 8in by 10in board our image is split into 320 sub squares (figure 11). 3. This should be done in verification 2 for the pin art board.

3.5 Circuit Schematics

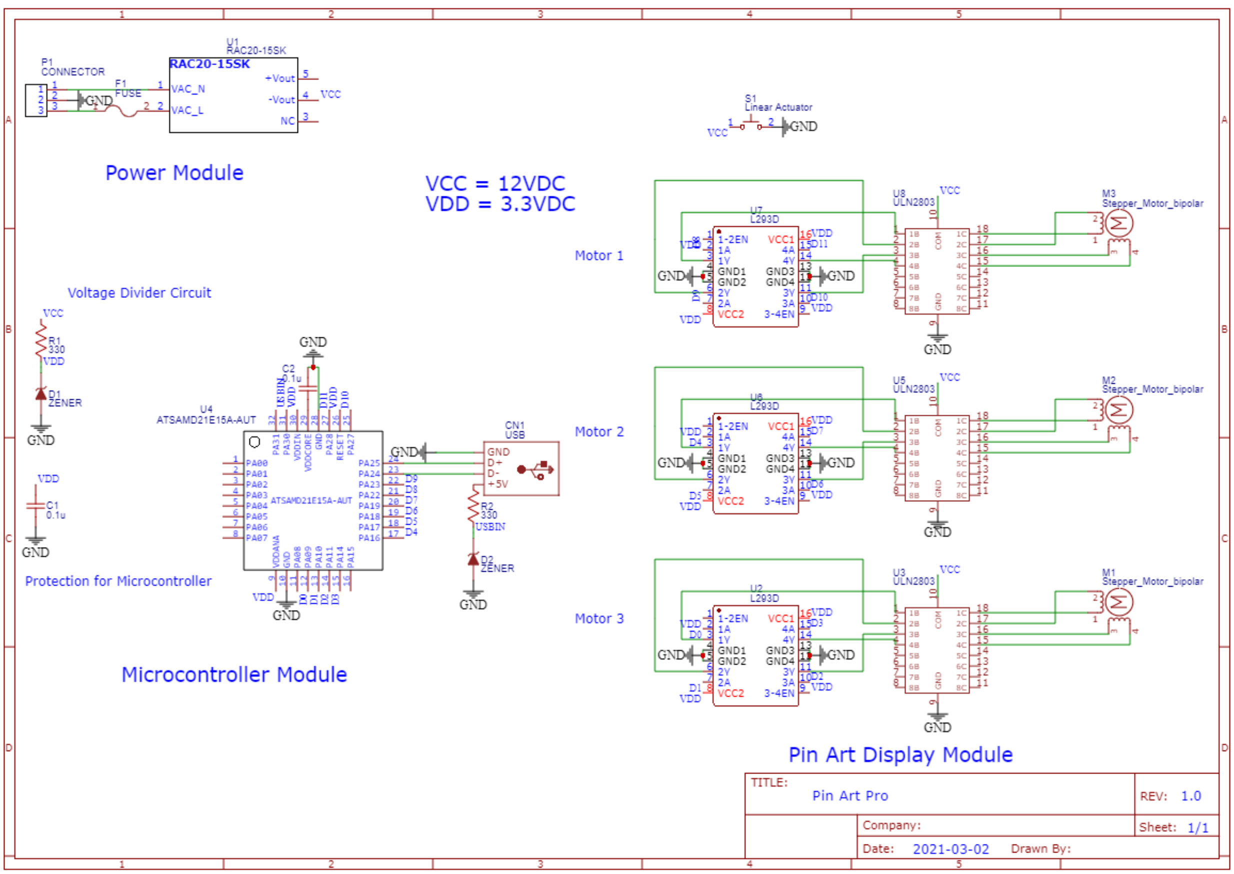

Fig. 14. Schematics of Modules.

Figure 14 shows the schematics of individual modules and components. The power module, the microcontroller module, and the Pin Art display module are shown separately.

3.6 Tolerance Analysis

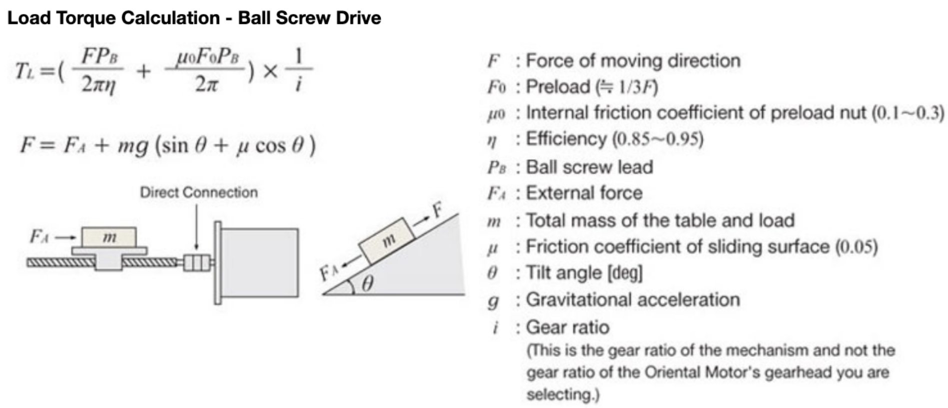

Fig. 15. Physics for Moving the Threaded Motors.

The above figure describes the equations for the torques needed for the servos that we have. First we have a threaded linear shaft motor like in the top ball screw drive equation: $T = \frac{FP}{2\pi\eta} + \frac{\mu F_\circ P}{2\pi}$ where since the screw drive has the mass coming down and the mass is 2Kg $F = 2kg * 10m/s^2 = 20$, $\eta = .9$, $\mu = .2$ based on dry steel screw friction coefficient, $P = .01$ which is our screw lead. With all of these plugged into our equation we have the torque needed to be 0.0348726Nm or 3.48726Ncm.

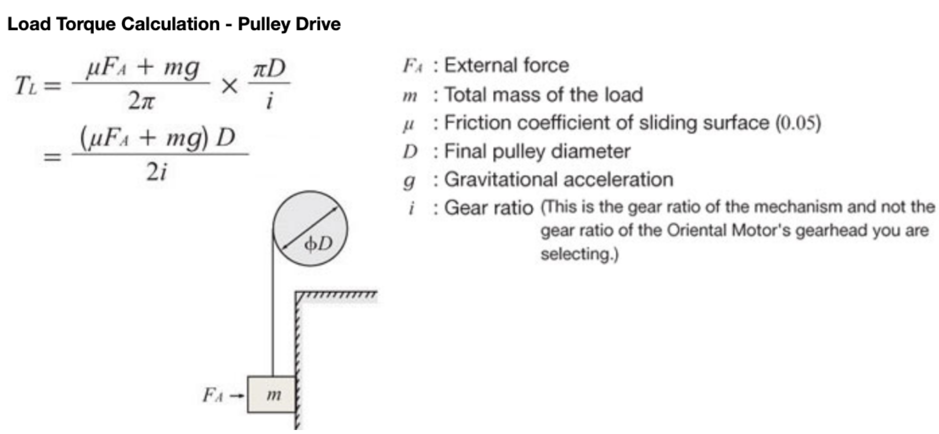

Fig. 16. Physics for Moving the Timing Belt Motors.

The above figure describes the equations for the torques needed for the servos that we have. First since we don't know the full amount of force putting the Y axis mover from side to side we decided to make it as if the full weight was being moved up and down which would be more torque than needed but give us a better estimate. Our equation: $T = \frac{mg}{2} * \frac{D}{1}$ where since the screw drive has the mass coming down and the mass is 1Kg $F = .5kg * 10m/s^2 = 5N$, since the circumference (c) is 15cm $D = \frac{c}{\pi} = 4.77$. With all of these plugged into our equation we have the torque needed to be 0.2385Nm or 23.85Ncm.

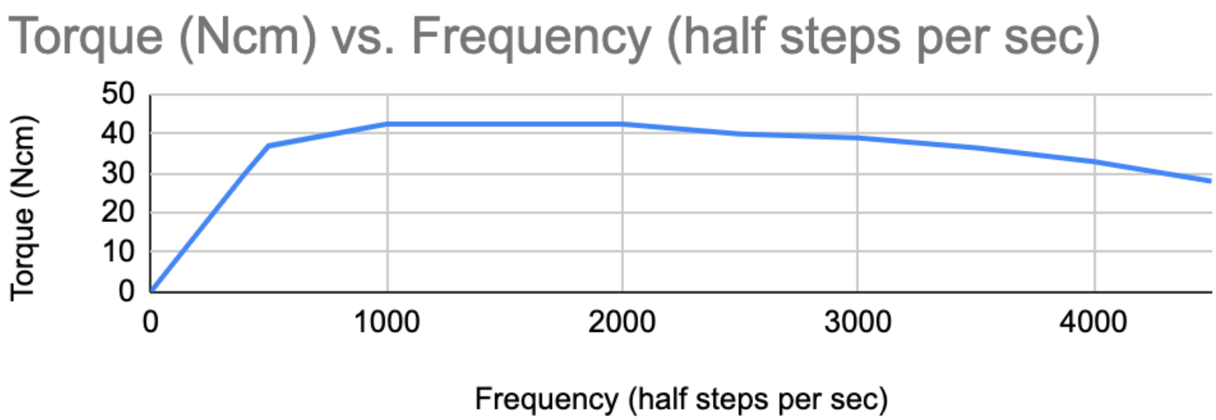

Fig. 17. Torque Vs Frequency Graph.

According to our stepper motor's spec sheets points of torque and frequency we were able to create the above graph. Because the minimum torque we need is 23.85Ncm, we need to be running at at least 450 half steps per second.

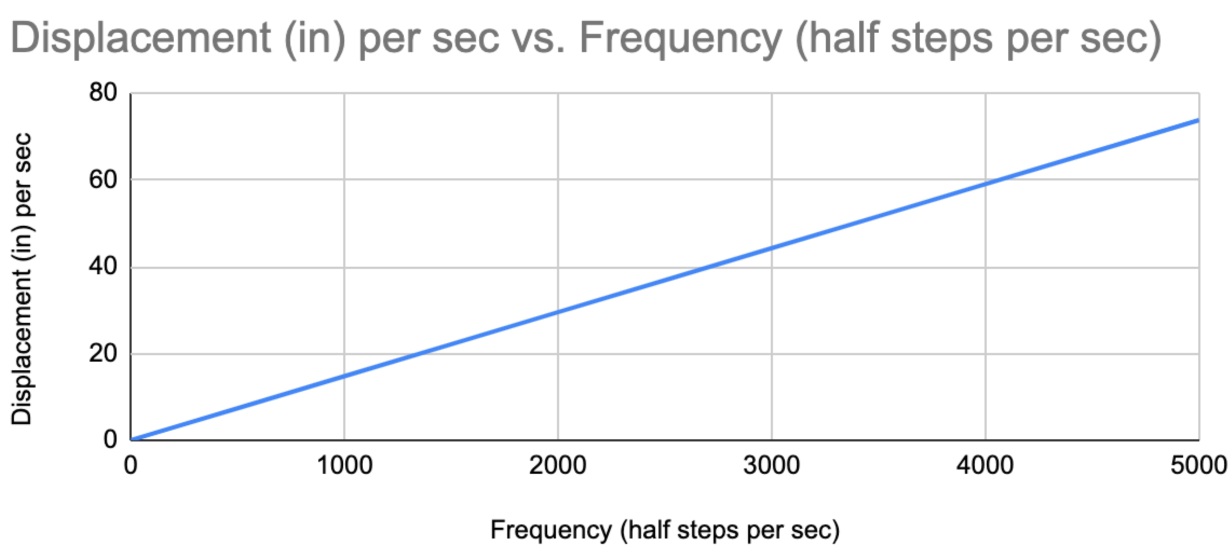

Fig. 18. Frequency vs Displacement.

We also do not want our motors to run too fast. At 500 half steps per second our timing belt Y axis moves 7.38 inches in 1 second. We had to find this out by using unit conversions. Since we know that the circumference of the timing belt shaft is 15cm or about 5.9 inches and that each half step rotates 9º then for each half step our Y axis mover moves about .015inches (.015inch per half step) so at 500 half steps per sec the units cancel out to 7.38 inches per sec. We only want to move at .5 inch increments at a time so we would be able to do that in .068 seconds

When looking at our linear actuator's spec sheet we realized that the max speed is 25mm/sec or .98 in/sec, sinc the linear actuator would need to at max move 2.3 inches which would take at least 4.69 seconds to move full displacement and back, see the dotted blue line in figure 19. This shows our biggest bottleneck in terms of time efficiency, the stepper motors need to wait on the linear actuator to move forward and back. Since we want a tolerance of .1inches and according to the spec sheet it takes between (.005s-.003s) to start and stop reaching max and 0 speed our actual tolerance would be .002inches+/- on our displacement.

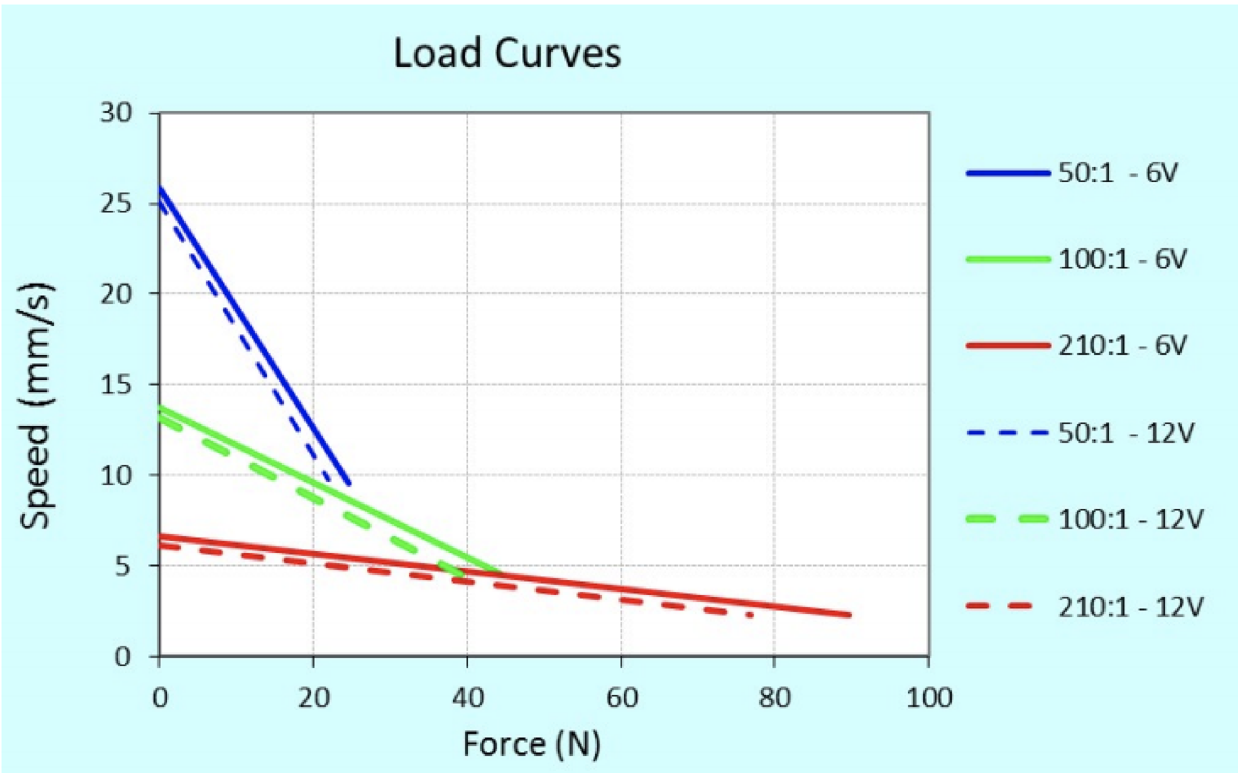

Fig. 19. Load Curve.

The figure curve above shows the speed the linear actuator would move based on the force applied to it. Since the push pins are plastic and touch the holes on one point of friction is pretty negligible making the applied force close to 0, meaning we could move close to max speed (25mm/sec).

4. Cost and Schedule

4.1 Cost Analysis

4.1.1 Labor Cost Analysis

Name	Hourly Rate	Hours	Total	Total x 2.5
Josh Sanchez	$50	150	$7,500	$18,750
Raymundo Vargas	$50	150	$7,500	$18,750
Justin Zhong	$50	150	$7,500	$18,750
Total				$56,250

Table 1. Labor Costs.

4.1.2 Parts Cost Analysis

Description	Quantity	Manufacturer	Vendor	Cost/unit	Total cost
F24-500 Power Transformer	1	Triad Magnetics	Digikey	$10.27	$10.27
1N4007-T Diode	4	Diodes Incorporated	Mouser	$0.19	$0.76
108CKS050M 1000uF Capacitor	1	Illinois Capacitor	Digikey	$1.17	$1.17
ATSAMD21E15 Microcontroller	1	Microchip	Microchip	$1.72	$1.72
292303-7 USB Connector	1	TE Connectivity AMP Connectors	Digikey	$2.57	$2.57
17HS15-1504S-X1 Stepper Motor	3	StepperOnline	StepperOnline	$10.74	$32.22
Pinart Board	1	E-FirstFeeling	Amazon	$25.99	$25.99
L11010101011-1 Linear Actuator	1	ECO LLC	Amazon	$39.99	$39.99
L293D H-Driver	3	STMicroelectronics	Digikey	$4.35	$13.05
ULN2003AN Transistor	3	Texas Instruments	Digikey	$0.70	$2.10
Total					$129.84

Table 2. Component Costs.

4.1.3 Grand Total

Section	Total
Labor	$56,250
Parts	$129.84
Grand Total	$56,379.84

Table 3. Total Cost.

4.2 Schedule

Week	Task	Responsibility
2/15/2021	**Project Proposal**	All
	Design	Raymundo
	Introduction	Joshua
	Ethics and Safety	Justin
2/22/2021	**Eagle Assignment**	All
	Prepare for DDC	All
	Contact machine shop and look into display module	Raymundo
	Research software image conversion	Joshua
	Research power module and connecting with other modules	Justin
3/1/2021	**DDC/Design Document**	All
	Revise Introduction and Design Sections	Raymundo
	Revise Requirements and Verification Sections	Joshua
	Revise Safety and Ethics	Justin
3/8/2021	**Design Review**	All
	Order parts, research microprocessor programming, research image edge detection	Joshua
	Research power system implementation	Justin
	Communicate with machine shop on motor systems design	Raymundo
3/15/2021	**Team Evaluation/First Round PCB Order/Soldering Assignment**	All
	Finalize circuit design	Justin
	Begin programming microcontroller	Joshua
	Research how to control motors and linear actuator	Raymundo
3/22/2021	**Second Round PCB Order**	All
	Test out circuit and PCB and revise	Justin
	Finish programming microcontroller, implement OpenCV edge	Joshua

	detector	
	Communicate with machine shop and design pusher	Raymundo
3/29/2021	Continue to test power system	Justin
	Set up USB comms with device, test program on microcontroller	Joshua
	Integrate pusher and motor system	Raymundo
4/5/2021	**Individual Progress/Third Round PCB Order**	All
	Finalize power system	Justin
	Continue to test program and integrate motor system with controller	Joshua, Raymundo
4/12/2021	Integrate all systems and verify	All
4/19/2021	**Mock Demo**	All
	Prepare for Demo	All
	Fix remaining issues	All
4/26/2021	Finalize project	All
	Prepare final paper	All
5/3/2021	**Final Papers/Presentation**	All
	Prepare for presentation	All
	Finalize final paper	All

Table 4. General Schedule and Task Allocation.

5. Ethics & Safety

5.1 Ethics Concerns

Our product could be hacked, and data could be stolen from users, causing piracy issues for artists and others. This is a serious violation of #1 in the IEEE Code of Ethics “to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others, and to disclose promptly factors that might endanger the public or the environment” [6]. We should consider educating our users on best practices to avoid such issues. We can also add more security to the ATSAMD21E15 microcontroller in our circuit to prevent data hacking in the future, although we do not plan to address this in the current development process.

There is also a probability that someone might use our product to print unlawful images that are offensive to others. It is also possible that someone uses our product for harassment or bullying activities. These behaviors are in violation of #4 “to avoid unlawful conduct in professional activities, and to reject bribery in all its forms”, #7 “to treat all persons fairly and with respect, and to not engage in discrimination based on characteristics such as race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression”, and #9 “to avoid injuring others, their property, reputation, or employment by false or malicious actions, rumors or any other verbal or physical abuses” [6]. Currently, we do not have a solution as we do not believe in overseeing every user’s usage of our product. Our product is not connected to the Internet, so it would be difficult for us to monitor user behavior. If we decide to enable communication via the Internet for our product in the future, then we would take part in prohibiting such images or behavior spreading across the platform.

5.2 Safety Concerns

Our product uses electricity from a household outlet of 120V. There is a risk that our design might overload the power grid. If our circuit is not designed well or the operator was not careful during the development phase, there could also be severe injuries to personnel and the circuit board. To resolve this issue, we must complete lab safety training before operating with high voltages. In addition, we need to complete special training for operating with high voltages. We also should minimize any exposure of electronic components that might endanger users to our customers. Our power system must be compliant with UL 498 [7] and ANSI C57.3-1942 [8]. Our power system and the power system of every part must satisfy requirements for UL/IEC 60950-1 [9] and IEC 62368 at the same time [10]. Even though other components use a lower voltage of 3.3V or 5V, we still need to make sure there are no risks of electric shock for our customers or developers.

Our product uses a ATSAMD21E15 microcontroller for interfacing between the PC and our circuit. There is a possibility that our microcontroller is overloaded and damages the whole circuit. Furthermore, the microcontroller might damage the USB port on the board and then damage the PC connected to it. Therefore, we must include safety protection in our design, and the design of our microcontroller circuit must comply with IEC 61508 [11].

We must also use a USB port in our design to interface between the PC and the microcontroller to pass data. If our USB port is not connected correctly, the 5V passed from the PC to the board could overload the microcontroller and destroy the circuit. Therefore, our USB ports must comply with USB-IF standards, and our computer software must comply with ISO/IEC 12207:2008 [12].

Our product uses electric motors for moving to designated locations and an actuator for pushing appropriate pins. Our stepper motor system must be compliant with NEMA standards. Our pin art system must be compliant with UL 1004-1 [13]. Our product requires manually resetting the pins. Our product does not have safety checks before operating. Starting operation while resetting pin locations or positioning one's hands on or near the surface, pins, motors, or actuator while operating might cause minor injuries.

References

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