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Oval-Mate: Ballot Marker

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Ethical Design Statement

This report, enclosed design, and described efforts of Team 110 were achieved in accordance with the IEEE Code of Ethics. Team 110 stands firmly behind the belief that safety to the public is forefront in any design project, including Oval-Mate.

Environmental Impact Statement

The purpose of creating Oval-Mate was to save time and effort for Election Systems and Software in the process of filling up ballots to test the accuracy and performance of the tabulating machines. These machines play an important role in electing elected officials. The elected officials will be responsible for regulating policies about the environment which will have an impact in many ways in which we have pollution, global warming, deforestation and much more.

Project Abstract

Oval-Mate is an automated ballot marking device designed and created by Engineering Team 110 under the sponsorship of Election Systems and Software (ES&S). Utilizing an XY plotter and complementary Windows application, Oval-Mate autonomously marks ballots used for internal testing in ES&S facilities. Previously completed by hand, our device completely marks 11” x 8.5” ballots in a fraction of the time while maintaining accuracy and precision. Ballots marked by Oval-Mate tabulate the same as hand marked ballots which satisfies testing criteria that ES&S has to adhere to. The Oval-Mate was designed to allow ES&S to extend its application to all ballot lengths that need to be tested during the Federal Certification process. As a result, the device can be easily modified under user recommendation to perform newly desired functions.

Acknowledgement

The Oval-Mate project has been a successful project not only because of Team 110's hard work and dedication, but also from the support of others throughout the process. This project would not have been possible without ES&S being our sponsor and sounding board. ES&S staff were always willing to take a moment and answer any questions we had along the way. We are extremely grateful to our Senior Project Officer, Professor Detloff, for his guidance and support throughout the project. Professor Detloff was instrumental in ensuring that key design processes were completed and thoroughly thought through. We'd also like to thank our Skill Team members for sharing their experience and answering questions during our meetings. Our family and friends are also to be commended for being supportive during this challenging and exciting time as we wrap up our academic careers.

Executive summary

This report outlines the complete engineering design process from start to finish. Starting with the problem formulation and definition, ES&S's need for this project is fully expressed through the identification of essential engineering requirements and success criteria. To follow up, the report will document the entire execution phase of the project with topics ranging from concept generation to system analysis and process definition. Including a thorough cost analysis, a breakdown of economic, social, and political impacts of the project are stated as well. Throughout the report many references to the design processes and decisions can be found in the appendices which provide a wide range of technical information and visual representation. Finally, the report concludes with a project audit review and a discussion of project flow, organization, and success.

Table of Contents

Table of Figures

List of Tables

Introduction

Team 110 has been sponsored by Election Systems and Software (ES&S) to create a ballot marking device to be used for internal testing in their facilities. Named Oval-Mate, this device will take over the ballot marking process that was originally completed by hand in ES&S offices by automating the markings using an XY plotter and a complementary windows application. The Oval-Mate must be accurate when marking the ballot so the oval is filled in correctly which will then tabulate correctly during the test. Speed is another objective that must be considered. Not only will the Oval-Mate mark a ballot faster than a human will, but the device then frees up that employee's time to do other tasks. Ease of use will also be a feature on the Oval-Mate to allow ES&S employees to set up and use the device without having to do anything complicated. This report will outline the engineering design process that Team 110 followed to define the issue, formulate a solution, and execute the plan in an organized and timely manner.

Problem Formulation

Problem Statement

Election Systems and Software is looking to save time and money when creating hand marked test decks. This project will automate the marking of ballots with speed and precision. A time savings of fifty percent will be realized while freeing up a person to do other tasks. A user interface will allow the user to select different oval positions to be marked. These oval location configurations can be saved, edited, and loaded for quick access. When the task has been completed, the device will notify the user if an error has occurred.

Background

The different aspects of our product are analyzed to ensure they do not infringe on other companies' patents which will include the pen holder, marking a ballot, mechanics of moving the print head, and how the ballot is held in place. If there is a potential risk of infringement, changes will be discussed on how to avoid those situations.

Results of Patent and Product Search

Four patents have been selected to evaluate the possible infringement our project may pose. The first patent is a pen plotter that uses a pen that marks a piece of paper according to instructions from a computer. This device uses a print head that houses the pen on the X-axis and moves the paper in the Y-axis much like an inkjet printer would. The internal processor takes instructions from a PC and then calculates the best path and speed at which to mark the paper. The claims listed below are related to how the product will accept and process instructions from the PC. Figure 1 shows how the product will hold the pen and move the paper. These claims and functions discussed are possible infringements that need to be evaluated. [1] The manufacturer has not responded to our request for future patent applications.

Pen Plotter - Patent 10796210

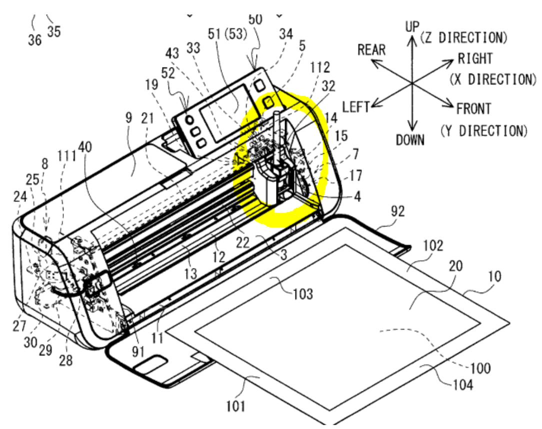


Figure 1: Pen Plotter

Abstract

A plotter includes a mounting portion, a first movement mechanism, a second movement mechanism, a processor, and a memory. The mounting portion is configured to mount with a pen containing a liquid. The first movement mechanism is configured to relatively move the mounting portion and a workpiece in a movement direction. The second movement mechanism is configured to relatively move the mounting portion and the workpiece in a direction intersecting the movement direction. The memory is configured to store computer-readable instructions that, when executed by the processor, instruct the processor to perform processes. The processes include acquiring plot data, acquiring information relating to a remaining amount of the liquid of the pen, setting a relative movement speed of the mounting portion and the

workpiece, and controlling the first movement mechanism and the second movement mechanism at the set movement speed, and performing drawing on the workpiece. [1]

Filing Date

02/07/2019 [1]

Claims

6. The plotter according to claim 5, wherein the computer-readable instructions further instruct the processor to perform a process comprising: identifying a distance of a line drawn on the workpiece, and the setting of the movement speed includes resetting the movement speed to be slower than the currently set movement speed when the identified distance exceeds a threshold value. [1]

7. The plotter according to claim 6, wherein the plot data includes data instructing drawing positions of a plurality of continuous line segments, and when the identified distance reaches the threshold value, the second movement mechanism relatively moves the workpiece and the mounting portion at the reset movement speed from a start point of a next line segment in a drawing order, among the plurality of line segments. [1]

Drawing Apparatus - Patent 0366317

The second patent is for a drawing apparatus that holds a marking device and lowers it onto a piece of paper with an elastic pressure to ensure it writes correctly. This apparatus can then be mounted to any other device where the intent is to mark a surface. When the marking device is not needed on the paper anymore, the drawing apparatus will lift the marking device off the paper. The claims state that the drawing apparatus applies pressure to the paper with a flat spring and then returns the marking device to the up position with a solenoid. This functionality can be seen below in figure 2. [2] The manufacturer has not responded to our request for future patent applications.

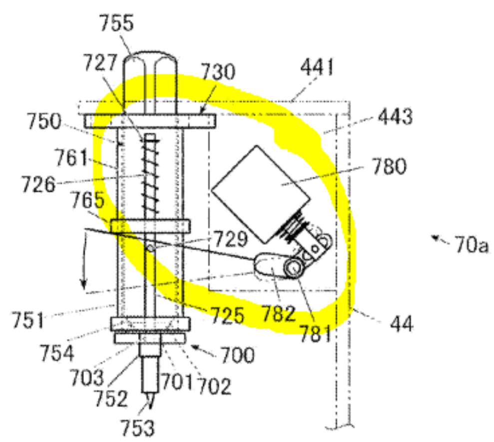


Figure 2: Drawing Apparatus

Abstract

A drawing apparatus includes a mounting section having a mounting surface for mounting thereon a drawing target object having a drawing target surface, a carriage for attaching thereto a drawing tool having a tip portion at one end, and a drawing tool pressing mechanism for bringing the tip portion of the drawing tool attached to the carriage into contact with the drawing target surface of the drawing target object mounted on the mounting surface.

The carriage includes a fitting member to be fitted with the tip portion of the drawing tool, and configured to be movable with the drawing tool having the fitted tip portion, and a biasing member biasing the fitting member in a direction away from the mounting surface.

The drawing tool pressing mechanism presses the drawing tool with the tip portion fitted with the fitting member in a direction where the tip portion approaches the mounting surface, and brings the tip portion into contact with the drawing target surface. [2]

Filing Date

02/18/2015 [2]

Claims

7. The drawing apparatus according to claim 1, wherein the drawing tool pressing mechanism includes an elastically deformable press side elastic member configured to come into contact with the drawing tool and press the drawing tool in the second direction, the press side elastic member is a flat spring, and the flat spring elastically deforms upon pressing the drawing tool in

the second direction, and bends and deforms upon the drawing tool being pressed up in accordance with the shape of the drawing target surface at the time of drawing. [2]

3. The drawing apparatus according to claim 2, wherein the biasing member is an elastic member placed on an outer periphery of the auxiliary shaft member and compressed upon the drawing tool being pressed by the drawing tool pressing mechanism in the first direction, the elastic member having a restoring force attempting to return to the original state against an external force. [2]

Ballot Marker - Patent 7100828

The third patent for evaluation is a ballot marker device that takes an unmarked ballot, then scans it so the ballot style can be determined, and then the selections of an individual are then marked on the ballot with a inkjet printer. The paper path consists of many rollers as the ballot is also turned around so both sides of the ballot can be printed on. The inkjet is on the X-axis, which is fixed and the paper moves in the Y-axis. Claims of this patent are that it marks selections made by a voter and the mark that it prints on the oval location is detectable by the voter and a ballot tabulation device. Figure 3 shows the paper path and printer functionality. The manufacturer of this patient is no longer in business.

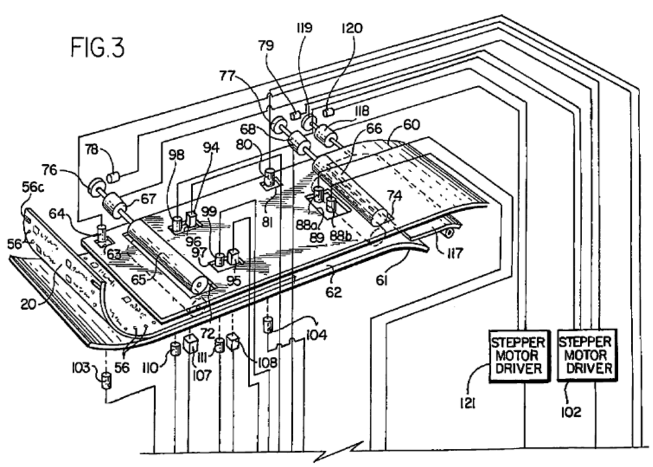


Figure 3: Ballot Marker

Abstract

A voting system utilizing a paper ballot listing a plurality of candidates which includes a marking space for each candidate which can be either hand-marked by a voter, or

machine-marked in an electronic voting station. The voting station includes a ballot marking device and a touch-screen voting terminal. If the ballot is to be machine marked, the ballot is inserted into the marking device and candidate selections are presented to the voter on the touch-screen. Candidate selections entered on the touch-screen are marked on the ballot by the marking device in marking spaces corresponding to the selected candidates, and the ballot is returned to the voter in a form which enables the voter to visually confirm that his selections have been marked. The ballot, whether hand-marked or machine-marked, is inserted in a ballot scanning device, wherein it is tallied and deposited in a ballot box. [3]

Filing Date

01/17/2003 [3]

Claims

1. A voting system for recording a voter's selection of one candidate from a slate of one or more candidates, comprising: a hand-markable physical ballot for receiving at least one voter-detectable mark indicating the voter's selection of a candidate from the slate of one or more candidates, said ballot providing the names of and an associated marking space for each candidate in said slate of candidates; a voting terminal for displaying to the voter one or more displays presenting a choice of candidates from said slate of candidates, and for receiving an input from the voter indicating the selection of a candidate from said slate of candidates; a ballot marking device for receiving said ballot, determining the slate appropriate to said ballot, and in response to said voter input to said voting terminal, providing a voter-detectable mark in the marking space corresponding to said selected candidate; and a ballot scanning device for receiving said ballot and recording said voter-detectable mark in said marking space associated with said selected candidate as a vote cast for said selected candidate. [3]

3. The voting system as defined in claim 2 wherein said marking device comprises a printer and said voter-detectable mark is a visually-detectable mark. [3]

Ballot Marker Device - Patent 20040140357

The fourth device is a form of a voting machine meant to assist voters in understanding and confirming their choices. It offers a GUI interface of the ballot with oral instructions to optionally assist voters in marking their choice. The GUI interface is a touch screen to allow user input for which options to mark. Figure 4 shows a visual representation of the machine with the GUI interface highlighted in yellow. The manufacturer of this patient is no longer in business.

Abstract

A terminal for marking a paper ballot which lists a plurality of candidates and which includes a marking space for each candidate which can be either hand-marked by a voter, or machine-marked by the terminal. The terminal scans the ballot to determine the ballot format, and then presents candidate selection options to the voter visually by means of an LCD touch screen menu and aurally by means of a synthesized speech menu. Candidate selections entered by means of the touch screen menu or by means of the audio menu are marked on the front and back sides of the ballot in marking spaces corresponding to the selected candidates, and the ballot is returned to the voter in a form which enables the voter to visually confirm that his or her selections have been marked. The ballot, whether hand-marked or machine-marked, is inserted in a ballot scanning device, wherein the ballot is tallied and deposited in a ballot box. [4]

Filing Date

12/11/2003 [4]

Claims

2. A voting system as defined in claim 1 wherein said physical ballot is a paper ballot. [4]

4. A voting system as defined in claim 1 wherein said menus presented to the voter are coordinated visual and aural menus. [4]

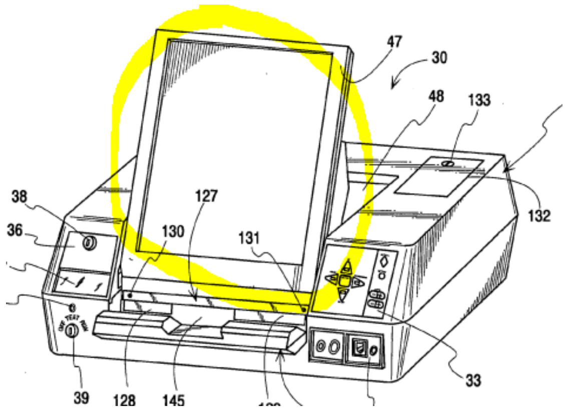


Figure 4: Ballot Marking Device

Analysis of Patent Liability

Pen Plotter - Patent 10796210

The pen plotter is similar to the Oval-Mate in that both use a marking device (pen), mark a piece of paper, receive instructions from a PC and then perform operations on those instructions to accurately mark the paper. The Oval-Mate allows for different marking devices to be used. Marking the paper is similar but different in approach on how to do so. The Y-axis on the pen plotter is controlled by rollers that move the paper in and out of the device like a inkjet printer. The Oval-Mate has the ballot in a fixed position and then moves the pen completely independently of the paper. Both devices receive instructions from a PC and then calculate the best way of marking the paper. This is only a similarity because the data the Oval-Mate is receiving is for a fixed grid ballot with selected locations to be marked. The pen plotter allows for complex line images to be sent and drawn such as floor plans or a coloring book image. The Oval-Mate will only draw a filled in oval. Calculating the operations to accurately mark the paper is another similarity however with a few differences. The Oval-Mate will also have to find the four corners of the ballot to calculate any skew to the printing on the ballot or the paper not installed properly. After calculating skew, the Oval-Mate will be able to go through the grid of markable positions and mark the ovals accurately. The pen plotter has to calculate a lot of vectors and lengths to be able to get the image drawn correctly. Since both the pen plotter and the Oval-Mate both mark paper there is a case for doctrine of equivalents. The element by element equivalence criteria does apply in that we receive data from a PC and translate that into marking a piece of paper. However, the task of marking a piece of paper and how the algorithms calculate the drawing path is not literally or substantially performed in the same way.

Drawing Apparatus - Patent 0366317

The drawing apparatus is similar in functionality in that it has a mechanism for a marking device to move up and down. While in the down position the pen has an elastic force pressing the marking device against the surface. The drawing apparatus similarly moves the pen up and down with a solenoid while the Oval-Mate uses a servo motor. The Oval-Mate will use a neoprene pulley to allow the pen to have a variable down force to allow for proper marking. This pulley affects a lever to move the pen about a central point while the drawing apparatus moves directly up and down. The drawing apparatus uses a flat spring to do this, so the functionality is similar but not identical. Due to the similarities, the doctrine of equivalents does need to be evaluated. The element by element equivalence criteria shows that there are elements that are similar but the mechanicals of the Oval-Mate on how it moves the pen up and down is significantly different.

Ballot Marker - Patent 7100828

Both the ballot marker and the Oval-Mate marks oval locations on a ballot. The ballot marker uses a fixed X-axis for the inkjet printer to mark oval locations with the ballot moving in the Y-axis via the drive rollers in the paper path. While the Oval-Mate uses a hand marking device on an XY-axis system with a stationary ballot. Even though both devices mark oval locations, the way the ovals are filled in is different enough to not be substantially similar. The doctrine of equivalents does have some element by element equivalence, the overall equivalence is not there due to the paper being flipped over automatically by the ballot marker.

Ballot Marker Device - Patent 20040140357

This device's LCD display is a comparable idea to the Windows application that is used in the Oval-Mate. However, the solution in the Oval-Mate offers aural assistance and doesn't require touch screen technology. The Windows application that sends commands to the Oval-Mate is for the purpose of creating test ballots. This does not offer a visual of the actual ballot being presented and will not scan it to determine the location of elements to properly display it on an LCD. This capability is not substantially similar.

The device also marks ballots, however it has additional capabilities, listed on the patent, that the Oval-Mate doesn't support. The device is capable of handling many different types of ballots whereas the Oval-Mate will only handle a single ballot format. Oval-Mate utilizes an XY-plotter to mark the ballot while this device uses a single plane while moving the ballot (akin to an inkjet printer). This behavior is not substantially similar.

Action Recommended

Pen Plotter - Patent 10796210 [1]

This apparatus performs substantially the same task but not in literally or substantially the same way. No action is required because of this patent's existence.

Drawing Apparatus - Patent 0366317 [2]

This apparatus performs substantially the same task but not in literally or substantially the same way. No action is required because of this patent's existence.

Ballot Marker - Patent 7100828 [3]

This device performs the same task of filling in ovals but uses an inkjet cartridge, while the Oval-Mate uses a pen. Because of the difference in marking method and that the Oval-Mate is designed as an Engineering tool, the Oval-Mate does not need any actions because of this patent.

Ballot Marker Device - Patent 20040140357 [4]

This product performs a similar task but not in literally or substantially the same way. No action is required because of this patent's existence.

Problem Formulation

To ensure the Oval-Mate is designed to meet ES&S needs, a weighted objective tree was created to help focus the development efforts. This objective tree lists out and weights the market requirements for the project. Speed is the most important factor, as allowing ES&S to better allocate their employee's time by removing a mundane task is at the core of their interest in this project. To accomplish this, precision is also necessary. A machine that can't do the job well but is fast isn't very useful. Because the audience of this product is directed towards engineers and system designers, the device's ease of use is not as important as whether it can perform the job, that is, be efficient. Verification that this product meets the needs of ES&S will be easy to verify by marking a ballot within the time frame allotted and to have that ballot process correctly in an ES&S tabulation device.

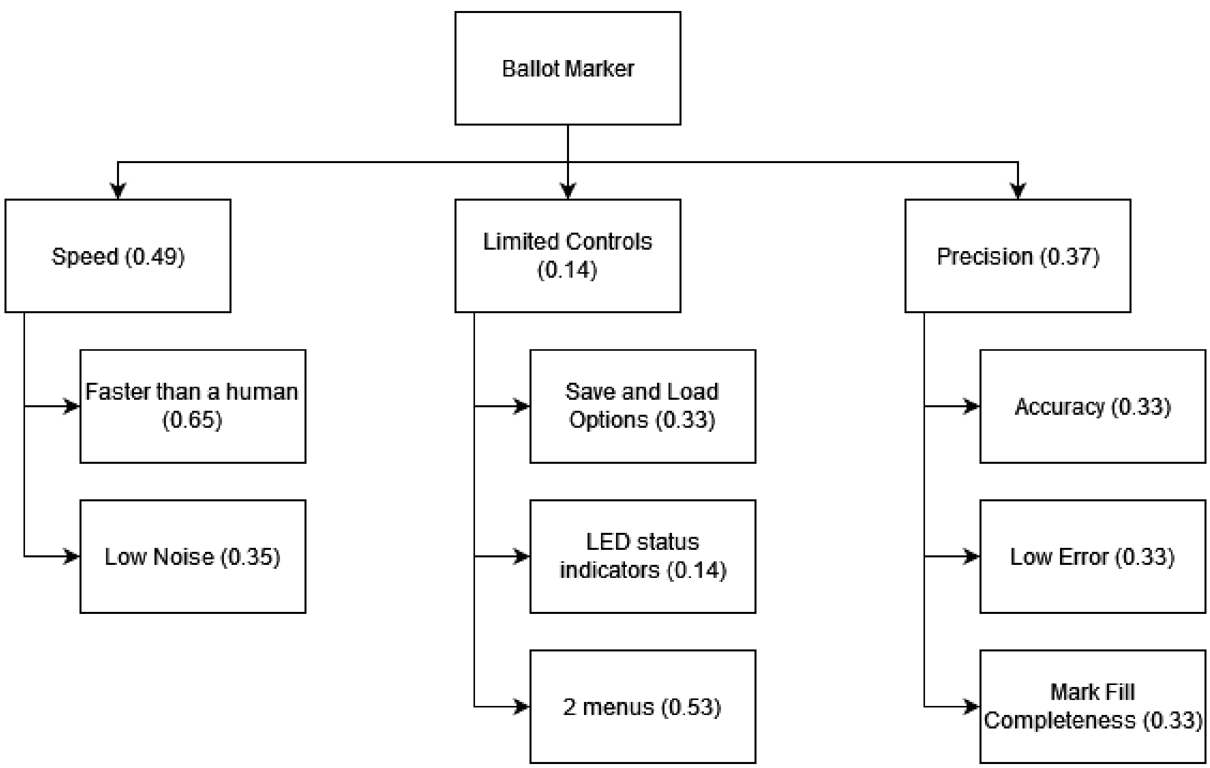


Figure 5: Objective Tree

Project Design Requirements, Specifications, and Success Criteria

Engineering Requirements

- Unit will complete task fast and effectively (Speed)
    - Unit will complete the necessary markings in half the time that a human could
    - Unit will produce <75dB (Low Noise)
- Unit will have limited controls for engineering-level users (Limited Controls)
    - Unit will have a User Interface to create, save, and load ballot configurations (Save and Load Options, Two Menus)
    - Unit will use a BiC Grip Roller ink pen to make markings (Limited Controls)
    - Unit will alert users to events such as completion or errors (LED status indicators)
        - Ballot completion, oval missed, pen out of ink, communication to device and host, failed offset calibration, motor error
- Unit will precisely mark oval locations on a standard 11x8.5” ballot (Precision)
    - Unit will verify that an oval has been filled(Accuracy)
    - Unit will produce a mark with <10% outside the target oval (Low Error)
    - Unit will fill >90% of oval space when marking ballot (Mark Fill Completeness)
        - ES&S’s machines testing standard

Project Common Success Criteria (PCSC)

Defined below are the success criteria which we will hold ourselves to as a team. When all of these criteria are met we can be sure that we made a worthy contribution to the team at ESS and all who will use their products.

1. Create a complete Bill of Materials to document the monetary investment needed to complete the project
2. Develop a complete schematic for analysis and future use
3. Develop a printed circuit board (PCB) that can be replicated
4. Populate the PCB with the needed components to complete the task
5. Professionally package the finished product

Project Specific Success Criteria (PSSC)

Along with the PCSC we also have items that are specific to our project including:

1. Conforming to IEEE standard 1220
2. Completely mark a test ballot in 7 minutes
3. In a 2 Menu application, the user will be able to save and load more than 100 different ballot configurations to the device and the LED status indicators will display progress
4. Tabulate 20 marked ballots in ESS tabulator and verify results
5. Fill more than 90% of oval space with mark by measuring oval with micro ruler (see Test Case 0002)

Regarding IEEE standard 1220:

To adhere to this standard, the team will need to perform a functional analysis on our design and our prototype. The functional analysis on the design has already been done on the long-form proposal document.

Project Scope

This project will involve creating a system to mark a ballot given ESS test specifications. Ballots consist of specific ovals that need to be marked. A user may decide which ovals are to be marked. A mark will consist of filling in the oval completely.

In Scope:

- The device will take user input as to which ovals the machine will mark
- The device will mark user specified ovals with 90% fill coverage
- The device will mark ballots of a single size, 11” x 8.5”
- The device will mark one ballot side completely in under 7 minutes
- The device will be able to save and load user ballot configurations

Out Of Scope:

- The device will not handle ballots that are not 11”x8.5”
- The device will not produce more than one type of mark
- The device will not handle different types of testing ballots
- The device will not handle more than one type of writing utensil
- The device will not flip the ballot
- The XY Plotter is not part of the project (will be purchased)

In order to produce a working product by April 7th, we will limit our scope to only include: one type of ballot, one type of utensil, and one type of mark. This will ensure that we have a proof of functionality that ESS will be able to expand upon at a later date.

Tolerances

Given these rigorous deadlines, a certain degree of potential deviation can occur. For that reason, as well as not consistently seeking counsel from the Senior Project Officer, the following tolerances are acceptable on this project:

- Time to mark a ballot can be no more than 5% over the time limit of 7 minute criteria
- Time to mark a ballot can be less than 7 minutes
- The total cost of the project, in monetary value, can exceed the $1000 limit by no more than 10%
- Noise produced during operation can exceed the limit of 75 dB by no more than 5dB

Concept Development, Synthesis, and Process Description

Literature Review and Research Summary

- X-Y plotter designs researched and how to build one from scratch. This included looking up part components necessary for building one
- Looked up possible solutions that have already been created. Nothing came up for this particular application
- Sensor that will be able to detect the size of the ballot
- Researched which microcontroller will be best for compatibility
- Reviewed which type of sensors would be necessary for oval and mark detection
- Looked at the functionality of different types of motors
- Researched ESS methods for testing ballots
- Researched time it takes a human to fill out a test ballot
- Average noise levels of different types of mechanical motors
- Researched IEEE 1220
- Examined ESS ballot design and specifications
- Researched ESS pen validation
- Researched feasibility of IR sensor black/white detection
- Researched Gantt chart styles
- Researched SCTIMER, CTIMER, uTick Timer, and OSTIMER modules in NXP documentation
- Mimicked and, later, improved motor acceleration algorithm written in Arduino C

Concept Generation and Reduction

Project Alternatives

Below is a concept fan that we have created to define project alternatives. The following tables detail the evaluations that have been done to decide on certain design elements. The use of Analytical Hierarchy Process(AHP) was used to evaluate and compare the different design alternatives. Each major component was analyzed this way with the Objective Tree in mind as we weighed the pros and cons of each component.

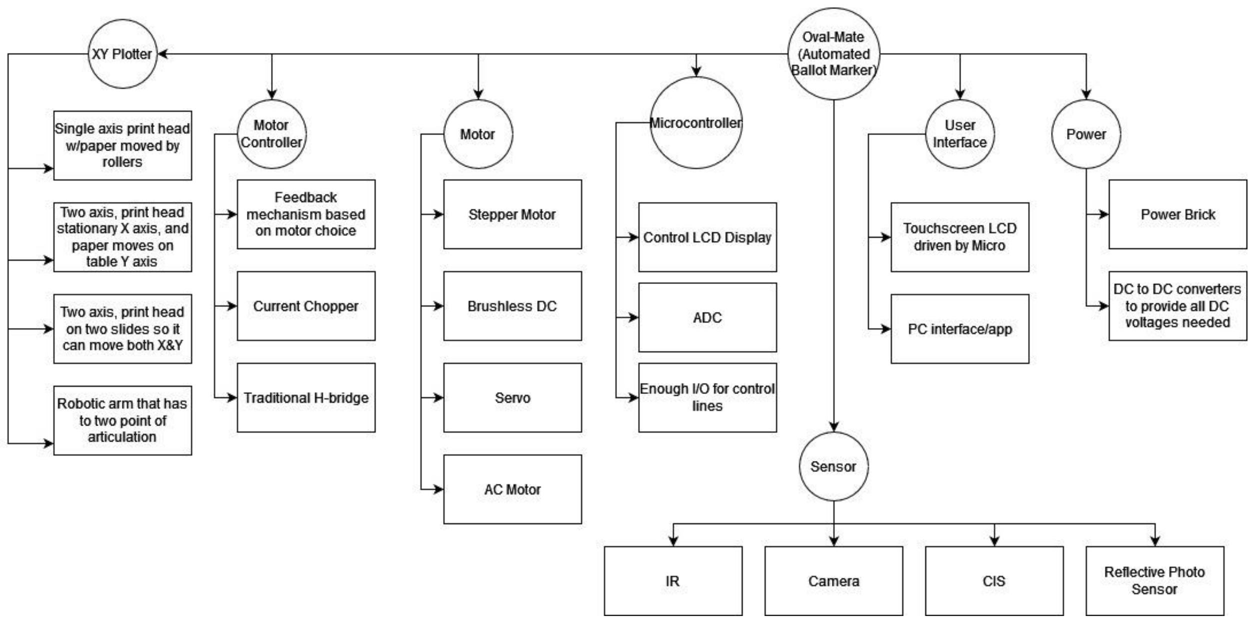


Figure 6: Alternatives Concept Fan

Sensors		IR	Camera	CIS	Reflective Photo Sensor
Cost	0.15	0.2	0.3	0.3	0.25
Complexity	0.4	0.3	0.1	0.1	0.3
Size	0.25	0.25	0.25	0.3	0.25
Availability	0.2	0.25	0.35	0.3	0.2
Score		0.2625	0.2175	0.22	0.26

Table 1: Sensor Alternatives

Motors		Stepper	Brushless DC	Servo	AC
Cost	0.18	0.5	0.2	0.2	0.1
Accuracy	0.6	0.6	0.2	0.1	0.1
Size	0.12	0.4	0.3	0.15	0.15
Availability	0.2	0.34	0.3	0.13	0.23
Score		0.566	0.252	0.14	0.142

Table 2: Motor Alternatives

XY Plotter		Single Axis w/ Roller	2 Axis w/ Stationary X	2 Axis	Single Arm controller
Cost	0.42	0.25	0.25	0.25	0.25
Accuracy	0.15	0.23	0.2	0.4	0.17
Size	0.12	0.17	0.3	0.43	0.1
Durability	0.31	0.3	0.3	0.3	0.1
Score		0.2529	0.264	0.3096	0.1735

Table 3: Plotter Alternatives

Motor Controller		Feedback mech for chosen motor	Current Chopper	Traditional H-Bridge
Cost	0.18	0.2	0.25	0.2
Complexity	0.4	0.2	0.3	0.2
Accuracy	0.22	0.25	0.3	0.3
Availability	0.2	0.35	0.15	0.3
Score		0.241	0.261	0.242

Table 4: Motor Controller Alternatives

Microcontroller		Control LCD Display	ADC	I/O for control lines
Cost	0.23	0.22	0.25	0.53
Complexity	0.45	0.34	0.33	0.33
# of Ports	0.11	0.29	0.3	0.41
Availability	0.21	0.3	0.3	0.4
Score		0.2985	0.302	0.3995

Table *5: Microcontroller Alternatives*

Power		Power Brick	DC to DC converter
Cost	0.18	0.3	0.25
Complexity	0.4	0.3	0.25
Accuracy	0.22	0.2	0.35
Availability	0.2	0.2	0.15
Score		0.258	0.252

Table 6: Power Supply Alternatives

User Interface		Touchscreen LCD driven by Micro	PC Interface/App
Cost	0.18	0.25	0.1
Complexity	0.3	0.2	0.27
Connectivity	0.22	0.2	0.25
Availability	0.3	0.35	0.38
Score		0.254	0.268

Table 7: User Interface Alternatives

Production Schedule

During our planning stage of the project the different tasks were grouped together into major sections. Hardware was the first major task that needed to be completed for the majority of the software design to finish. While the hardware was being developed, the user interface which would run on a Windows machine could be developed. Development boards were purchased to allow software development to begin with the different ICs we chose during the hardware development stages of the various boards. Getting the XY plotter built, boards designed, and mounted allowed the software to fully test all the different components together to get the unit moving. Testing and documenting the project was a task that touched each step along the way. The WBS below and Gantt chart shows the schedule that was used to complete the project.

WBS #	START DATE	DUE DATE	DURATION
1			**Ongoing**
1.1	12/26/21	4/7/22	Ongoing
1.2	12/26/21	4/7/22	Ongoing
2			
2.1	12/26/21	1/29/22	35
2.1.1	12/26/21	1/10/22	16
2.1.2	1/18/22	1/29/22	11
2.1.3	1/11/22	1/14/22	3
2.2	1/10/22	2/16/22	33
2.2.1	1/26/22	2/18/22	23
2.2.2	1/10/22	1/20/22	10
3			
3.1	12/26/21	1/24/22	29
3.1.1	12/26/21	1/17/22	23
3.1.2	12/26/21	1/2/22	7
3.1.3	1/6/22	1/25/22	19
3.2	1/18/22	1/28/22	10
3.2.1	1/18/22	1/28/22	10
3.2.2	1/24/22	1/27/22	3
3.3	12/26/21	1/9/22	20
3.3.1	12/26/21	1/5/22	10
3.3.2	1/3/22	1/9/22	6
3.3.3	12/26/21	12/30/21	4
4			
4.1	1/29/22	2/28/22	24
4.1.1	2/19/22	2/28/22	9
4.1.2	1/29/22	2/11/22	13
4.2	1/29/22	2/3/22	5
4.3	3/1/22	3/17/22	16
5			
5.1	3/18/22	3/21/22	3
5.2	12/26/21	4/7/21	Ongoing
5.3	3/18/22	3/24/22	8
5.4	3/25/22	4/16/22	23

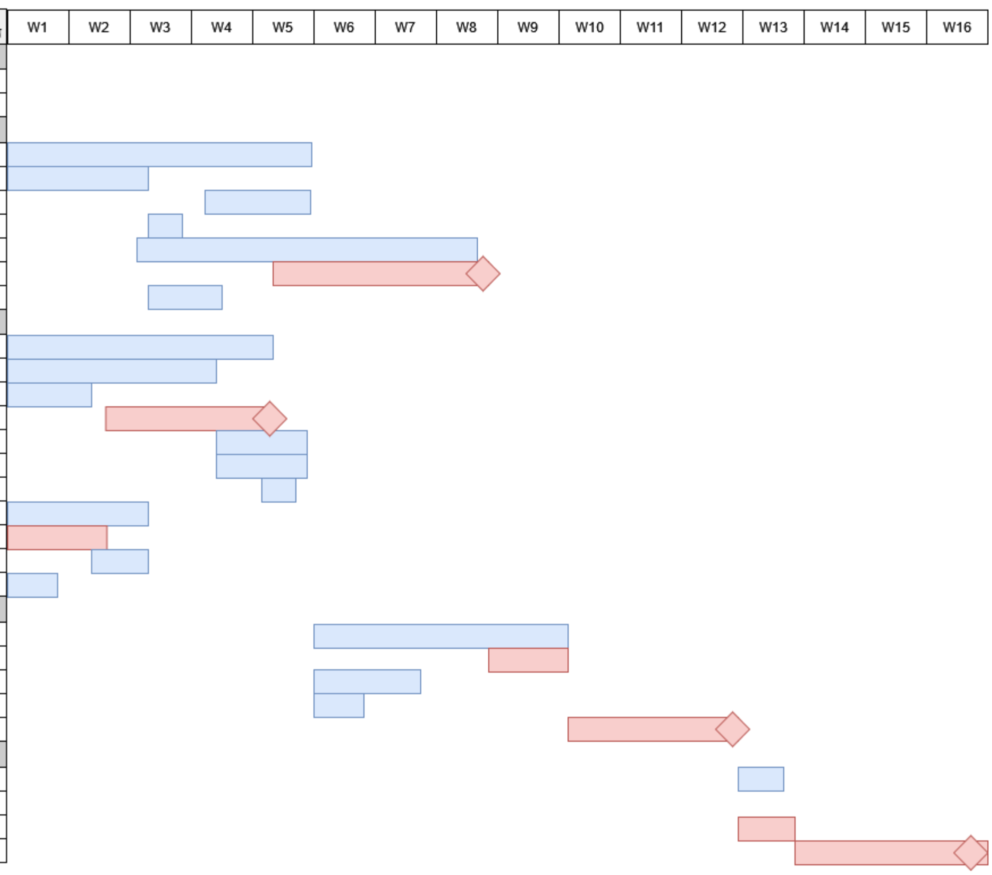


Figure 7: Gantt Chart

WBS with Descriptions and Deliverables			
ID	**Activity**	**Description**	**Deliverables/Milestones**
1	Manage Project	Maintain the project as it progresses	A well managed project
2	Design Software	Develop the software needed to take in user input and operate the ballot marker given user feedback	A windows-based program that communicates with an microcontroller based program that controls the XY-plotter
2.1	User Interface	Develop Windows-based platform for more easily creatable user interface and communicate to the microcontroller	A windows-based user interface capable of taking and preparing input for transmission
2.2	Create Marking Software	Develop software for Microcontroller so it can mark ballots	A microcontroller program that takes input from the Windows program and controls the XY-plotter
3	Design Hardware	Build XY plotter	Power and XY-plotter systems
3.1	Design Circuits	Develop circuit schematics and PCBs	Design PCB and buy components
3.2	Design Power Systems	Create systems to manage power for the circuit from a wall outlet	Build power system
3.3	Design XY-Plotter	Select and build upon a purchased XY-Plotter to accept the size of ballot we need	Buy a XY plotter for mechanical parts
4	Test System	Test subsystems independently and system integration to ensure proper performance	Create test plans for each phase of the design
5	Documentation	All methods and processes will be cataloged in Engineering logbooks, test cases and reports	Logbooks, test cases, result reports will be kept either online or in a group binder
5.4	Final Report	Create a Final Report which describes the design process from start to finish	Final Report of project with all necessary documentation

Table 8: Work Breakdown Structure

Detailed Engineering Analysis and Design Product Presentation

This section will discuss the different engineering specification analysis that were used to create the Oval-Mate. These analysis are packaging, PCB Design, hardware and software design elements. Each section will go into detail on why components or design choices were made.

Project Packaging Specifications

For the packaging for our project, we are going to mount the plotter along with the PCBs on a flat piece of finished wood. The wood base is roughly 3' by 2' with a 1' height. On the right side the plotter will be bracketed into place for stability. On the left side of the base is where we will mount all of our PCBs (4 in Total). Figures 3 and 4 from appendix A visualize this configuration with a CAD drawing.

The reason for this open layout is because fellow engineers at ESS will be using this product and we wanted an open design so they could see and understand what was going on with the electronics. An open layout will also provide for easy accessibility and necessary maintenance. Even though the case is an open layout, a plexi glass top is used to provide safety during normal operations.

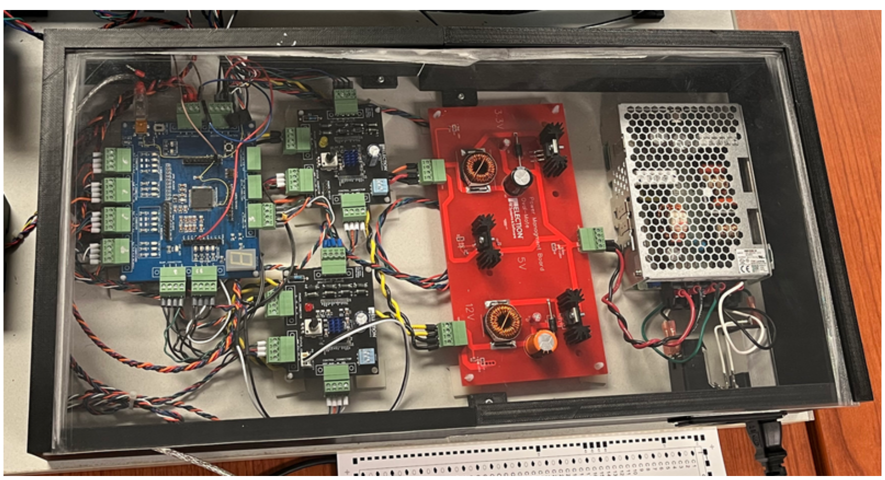


Figure 8: Enclosed Case

The base board is responsible for the majority of the weight for the system at roughly 30lbs. The relatively light weight will allow the engineers to move the product as they please to the desired work location.

As there are many moving wires connected to the plotter we are installing cable rails that will house our wiring and move along each access with the plotter. This will keep all the components tight together for a more professional look.

Figure 9: Cable Management

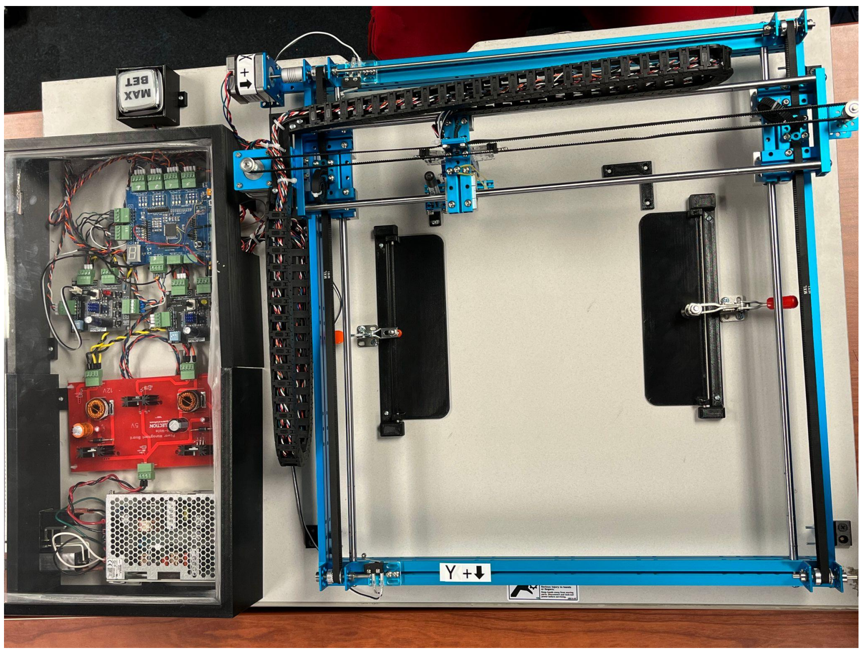


Figure 10: Birdseye View

Theory of Operation

A 24V power supply will be used to power the project from a standard AC wall outlet. The Power Management Board then converts that 24V down to 12V, 5V, and 3.3V. The 12V is used to power two stepper motor drivers that will move the XY plotter. We are using 12V for the stepper motor so they will generate enough torque to be able to start and stop accurately. The 5V will power the IR sensor, seven segment display, and the servo motor. The IR sensor will read the difference between black and white on the ballot. The servo motor will be used to raise and lower the pen to the ballot. The 3.3V will be used to power the microcontroller and the bump switches. The microcontroller will use an ADC to translate the IR readings to digital. The stepper controllers will also be controlled by the microcontroller. Status values are also sent back to the microcontroller to alert if an error occurred on the stepper motor driver.

Hardware Design Narrative

The LPC5512JBD100E has 64 data pins. For our needs, we need a rather large amount of I/O and a decent amount of memory. However, our I/O needs don't overcome our 64 pin limit, rather we need a total of 41 pins. The option to utilize a data bus and decoder in a traditional microprocessor technique could have been used to lower the total number of needed pins, but it was simpler to utilize the breadth of pins available.

Our design uses several features: ADC, CTIMER, SCTIMER, USB (1.0), pin interrupts, GPIO and SWD (for loading new programs and on board debugging). Each section has a portion of pins it utilizes and specific configurations to ensure intended operation.

For the ADC, our system brings in readings from a lone IR sensor to distinguish between white and black portions of the paper ballot. For this we only need a single channel of our ADC. Pin 14, ADC input 8 (of 10), was chosen for this task. ADC channel 8 was set up for single-ended conversion as it can also handle differential-pair conversion.

For the CTIMER, a single output is needed for PWM control of our servo motor which manages the pen. During our design review, we noticed an issue relating to our handling of our different types of motors. The stepper motors can operate rather slowly, around 2KHz, with smooth operation and a steady speed. The pulse-width for stepper motors is irrelevant. Our servo motor expects a particular frequency for best operation and the pulse-width determines the angle. The original plan was to do both of these operations from a single SCTIMER, but the frequency is important for the servo motor. To remedy this problem, we used one of the GPIO pins Lloyd left open, pin 27, CTIMER 3 match output channel 2.

For the SCTIMER, 2 outputs were needed but only a single SCTIMER was available. The SCTIMER has 8 inputs and 10 outputs with the capability to generate several interruptible events and manage several states. We'll be using pin 81, SCTIMER output channel 0, and pin 83, SCTIMER output channel 1, for the X and Y stepper motors' PWM requirements. Both of these outputs will be at a 50% duty cycle, and operated at various frequencies to achieve desired movement. A minimum frequency was found to be 1KHz and a maximum frequency is known to be 600 RPM or 32KHz per stepper.

For USB, USB FullSpeed (1.0) will be used for data transfer from the Window application. The host port can transfer 12Mbps to our device. Estimates for our max data size range from 5KB to 40KB, so this rate ought to transfer in a fast time that will be difficult to notice. This will utilize the USB0 port on the board which are pin 98, 97, 99, 96 which are DM, DP, VSS, and 3.3V.

For pin interrupts, bump switches will be used to make sure the XY-plotter’s motors don’t drive it into the side rails. These will inform the microcontroller, via interrupts, to stop PWM signals to avoid damaging the plotter. There is also an emergency switch interrupt that can be pressed at any time to completely stop movement of the device. Pin 85, pin 68, pin 77, and pin 55 will signal a DOWN, LEFT, RIGHT, and UP interrupt to inform the controller which side rail was hit. The emergency switch interrupt is on pin 54. A reset switch is also present on the board’s dedicated reset interrupt pin, pin 32.

For GPIO, the stepper motor controller requires several inputs and outputs but our 7-segment display needs a dedicated 7 pins. Additional pins, 8 in total, were wired to a header for extra GPIO (one is being used by the servo motor via the CTIMER match output). Legs A, B, C, D, E, F, and G are tied to pins 86, 88, 89, 26, 71, 72, 56. The stepper motor controllers each require 2 inputs to the microcontroller: Home informs our controller when the Stepper is at the beginning of a revolution (Step 0), Fault informs the microcontroller if a significant problem has occurred with the motors, signaling a need to disable them for safety. They also require 4 outputs from our controller: Direction informs the stepper whether to rotate clockwise or counterclockwise, Enable enables the stepper motor controller to begin functioning (chip select), Reset power cycles the stepper motor (also removed any microsteps that aren’t aligned with a near-by whole step), and Sleep allows for better power management of the stepper motors by keeping them in a non-functional, low-power state while the microcontroller is still operating. Home, Fault, Direction, Enable, Reset, and Sleep are, for the X stepper controller, pins 1, 2, 5, 4, 6, 3 and, for the Y stepper controller, pins 7, 9, 65, 59, 80, 93. For extra GPIO, pin 27 (used by servo), pin 92, pin 94, pin 66, pin 79, pin 70, pin 60, and pin 61 are available for additional functions.

For SWD, SWO is pin 21, SWDIO is pin 12 and SWCLK is pin 13. SWD is used to load programs onto the microcontroller but can also be used alongside a NXP LPC-Link2 for onboard debugging.

For pin selection rationale, we decided to select the pins that were able to meet our needs. For our project, we needed pins for PWM, ADC, and GPIO. Going through the datasheet of the microcontroller, we decided to use 3 pins for PWM to control the stepper motors and the servo. We also used 1 pin for ADC for the IR sensor and multiple GPIO for the switches and the seven segment display. To be safe, we assigned some header extra GPIOs, PWM, and ADC pins.

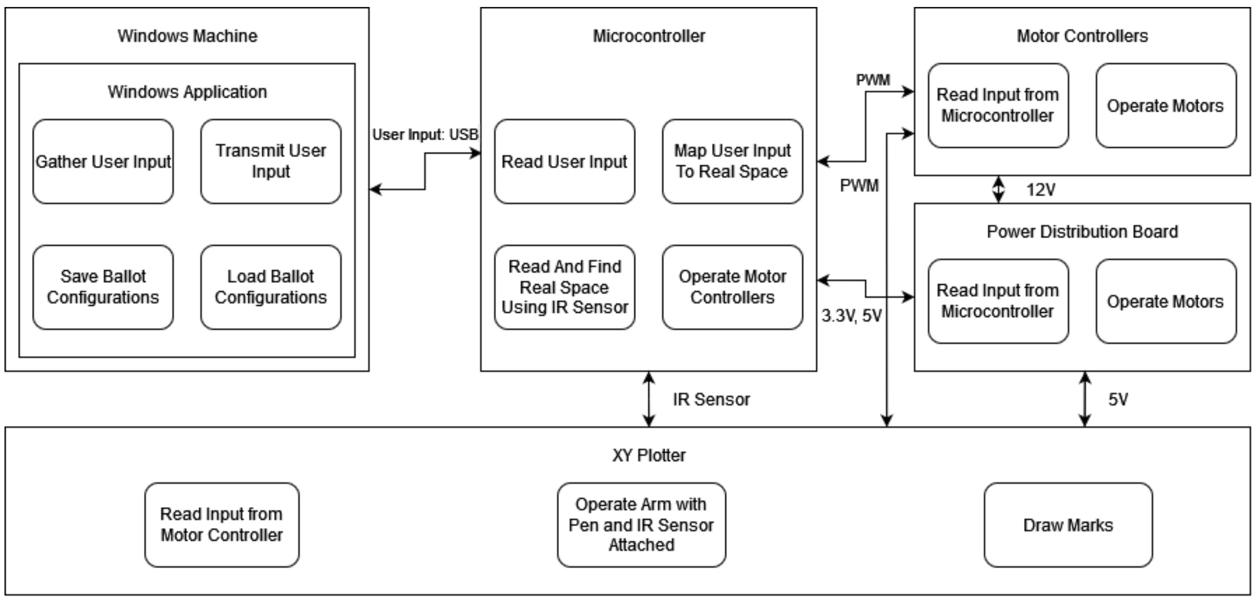


Figure 11: Block Diagram of Theory of Operation

PCB Layout Design Considerations - Overall

Our project required three PCBs to be laid out. The first one was the Power Management Board layout. In order to get it done, we first focused on the traces so they would carry the amperage needed. We chose 3.6mm trace widths to conduct the current along with the 12V. For the 3.3V and 5v, we used a smaller size 3.0mm. Additionally, we added through holes all over the PMB to mount heat sinks due to the high power used on it which causes heat. We also placed the connectors on the edge of the board to have better access.

Second, we designed the Motor Controller Board layout. While designing the layout, we had to consider the heat sink that will absorb the heat from the IC used (DR8824) using a small area underneath the IC. Then, we added the connectors for the control lines, the power, and the output for the stepper on the edges of the board to access them easily.

Lastly, on the Microcontroller Board layout, we decided to use surface mount on most of our components because it takes less space and has a better look. The connectors were on all edges of the board for better access. The X and Y plotter connectors were next to each other with each control line labeled with indicators. The connector for the power was on its side. We decided to leave it by itself to avoid any interference. A seven segment display with through holes was used to allow us to indicate codes for status. Instead of soldering it directly to the board, we used female headers. Additionally, we used male headers around the microcontroller to monitor and have access to all the pins used with all the components the microcontroller is interfacing with. This will help us during troubleshooting.

PCB Layout Design Considerations - Microcontroller

The microcontroller PCB layout required consideration of high and low frequency signals as well as managing different voltages to interact with all the necessary components. The design used FullSpeed USB which has a maximum throughput of 12Mbps. USB also uses a differential pair for transferring data. To place the traces for this, the USB port location was set early and their traces routed before others. This was done to prevent usage of vias which can have a detrimental effect on differential pair and high frequency signals. Because we were working with USB, shielding and ESD protection were also used.

The low frequency signals were between 50Hz and 3kHz. A similar aversion to vias was used for these connections as well.

To handle different voltages, the lines were clearly marked and kept at a further distance from traces of the other voltage. Their grounds were the same, as they were provided by the PMB.

Another consideration was the idea of a potential mistake. To account for this, a selection of extra GPIO pins were traced to a header. This is useful for a prototype as it can avoid reordering, but also useful for ES&S as it allows further customization without reordering or redesigning.

PCB Layout Design Considerations - Power Supply

The design of the Power Management Board had to consider the three voltages needed along with the current needed by the project. Since we are using three different voltages, different voltage regulators were needed to accomplish this. Due to both the 3.3V [3] and 12V [1] needing to supply 3A, which includes a safety margin of twenty five percent, we had to use buck boost regulators. These include large capacitors and inductors to be able to keep the current and voltage regulated during the "off" portion of the switching regulator. With the large inductors switching at a high frequency and at a large current, spacing the two inductors away from each other was necessary. If the inductors were too close to each other they could interfere with each other and not function properly. This resulted in the board being bigger than we thought it would. However, we do not have any size limitations for our design. The trace widths also had to be increased from the default to allow for the larger current that we will be using on this board. The 5V [2] is a linear regulator that supplies 1.5A. The terminal block connectors that we are using are able to handle 8A which has more than enough safety margin. These terminal blocks are also easy to connect and disconnect for troubleshooting. The capacitors are also low ESR (Equivalent Series Resistance) so that way the feedback circuits are not affected and the regulator will output the correct voltage at varying loads. We also tried to make sure the outputs of the regulators were as short as possible to the output connectors. Due to the regulators producing heat, we made mounting holes in the PCB for heatsinks. To get power traces [5] transferred from the top to the bottom layer, a series of large vias were used to ensure there was enough surface area to carry enough current through to the other side.

Software Design Narrative

From a software perspective, the Ovalmate project utilizes a wide range of firmware both through libraries created by the team and by others. The project requires a Windows-based Application that is capable of utilizing USB capabilities to communicate with dedicated hardware. That hardware is programmed with the team's additions to NXP's LPC551x/LPC55S1x driver through NXP's MCUXpresso IDE.

Major software design considerations include USB capability from both the Windows application and the microcontroller. USB is a complex variant of serial communication and creating a library on our own isn't feasible, so the team needs to consider libraries created by others that can be used on Ovalmate hardware.

Another major design consideration is program space and memory space. The microcontroller of choice, the LPC5512JBD100, has 64KB of Flash memory (program memory), and 48KB of SRAM (memory space). No additional memory chips are used.

The use of stepper motor controllers set to perform microstepping also adds some complexity. Should the motors be slept, say to reduce power consumption when no job is present, the steppers will be pulled to their nearest whole step. Alongside this, the microstepping is prone to slippage at higher frequencies, particularly when going from high frequency to stopped in a single step.

Software Design Considerations

Memory Usage

- SRAM 12KB of 48KB 38.1% used
- Flash 53KB of 64KB 83.1% used
- USB SRAM 11.5KB of 16KB 71.8% used
- Stack Start Address: 0x20007800
  - Total Stack Space: 0x20007800-0x20008000 => 800 bytes
- Heap memory Start Address: 0x200007c4
  - Total Heap Memory Space: 0x200007c4-0x20000fc4 => 800 bytes

The LPC5512JBD100 follows the design specified by ARM’s Cortex M33 specifications. The Cortex M33 has two major buses called the Advanced High-performance Bus (AHB) and Advanced Peripheral Bus (APB)

Non-Secure Start Address	Non-Secure End Address	TrustZone	CPU Bus	Usage
0x0000 0000	0x0FFF FFFF	Non-Secure	Code	Flash Memory, Boot ROM, SRAM X
0x1000 0000	0x1FFF FFFF	Secure	Code	Same as above
0x2000 0000	0x2FFF FFFF	Non-Secure	Data	SRAM 0, 1 & 2, USB-HS SRAM
0x3000 0000	0x3FFF FFFF	Secure	Data	Same as above
0x4000 0000	0x4FFF FFFF	Non-Secure	Data	AHB & APB peripherals
0x5000 0000	0x5FFF FFFF	Secure	Data	Same as above

Table 9: General Memory Map for Cortex M33

Non-Secure Start Address	**Non-Secure End Address**	**Secure Start Address**	**Secure End Address**	**Usage**
0x0000 0000	0x0003 FFFF	0x1000 0000	0x1003 FFFF	Flash memory, on CM33 code bus. The last 17 pages (12 KB) are reserved on the 256KB flash devices resulting in 244 KB internal flash memory. (64KB available in this microcontroller)
0x0300 0000	0x0301 FFFF	0x1300 0000	0x1301 FFFF	Boot ROM, on CM33 code bus
0x2000 0000	0x2000 7FFF	0x3000 0000	0x3000 7FFF	SRAM 0 on CM33 data bus, 32 KB
0x2000 8000	0x2000 BFFF	0x3000 8000	0x3000 BFFF	SRAM 1 on CM33 data bus, 16 KB
0x2000 C000	0x2000 FFFF	0x3000 C000	0x3000 FFFF	SRAM 2 on CM33 data bus, 16 KB. (Not available in this microcontroller)
0x2001 0000	0x2001 3FFF	0x3001 0000	0x3001 3FFF	USB SRAM, 16 KB.

Table 10: Specific Memory Map for Flash, SRAM, and USB SRAM

Port	**Pin (on Port)**	**Pin (on Package)**	**Out/In**	**Usage**
0	2	81	Output	PWM output (1KHz-8KHz, 50% duty cycle)
1	6	5	Output	Direction (clockwise or counter-clockwise)
1	20	4	Output	Enable (chip select)
1	13	2	Input	Fault (tied to Pin Interrupt 5)
1	4	1	Input	Home (motor home position)
0	7	6	Output	Reset (reset for motor controller)
1	24	3	Output	Sleep (sleep motor)

Table 11: Stepper Motor Controller X Pins

Port	Pin (on Port)	Pin (on Package)	Out/In	Usage
0	3	83	Output	PWM output (1KHz-8KHz, 50% duty cycle)
1	30	65	Output	Direction (clockwise or counter-clockwise)
1	1	65	Output	Enable (chip select)
1	7	9	Input	Fault (tied to Pin Interrupt 6)
0	1	7	Input	Home (motor home position)
1	29	80	Output	Reset (reset for motor controller)
1	11	93	Output	Sleep (sleep motor)

Table 12: Stepper Motor Controller Y Pins

Port	Pin (on Port)	Pin (on Package)	Usage
0	4	86	7-Segment Leg A
0	5	88	7-Segment Leg B
0	6	89	7-Segment Leg C
0	8	26	7-Segment Leg D
0	13	71	7-Segment Leg E
0	14	72	7-Segment Leg F
0	18	56	7-Segment Leg G

Table 13: 7-Segment Display Pins

Port	Pin (on Port)	Pin (on Package)	Usage
0	0	54	Emergency Bump Switch (Pin Interrupt 0)
1	25	77	Right Bump Switch (Pin Interrupt 1)
1	26	68	Left Bump Switch (Pin Interrupt 2)
1	27	85	Down Bump Switch (Pin Interrupt 3)
0	9	55	Up Bump Switch (Pin Interrupt 4)

Table 14: Bump Switch Interrupt Pins

Port	Pin (on Port)	Pin (on Package)	ADC; ADC Channel	Usage
0	16	14	ADC0; Channel 0B	IR sensor input

Table 15: IR Sensor Pins

Port	Pin (on Port)	Pin (on Package)	Usage
0	15	22	Servo PWM output (50Hz, 7%-9% duty cycle) (not currently being used)

Table 16: Servo Motor Pins

Pin (on Package)	Usage
78	USB0 VBUS
96	USB0 3.3V
97	USB0 D+
98	USB0 D-
99	USB0 GND

Table 17: USB Pins

Port	Pin (on Port)	Pin (on Package)	Usage
0	27	27	Servo PWM output (currently)
0	26	60	None
1	2	61	None
0	28	66	None
0	24	70	None
0	25	79	None
0	29	92	None
0	30	94	None

Table 18: Extra GPIO Pins

Integrated peripherals used:

- 12 MHz clock
  - Drives processor @ 150MHz through Phase-Locked Loop 1
  - Drives CTIMER0 (Stepper X) & CTIMER1 (Stepper Y)
- 96 MHz clock
  - Drives ADC & USB. 48MHz is max frequency for those components. This clock divided by 2 gives that frequency easily.
- 1 MHz clock
  - Drives CTIMER3 (Servo)
- ADC0, channel 0B (ADC0_8) @48 MHz (2Msamples/s)
  - 128 sample hardware average during conversion
  - Analog conversion circuits pre-enabled
  - Internal voltage reference
  - Channel 0
  - Single-Ended, Side B (ADC0_8)
  - 16 bit ADC
- FS USB @ 48MHz (12 Mbps)
  - Full Speed USB
  - HID (Human Interface Device)
- CTIMER0 (StepperX)
  - No Prescaling
  - Timer Mode
  - Reset on Match
  - Don’t stop on Match
  - Interrupt enabled
- CTIMER1 (StepperY)
  - No Prescaling

    - Timer Mode
    - Reset on Match
    - Don't stop on Match
    - Interrupt enabled
- CTIMER3 (Servo)
    - No Prescaling
    - Timer Mode
    - Reset on Match
    - Don't stop on Match
    - Interrupt Enabled
- GPIO
- NVIC (Nested Vector Interrupt Controller) (7 of 8 custom pin interrupts used)
    - Pin Interrupt 0 (Emergency Bump)
        - Rising Edge Interrupt
    - Pin Interrupt 1 (Right Bump)
        - Rising Edge Interrupt
    - Pin Interrupt 2 (Left Bump)
        - Rising Edge Interrupt
    - Pin Interrupt 3 (Down Bump)
        - Rising Edge Interrupt
    - Pin Interrupt 4 (Up Bump)
        - Rising Edge Interrupt
    - Pin Interrupt 5 (Stepper X Fault)
        - Falling Edge Interrupt
    - Pin Interrupt 6 (Stepper Y Fault)
        - Falling Edge Interrupt

Overall Organization: The microcontroller is sort of a combination of interrupt-based and polling. The main program runs based on polling whether a structure has defined members. That structure is populated by interrupt-driven USB communication with the Windows application (which is event driven). During the main program, much of the behaviors are handled via interrupts. The servo motor and both stepper motors are driven by interrupt-based PWM signals triggered by internal timers. Buttons and bump sensors are also connected to interrupts. From this the application code is organized in Interrupt-driven style with a little bit of polling.

Debugging Provisions are provided by NXP. The JTAG connector on the board can flash and perform live debugging on the microcontroller using NXP's LPC-Link2. NXP also includes functions for printing information over this JTAG connection (SWD over JTAG) to a connected instance of MCUXpresso

Software Design Narrative

The 7-Segment module handles initializing and interacting with the 7-segment display on the microcontroller board. The module requires the initialization function "SEVENSEG_initializeLegs()" to be called to initialize the pins. Afterward, any of the macro functions (which automatically place a hex value on the 7seg) as well as the two functions that set the legs will properly function and are ready to use. One way to set the legs is with a set of 7 boolean variables, another is using the first 7 bits of an 8 bit value. This module is complete, tested, and successfully ported to the board.

The Bump Sensor module handles initializing the pin interrupts for the bump switches and allows users to pass a handling function to deal with a button press. After calling "BUTTONS_assignPinsToInterrupts()" the bump switches will be enabled as will their interrupts. Their interrupt functions are defined in this module. Functions can be passed via variables provided by this module to handle bump switch interrupts. They can be replaced freely. This module is complete, tested, and successfully ported to the board.

The IR Sensor module interacts with the ADC in order to take in the analog signal output from the IR sensor. This module requires initialization via the "IRSENSOR_initializeADC()". Afterward, values can be accessed from the IR sensor from the single input channel used. The programmer can also use a built in averaging function for more consistent readings by specifying a number of samples. This module is complete, tested, and successfully ported to the board.

The Black Dots module stores the oval's that the plotter needs to fill in and manages interactions with this information. This module does not require initialization. This module exists to preserve space. The forms are a maximum of 24 ovals wide and for the form we're handling, exactly 70 ovals tall. This would mean storing x and y coordinates for 1680 potential ovals being stored. Instead, this module stores a number of 32 bit integers equal to the height of the ovals (70). It then uses bit manipulation to store entire rows of ovals in a single 32 bit integer. The module contains several functions for interacting with rows and columns in this structure. This module is complete and ported to the device but has not undergone thorough testing.

The Utils module handles converting between the different domains present in the system. Those include millimeters, nanometers, blackDots, and steps. Supposing we know the coordinates of a black dot, given an offset determined by the form's location in the polotter, these functions can calculate a number of steps needed to get to that location. The addition of converting to real world measurement systems is useful when working with mathematically constructed algorithms, such as drawing an oval. This module is not yet complete (it lacks the functions for converting from and to blackDots, but the other functions have been tested and ported to the board.

The Servo module uses the additional ctimer PWM adapter library from NXP in order to manage and control the servo motor. This module does require initialization via the "SERVO_initializePWM()" function. Afterward, the motor can be started by setting the match value using the "SERVO_setupPWM()" and driving the motor using the "SERVO_startPWM()". The duty cycle is managed by interrupts and can be modified while it runs using the "SERVO_updatePWMDutyCycle()" or it's more understandably named macro "SERVO_setPenMode()" using the "PENUP" and "PENDOWN" definitions. This module is complete, tested, and ported to the board. With time permitting, this module will be improved, as the servo motor doesn't need constant input.

The Stepper module uses 2 timers to drive the stepper motors of the plotter. Almost all functions, aside from initialization and functions that affect both motors, require a pointer to the motor to be passed in order to determine which should be driven. This module does require initialization. There are 2 initialization functions for the stepper motors "STEPPERS_intializeMotors()" and "STEPPERS_initializePins()". Both need to be called for functionality, as the stepper motor controller has several pins that need to be managed with GPIO as well as needing a PWM signal to determine when to step. The former function initializes the timers and the latter initializes the pins. Once both are run, the motors can be driven most easily using several macros which allow for a programmer to specify both or just one motor to be driven to particular locations with or without acceleration in its movement and with or without blocking as the motion completes. The information for each motor is contained in a struct provided via a pointer. This pointer contains the current "position" of the motor on its axis in the steps domain. The "status" of the motor indicates it's current movement, and can be polled to block while the motor is moving. This module has been completed, tested, and ported onto the board.

The Main Include module combines many of the aforementioned modules into a single include file, so they can be included into main easily. It also contains a function that can be called to initialize all included modules. It provides a few functions for interactive functionality between the modules. For instance, it provides a bump interrupt callback function which stops any running motors if an interrupt is triggered. This module is not complete, but what is there now has been tested and ported to the board.

The Advanced Steppers module contains functions between the servo motor and stepper motors. It requires that the servo motor and stepper motors have been initialized. There are only 2 behaviors in this module, “drawOval()” and “drawRectangle()”. This module is complete, tested, and ported to the board.

The Localization module handles figuring out where the arm of the plotter is. It requires that the stepper motors, servo motor, and IR sensor have been initialized. Using the “findHome()” function, the plotter can zero itself in the upper left corner of the plot. From there, it can poll the adc across a range and analyze what it drove over as it moves towards the ballot in the center. It can then find the center of rectangles on the sheet in order to figure out the locations of ovals (rectangle and oval placement are standardized). After figuring out where the ovals are, the plotter can move onto filling them out. This module is incomplete, untested, but largely written out and ported to the board.

The USB module handled interfacing with a windows computer as a HID (Human Interface Device). This module does require initialization. Using interrupts to handle messages from the host, this module will work to populate the blackDots structure based on data from the windows application and communicate errors back to the desktop.

Performance Estimates and Results

The Oval-Mate was designed to fill out a eleven inch test ballot in seven minutes or less. This number comes from the fact that a human can mark a ballot in fifteen minutes. The speed of the XY plotter is more than fast enough to be able to move a marking device around the ballot to achieve this goal. The limiting factor is going to be how quickly can the marking device write as its being moved across the ballot paper. Another aspect that has to be taken into consideration is that the ballot image, or printing of the ovals, can be skewed slightly. Thus the ovals are not always in the same location from ballot to ballot. This skew is small but must be measured each time a new ballot is inserted into the Oval-Mate. This measurement does take time and is currently being considered part of the marking process that falls within the time goal.

Ease of use is another aspect of our design that was a key result. The Oval-Mate is to be easy to use by engineering level operators as the device is only going to be used in a laboratory environment. The ballot has to be easy to load and unload with minimal setup time. The software interface to set up a ballot also needs to be streamlined to allow swapping between different styles or configurations of ballots can be done quickly.

Power consumption is not a direct requirement of this project, however making a green product is always something that needs to be considered. The components used are geared towards conserving energy. The power supply and regulators each have an efficiency rating of eighty percent or higher. Also the ICs used in this product all have deep sleep modes to conserve energy when not in use.

The marking of the oval takes 1.462 seconds to mark and with 100 ovals needing to be marked, one side will take 146.2 seconds to be completely marked. This is roughly 2.5 minutes per side. Finding the offset of the ballot does take a few minutes to locate landmarks on the ballot itself and calculate the offset needed for the ballot. The travel time between ovals is a few seconds. So with everything added up, we are around 6.5 minutes to mark a ballot side. This is without optimizing the speed of the Oval-mate. The speed will be able to be increased as we test with it more.

The oval marking accuracy is also a result that needs to be discussed. Marking the oval by 90 percent completeness is our goal based on how accurately a human fills in an oval. We were able to achieve this by drawing filled ovals on top of the empty ovals on the ballot. With the ovals being 2x3mm in size the measured white space needs to be less than $0.6mm^2$. A microruler was used to measure 5 ovals marked and each oval came out to be less than $0.6mm^2$ white space left inside the oval. Below in Figure 9, it can be seen that the Oval-Mate is very accurate in how it fills in ovals.

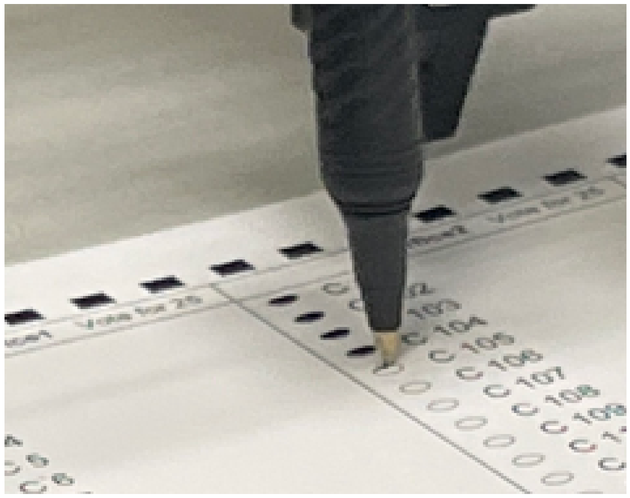


Figure 12: Marked Oval Precision

Suggestions on how to improve performance includes having the stepper motor speed turned up. However, caution should be used as the marking device can only mark so fast with a reliable and readable line. The momentum of the print mechanism is another factor that needs to be considered, as acceleration and deceleration torque requirements go up with speed. This could mean that the stepper motors could mis-step and the microcontroller wouldn't know that it happened which would result in mismarked ovals. The pen holder mechanism could be better than what came with the XY plotter that was purchased. During marking of ovals the pen does move a bit which creates some inconsistencies, but not enough to make it fall out of its accuracy goal.

The next page has our test cases that were developed during our design phase. These verified that individual components would work in the system and also tested the whole system.

Test Writer: Nick Guida						
Test Case Name:	Ballot Mark Fill Acceptance Test				Test ID#	0001
Description:	The ovals on the ballot will be filled with less than 10% of the marking occurring outside of the oval.					
Tester Information						
Name of Tester:	Adam Krajicek					
Hardware Ver:	1.0					
Setup:	XY plotter connected to computer program and powered on ready for input.					

Setup	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**
1	Input all oval locations to be filled	The program will set a path for the motors to follow which will visit every oval location on the ballot.	X			Selected multiple ovals in different areas of the ballot
2	Run the program	The plotter will activate and begin to visit and mark every oval	X			
3	Observe for any missed ovals	Plotter will not be marking any blank spaces without an oval	X			
4	Record Findings	All ovals on the ballot are filled with less than 10% error	X			
Overall test result:			X			All ovals selected in application were marked by the Oval-Mate

Table 19: Test Case 0001

Test Writer: Adam Krajicek							
Test Case Name:		Percentage of Oval Space Marked				Test ID #:	0002
Description:		Measure the percentage of space marked within the printed oval space. Oval-mate will mark 90% or more of oval space with mark on ballot.				Type:	White Box
Tester Information							
Name of Tester:		Alex Wissing				Date:	4/15/22
Hardware Ver:		1.0				Time:	13:00
Setup:		Oval-mate will print nine ovals. Ovals will be placed in the four corners, then single ovals centered between the four corners which will count for four more ovals. Then the last oval will be in the center of the ballot. This will test for all skew or slippage that would occur during printing. A micro ruler will be used to measure mark coverage of the oval.					
Step	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**	
1	Measure width of white space of oval	Record measurement				1mm	
2	Measure height of white space of oval	Record measurement				0.3mm	
3	Multiply H x W to get area of white space	Area must be 0.6mm or less	X			$0.3mm^2$	
Overall test result:			X			Oval-Mate passed this test.	

Table 20: Test Case 0002

Test Writer: Adam Krajicek							
Test Case Name:		Final Functional Test				Test ID #:	0003
Description:		Go through the full end to end functionality of the unit as if a user would mark a ballot. Verifies that all systems and functions work as expected.				Type:	White Box
Tester Information							
Name of Tester:		Nick Guida				Date:	4-20-22
Hardware Ver:		1.0				Time:	14:00
Setup:		Ensure that the 11" blank ballot is set up correctly on the print bed.					
Step	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**	
1	Turn on XY plotter	XY plotter is ready to communicate	X				
2	Double Click EXE file for Ballot marking app	App will launch	X				
3	Press "Connect" button on app menu	App will confirm that communication with the XY plotter has been established. XY plotter will have LED indicators to verify as well	X				
4	Select 10 random oval locations on the app setup screen	Clicked ovals will show they are filled in	X				
5	Press the Apply button on the app to mark the ballot	XY plotter will find its zero position, locate landmarks on ballot, and mark selected ovals	X				
6	Insert marked ballot into ESS tabulator	ESS tabulator will digitally analyze markings and tabulate.	X				
Overall test result:			X			Ballot was tabulated correctly by the DS950 central count tabulator	

Table 21: Test Case 0003

Test Writer: Adam Krajicek						
Test Case Name:	Motor Controller Driver Circuit				Test ID #:	0004
Description:	Test motor controller driver circuit to verify it outputs correct voltage and sources enough current to drive the stepper motor				Type:	White Box
Tester Information						
Name of Tester:	Adam Krajicek				Date:	2-15-22
Hardware Ver:	1.0				Time:	
Setup:	Motor controller driver circuit will be driven by a microprocessor to activate the gates of the MOSFET transistors as if a motor controller were connected. Voltages and currents will be measured using a dummy load.					

Step	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect dummy load to output of MOSFET	This load will simulate a motor winding				
2	Connect a Oscilloscope to output of MOSFET	This will measure the pulse voltage				
3	Turn on microcontroller that will produce a 10Hz PWM	This will turn the MOSFETS on and off at 10Hz				
4	Observe Oscilloscope Voltage reading and ability to follow input signal	Voltage will be XXV and the output/input signals will be very close to each other (I don't know yet what is to be expected on the phase difference)				
5	Increase PWM to 50% max speed	This will stress the MOSFET				
6	Observe Oscilloscope Voltage reading and ability to follow input signal	Voltage will be XXV and the output/input signals will be very close to each other (I don't know yet what is to be expected on the phase difference)				
7	Increase PWM to 100% max speed	This will stress the MOSFET				

Step	Action	Expected Result	Pass	Fail	N/A	Comments
8	Observe Oscilloscope Voltage reading and ability to follow input signal	Voltage will be XXV and the output/input signals will be very close to each other (I don't know yet what is to be expected on the phase difference)				
9	Measure temperature of MOSFET	Temperature will not exceed XXC				
10	Measure Current with DMM in line with power supply to MOSFET	Current will be XXA, to not exceed current for MOSFET and motor				
Overall test result:					X	This test is no longer valid as we are not using discrete MOSFET components.

Table 22: Test Case 0004

Test Writer: Adam Krajicek			
Test Case Name:	Stepper Motor Controller Circuit	Test ID #:	0005
Description:	Test Circuit to ensure input result in correct output	Type:	White Box
Tester Information			
Name of Tester:	Adam Krajicek	Date:	3-22-22
Hardware Ver:	1.0	Time:	10:05
Setup:	Oscilloscope will need to be connected to the output pins of the controller to monitor correct timing of output to successfully drive a stepper motor. A microcontroller with minimal code will need to be used to provide inputs such as stepping direction, mode, and speed. Verification of correct stepper timing will allow for integration with the stepper motor driver circuit.		

Step	Action	Expected Result	Pass	Fail	N/A	Comments
1	Turn on microcontroller and stepper motor controller circuit	Both boards will turn their appropriate LED indicators on.	X			We had to modify the circuit because of Open-Drain outputs.
2	Set stepping speed to 10Hz, forward direction and mode to normal (no micro stepping)	Inputs of the stepper motor controller will have the correct digital levels to enable forward movement at 10 Hz intervals	X			
3	Observe oscilloscope	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			
4	Increase frequency of the stepping speed to 100Hz	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			
5	Observe oscilloscope	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			

Step	Action	Expected Result	Pass	Fail	N/A	Comments
6	Increase frequency of the stepping speed to top speed of 10KHz	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			
7	Set stepping speed to 10Hz, reverse direction and mode to normal (no micro stepping)	Inputs of the stepper motor controller will have the correct digital levels to enable reverse movement at 10Hz intervals	X			
8	Observe oscilloscope	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			
9	Increase frequency of the stepping speed to 100Hz	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			
10	Observe oscilloscope	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			
11	Increase frequency of the stepping speed to top speed of ###Hz	Oscilloscope will have four pulse trains that are offset by a few milliseconds which is determined by the datasheet	X			
12	Set stepping speed to 10Hz, forward direction and mode to 1/8 micro stepping	Inputs of the stepper motor controller will have the correct digital levels to enable forward movement at 10 Hz intervals	X			
13	Set stepping speed to 10Hz, reverse direction and mode to 1/8 micro stepping	Inputs of the stepper motor controller will have the correct digital levels to enable reverse movement at 10Hz intervals	X			

Step	Action	Expected Result	Pass	Fail	N/A	Comments
14	Set stepping speed to 10Hz, forward direction and mode to 1/16 micro stepping	Inputs of the stepper motor controller will have the correct digital levels to enable forward movement at 10 Hz intervals	X			
15	Set stepping speed to 10Hz, reverse direction and mode to 1/16 micro stepping	Inputs of the stepper motor controller will have the correct digital levels to enable reverse movement at 10Hz intervals	X			
Overall test result:			X			Stepper motor circuit works correctly with all modes needed for the project.

Table 23: Test Case 0005

Test Writer: Alex Wissing							
Test Case Name:		Test Motor Controllability				Test ID #:	0006
Description:		Verify the microcontroller circuit has the ability to manipulate the motors in expected direction (X+, Y+, X-, Y-). For this test, where (0, 0) or (5, 8) isn't relevant beyond direction.				Type:	White Box
Tester Information							
Name of Tester:		Alex Wissing				Date:	3-05-22
Hardware Ver:		1.0				Time:	
Setup:		Call a function that takes the x and y location and moves the plotter's head. The values are large due to microstepping.					
Setup	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**	
1	STEPPERS_moveBothToNoAccel(1000, 0)	X+	X				
2	STEPPERS_moveBothToNoAccel(0, 1000)	Y+	X				
3	STEPPERS_moveBothToNoAccel(1000, 0) STEPPERS_moveBothToNoAccel(0, 0)	X+, X-	X				
4	STEPPERS_moveBothToNoAccel(0, 1000) STEPPERS_moveBothToNoAccel(0, 0)	Y+, Y-	X				
5	STEPPERS_moveBothToNoAccel(1000, 1000)	X+Y+	X				
6	STEPPERS_moveBothToNoAccel(1000, 1000) STEPPERS_moveBothToNoAccel(-1000, -1000)	X+Y+, X-Y-	X				
7	STEPPERS_moveBothToNoAccel(1000, 0) STEPPERS_moveBothToNoAccel(0, 1000)	X+, X-Y+	X				
8	STEPPERS_moveBothToNoAccel(0, 1000) STEPPERS_moveBothToNoAccel(1000, 0)	Y+, X+Y-	X				
Overall test result:			X			The motors moved as expected	

Table 24: Test Case 0006

<table>
<tr><td colspan="6">Test Writer: Alex Wissing</td></tr>
<tr><td colspan="2">Test Case Name:</td><td colspan="2">Mapping Algorithm</td><td>Test ID #:</td><td>0007</td></tr>
<tr><td colspan="2">Description:</td><td colspan="2">Verify accurate mapping from black-dot-based coordinate system to real world space given a particular orientation. The document we use has all possible ovals lines up to the black rectangles on the edges, creating a plane.</td><td>Type:</td><td>White Box</td></tr>
<tr><td colspan="6">Tester Information</td></tr>
<tr><td colspan="2">Name of Tester:</td><td colspan="2">Alex Wissing</td><td>Date:</td><td>4-5-22</td></tr>
<tr><td colspan="2">Hardware Ver:</td><td colspan="2">1.0</td><td>Time:</td><td></td></tr>
<tr><td colspan="2">Setup:</td><td colspan="4">Given a real-world XY-coordinate of the center of the upper left black rectangle a real-world XY-coordinate of the center of the upper right black rectangle, and a real-world XY-coordinate of the center of the lower left black rectangle, take a given black-dot XY-coordinate and translate it to the real-world coordinate system.</td></tr>
</table>

Setup	Action	Expected Result	Pass	Fail	N/A	Comments
1	Real-world Corners: (5600, 3200), (20700, 3140), (5710, 24000) Black-dot Coordinate: (5, 5)	Real-world Coordinate: (8745.833, 5280)	X			
2	Real-world Corners: (6400, 3300), (19300, 3340), (6530, 23600) Black-dot Coordinate: (20, 37)	Real-world Coordinate: (17150, 18332.4)	X			
Overall test result:			X			Oval-Mate found the locations correctly.

Table 25: Test Case 0007

Test Writer: Alex							
Test Case Name:		Windows Platform Button Test				Test ID #:	0008
Description:		The Windows platform will have many buttons which will perform actions listed in the Data Flow diagram in problem 6.14. This test expects those behaviors.				Type:	White Box
Tester Information							
Name of Tester:		Alex Wissing				Date:	2-10-22
Hardware Ver:		1.0				Time:	
Setup:		Launch the Windows Application and have it connected over USB to the Microcontroller					
Setup	**Action**	**Expected Result**	**Pass**	**Fail**	**N/A**	**Comments**	
1	Click “Connect”	App will begin connection to the Microcontroller and load the document view page	X				
2	Click an Oval	The oval will fill	X				
3	Click “Save”	App will open a windows explorer window that allows the user to select a location to save the file as well as a name for the file	X				
4	Click “Apply”	A loading window will appear, disabling the app, while it communicates to the microcontroller. After communication finishes, the loading window will become a processing window, which will await a message from the microcontroller for a completed or failed job.	X				
5	Click “Load”	Opens a windows dialog window that allows a user to load a saved file containing selected oval information	X				
Overall test result:			X			Application connects to micro, and also load/save feature works.	

Table 26: Test Case 0008

Economic Analysis

Cost Analysis

With the estimated engineers salary of $80,000 yearly we can estimate how many ballots we would have to mark to break even on the costs and time spent developing Oval-Mate. In total, $810 has been spent on materials and an estimated 1264 engineering hours has been spent between team members. On average, an engineer at ES&S would spend roughly 15 minutes marking a ballot by hand. With the average salary at $41.03 an hour, the total monetary value spent on this project equates to $52,671. Because each ballet takes 15 minutes to mark a ballot, Oval-Mate would have to mark 5,133 ballots to break even for this investment. It should be mentioned that by freeing up the engineer's time by making these markings autonomously, during the breakeven period they would accumulate 1283 hours to be spent on engineering rather than marking ballots.

Estimated Engineer's Salary	$80,000
Hourly rate	$41.03
Nick Guida	274 Hours
Adam Krajicek	310 Hours
Alex Wissing	380.25 Hours
Lloyd BaOumar	290 Hours
Total Engineering Hours	1,264
Total Hours Costs (Hours Spent x Hourly rate)	$51,861
Total Spent	$810
Total Monetary Investment (Total Hours Costs + Total Spent)	$52,671
Money Saved from each Ballot (Hourly rate / 4 = 15 minutes)	$10.26
Number of ballots to break even (Total Investment / Money Saved)	5,133 ballots
Time saved (Number of ballots x 15 minutes)	1,283 Hours

Table 27: Economic Break Even Analysis

Bill of Materials

Description	MFG Part Number	Qty	Mouser Part Number	Cost per part	Place of Purchase	Website Link
Microcontroller Board Parts						
Panasonic 1206 2.2Kohms 5	ERJ-8GEYJ222	20	667-ERJ-8GEYJ222V	$0.115	Mouser	
KEMET 50V 0.1uF X7R 1206 Ceramic Capacitor	C1206C104M5RACT	15	80-C1206C104M5	$0.059	Mouser	
Wurth Elektronik WCAP-CSGP 47pF 1206 Ceramic Capacitor	88501200804	1	710-885012008041	$0.11	Mouser	
Stanley Electric Surface Mount LED	BR1101W-T	20	327-BR1101WTR	$0.245	Mouser	
Wurth Elektronik WS-SLSV Slide Switch	45240301201	1	710-45240301201	$2.51	Mouser	
YAGEO 10 kOhms 250 mW 120	RC1206JR-0710K	2	603-RC1206JR-0710KL	$0.063	Mouser	
GCT Mini B Skt, 5P, Top- / USB Connectors\u00F	USB2066-05-RBHM-15-STB-00-00	1	640-2665RBHM15STB00A	$0.70	Mouser	
Schurter SHORT TRAVEL SWITCH, push button switch	1301.9315	1	693-1301.9315	$0.29	Mouser	
Kingbright SUPER RED DIFFUSED 1 / LED Displays/7 segment	SA56-11SRWA	1	604-SA56-11SRWA	$1.94	Mouser	
Molex 40CKT DR VERT HDR / Headers	10-89-7400	5	538-10-89-7400	$3.71	Mouser	
Vishay / Dale 3.3 Kohms 1%	RCC12063K30FKE	1	71-RCC12063K30FKE	$0.32	Mouser	
ROHM Semiconductor 1206 2.7Kohm 1	ESR18EZPF2701	2	755-ESR18EZPF2701	$0.16	Mouser	
Texas Instruments Dual 1.5-pF, 5.5-V, / ESD Suppressors / TVS Diodes	TPD2E2U06DCK	1	595-TPD2E2U06DCKR	$1.59	Mouser	
Bourns 1M 1%	CR1206-FX-1004EL	1	652-CR1206FX-1004ELF	$0.11	Mouser	
Wurth Elektronik WCAP-CSGP 4700pF Ceramic Capacitor	885012208079	1	710-885012208079	$0.12	Mouser	
Cermant 10 Set 4 Pin 15EDG 3.81mm KF2EDG PCB Screw Terminal Block Connector Plug-Pin Right Angle Header Socket		11		$0.53	Amazon	https://www.amazon.com/dp/B09K3VSBV1?psc=1&ref=ppx_yo2_dt_b_product_details
Microcontroller PCB		1		$11.50	JLCPCB	

Description	MFG Part Number	Qty	Mouser Part Number	Cost per part	Place of Purchase	Website Link
ARM Microcontrollers - MCU High Efficiency Arm Cortex-M33-	LPC5512JBD100E	1	771-LPC5512JBD100E	$8.11	Mouser	
Multilayer Ceramic Capacitors MLCC - SMD/SMT 2.2uF+/-10% 25V X7R 1206	CL31B225KAHNNNE	1	187-CL31B225KAHNNNE	$0.095	Mouser	
Multilayer Ceramic Capacitors MLCC - SMD/SMT 16V 10uF X5R 1206 10%	C1206C106K4PACTU	1	80-C1206C106K4P	$0.067	Mouser	
JTAG header	M50-3600542R	1	855-M50-3600542R	$2.90	Mouser	
Fixed Inductors 1210 4.7uH 130mOhms +/-20% 1010mA HiCur	CBC3225T4R7MR	1	963-CBC3225T4R7MR	$0.23	Mouser	
470 ohm 1206 resistor	RCC1206470RFKEA	1	71-RCC1206470RFKEA	$0.056	Mouser	
3.3V regulator	MIC5317-3.3YM5TR	1	998-MIC5317-3.3YM5TR	$1.52	Mouser	
Power Management Board						
TO220 heatsink		3		$0.89	Amazon	
STMicroelectronics 5.0V 1.0A Positive / Linear Voltage Regulators	L7805ACP	1	511-L7805ACP	$1.23	Mouser	
Texas Instruments Switching Voltage Regulators 3.3V	LM2576T-3.3/LF03	1	926-LM2576T-33/LF03	$3.69	Mouser	
onsemi 12V 3A Buck PWM / Switching Voltage Regulators	LM2576T-012G	1	863-LM2576T-012G	$2.28	Mouser	
onsemi / Fairchild 5a/40V Rectifier Sch / Schottky Diodes	SB540	2	512-SB540	$0.75	Mouser	
Bourns 150uH 10% / Fixed Inductors	PM2110-151K-RC	1	542-PM2110-151K-RC	$3.02	Mouser	
Bourns 100uH 10% / Fixed Inductors	PM2110-101K-RC	1	542-PM2110-101K-RC	$3.02	Mouser	
Taiyo Yuden 0805 35VDC 0.33uF Ceramic Capacitor	GMK212B7334KG-T	1	963-GMK212B7334KG-T	$0.16	Mouser	
KEMET 35V 0.1uF X7R 0805 Ceramic Capacitor	C0805C104K6RACTU	1	80-C0805C104K6R	$0.51	Mouser	
Wurth Elektronik WCAP-ATG5 100uF 35V Electrolytic Capacitors	860020573008	2	710-860020573008	$0.14	Mouser	
EPCOS / TDK 25VDC 1000uF 20% Electrolytic Capacitors	B41896D5108M000	1	871-B41896D5108M000	$1.81	Mouser	
Panasonic 2000uF 25volts AEC-Q Electrolytic Capacitors	EEU-TP1E202S	1	667-EEU-TP1E202S	$2.93	Mouser	
TE Connectivity / Holsworthy CPF 0603 10K	CPF0603F10K2C1	3	279-CPF0603F10K2C1	$0.18	Mouser	
Vishay / Dale 100Kohms .1% 25ppm	TNPW0603100KBEEA	1	71-TNPW0603100KBEEA	$0.56	Mouser	
Wurth Elektronik WL-SMCD SMD MonoChip Standard LEDs	150060VS55040	4	710-150060VS55040	$0.168	Mouser	
PMB PCB		1		$7.56	JLCPCB	

Description	MFG Part Number	Qty	Mouser Part Number	Cost per part	Place of Purchase	Website Link
Cermant 10 Set 4 Pin 15EDG 3.81mm KF2EDG PCB Screw Terminal Block Connector Plug-Pin Right Angle Header Socket		3		$0.11	Amazon	https://www.amazon.com/dp/B09K3VSBV1?psc=1&ref=ppx_yo2_dt_b_product_details
Header-Male-2.54_1x2	M20-9990246	4	855-M20-9990246	$0.155	Mouser	
Motor Controller Board						
Taiwan Semiconductor 2A, 30V, Schottky Re / Schottky Diodes	SR203 R0G	8	821-SR203R0G	$0.369	Mouser	
PMB PCB		1		$8.32	JLCPCB	
Cermant 10 Set 4 Pin 15EDG 3.81mm KF2EDG PCB Screw Terminal Block Connector Plug-Pin Right Angle Header Socket		4		$0.869	Amazon	https://www.amazon.com/dp/B09K3VSBV1?psc=1&ref=ppx_yo2_dt_b_product_details
3D Printer Heatsink Kit + Thermal Conductive Adhesive Tape		2		$0.25	Amazon	
Motor / Motion / Ignition Controllers & Drivers DUAL BRIDGE IC	DRV8824QPWPRQ1	1	595-DRV8824QPWPRQ1	$5.646	Mouser	
YAGEO .4 OHM 1% 1/4W / Current Sense Resistors	RL1206FR-7W0R4L	2	603-RL1206FR-7W0R4L	$0.44	Mouser	
Vishay / Dale 1Mohms 1%	RCC12061M00FKEA	1	71-RCC12061M00FKEA	$0.32	Mouser	
Bourns ResHighPowerA 10k 1206 1 / Thick Film Resistors	CHP1206AFX-1002ELF	2	652-CHP1206AFX1002EL	$0.70	Mouser	
CTS Electronic Components 3 switch sections SP / DIP Switches	206-3S	1	774-2063S	$0.91	Mouser	
Bourns 100K 20% 9MM CARBON / Potentiometers	PTV09A-4225F-B104	1	652-PTV09A-4225FB104	$0.81	Mouser	
KEMET 50V 0.01uF X7R 1206 Ceramic Capacitor	C1206C103K5RACAUTO	1	80-C1206C103K5RAUTO	$0.21	Mouser	
KEMET 100V 0.47uF X7R 1206 Ceramic Capacitor	C1206C474K1REC7210	1	80-C1206C474K1RECLR	$0.39	Mouser	
KEMET 16V 0.1uF C0G 1206 Ceramic Capacitor	C1206C104J4GACTU	3	80-C1206C104J4GACTU	$2.03	Mouser	
KEMET 100V 100uF 85C 2k Ho / Aluminum Electrolytic Capacitors	ESK107M100AH4AA	1	80-ESK107M100AH4AA	$0.78	Mouser	
KEMET 50V 0.47uF X7R 1206 Ceramic Capacitor	C1206R474K5RAC7800	1	80-C1206R474K5R7800	$3.60	Mouser	
YAGEO 50K ohm 0.1%	RT1206BRD0750KL	1	603-RT1206BRD0750KL	$0.63	Mouser	

Description	MFG Part Number	Qty	Mouser Part Number	Cost per part	Place of Purchase	Website Link
Preci-dip / Headers & Wire Housing 1.27mm pitch	851-87-014-40-25210	2	437-8518701440252101	$1.21	Mouser	
Through hole LED	HLMP-BD06-P00DD	1	630-HLMP-BD06-P00DD	$0.243	Mouser	
Carbon Film Resistors - Through Hole 1/4W 27K Ohm 5%	CFR-25JB-52-27K	1	603-CFR-25JB-52-27K	$0.025	Mouser	
Misc Parts						
Xiaoyztan 0.5" Supporting Height Adhesive Insulated Standoffs Sticky Reverse Mount PCB Spacer Fit for 4mm/0.157" Hole		12		$0.34	amazon	https://www.amazon.com/dp/B07F23656R?psc=1&ref=ppx_yo2_dt_b_product_details
39.4inch Drag Chain Cable Carrier Open Type R18 Wire Cable Chain		2		$12.46	amazon	https://www.amazon.com/dp/B098NT51ZC?psc=1&ref=ppx_yo2_dt_b_product_details
Terminal Connector Sleeves E1508 Black		4		$0.02	amazon	https://www.amazon.com/dp/B077VGG18B?psc=1&ref=ppx_yo2_dt_b_product_details
Terminal Connector Sleeves E1008 Red		4		$0.02	amazon	https://www.amazon.com/dp/B077VGG18B?psc=1&ref=ppx_yo2_dt_b_product_details
Terminal Connector Sleeves E0508 White		20		$0.02	amazon	https://www.amazon.com/dp/B077VGG18B?psc=1&ref=ppx_yo2_dt_b_product_details
Terminal Connector Sleeves E4009 Gray		14		$0.02	amazon	https://www.amazon.com
2'x3' particle board with finish		1		$0.00	ESS	
9"x19" plexiglass		1		$0.00	ESS	

Description	MFG Part Number	Qty	Mouser Part Number	Cost per part	Place of Purchase	Website Link
Horizontal clamps		2		$0.00	ESS	
Makeblock DIY XY plotter		1		$0.00	Ebay	
3D printed housing		1		$0.00	ESS	
3D printed ballot edge guide		1		$0.00	ESS	
3D printed ballot holder		2		$0.00	ESS	
3D printed cable management mounts		2		$0.00	ESS	
3D printed IR sensor mount		1		$0.00	ESS	
3D printed XY plotter mount		4		$0.00	ESS	
6' USB A to USB micro B		1		$0.00	ESS	amazon
24V power supply	RWS150B-24	1	967-RWS150B-24	$0.00	ESS	
Power entry module-Schurter	4304.5065	1	693-4304.5065	$0.00	ESS	

Table 28: Bill of Materials

Reliability and Safety Analysis

Of concern regarding safety, the Power Entry Module that is used to introduce a wall-socket AC power into the components. This module has lines exposed that can produce a shock. The power supply we use to convert from AC to DC is also a potential concern for a similar reason. The XY-plotter, while it does have bump switches to stop it from hitting the edge of the plotter, does not have a case for detecting other objects. This could lead to pinching, though the emergency button and low speed should keep those occurrences seldom.

Of concern regarding reliability, the microcontroller is a complex IC. Many of the pins can be easily damaged with different voltage values and these damaging values are present in our circuit. The motor controllers, too, are complex IC's. The motor controllers also have the added danger of receiving back-EMF from the motors if they are moved while the circuit is off or the motors are in sleep mode. The 12V regulator is also a concern as it will handle the large amperes required for the motors (up to 2A).

Most critical components are the Power Entry Module, and the reliability of the microcontroller and motor controller ICs.

Reliability Analysis

In our system there are 3 major components that we believe are the most likely to fail. These components are; The 12 V regulator from our power management board used to power our stepper motors; The Microcontroller located on the main board which is the core component of the system; and the Motor controller ICs used to drive the stepper motors.

These 3 ICs play a key role in the ballot markers success. With the stepper motor's importance, it is only necessary that we be cautious of the parts that make it work. In the following figures we have provided a summary of the Mean Time To Failure (MTTF) for each of these components.

Part 1: µC

Parameter name	**Description**	**Value**	**Comments**
C1	Complexity failure rate for microprocessors	0.56	Our processor is 32 bits
C2	Package failure rate for all microcircuits.	3 x 10^-5 x Np^1.08	
Np	Number of pins of package	100	
Ea	Activation energies	0.35	
OmegajA	Junction to ambient thermal resistance	25	From datasheet page 75
PD	Power dissipated in the device	3A x 3.3V= 9.9W	From datasheet page 75
TA	Ambient temperature	20 Celsius	Room temp
PIE L	Learning factor	1	Over 2 years in production
PIE T	Temperature Factor	49.64	
PIE Q	Part Quality factor	0.25	TI is quality parts
PIE E	Environmental Factor	0.5	Lab environment
MTTF	Mean Time To Failure	16.65 Years	

Table 29: µC *MTTF Summary*

Part 2: Motor Controller

Parameter name	**Description**	**Value**	**Comments**
C1	Complexity failure rate for microprocessors	0.04	MOSFET device with less than 1000 transistors
C2	Package failure rate for all microcircuits.	3 x 10^-5 x Np^1.08	
Np	Number of pins of package	28	
Ea	Activation energies	0.65	
OmegajA	Junction to ambient thermal resistance	38.9	Datasheet page 5
PD	Power dissipated in the device	1.764	Datasheet page 16
TA	Ambient temperature	20 Celsius	
PIE L	Learning factor	1	
PIE Q	Part Quality factor	0.25	
PIE T	Temperature Factor	10.19	
PIE E	Environmental Factor	0.5	
MTTF	Mean Time To Failure	24.78 Years	

Table 30: Motor Controller MTTF Summary

Part 3: 12V Voltage Regulator

Parameter name	**Description**	**Value**	**Comments**
OmegajA	Junction to ambient thermal resistance	65	
Beta b	Base Failure Rate	0.012	
PD	Power dissipated in the device	36	Current supplied x Voltage supplied
TA	Ambient temperature	20 Celsius	
TJ	Junction Temperature	2360	
PIE A	Application Factor	4	
PIE Q	Part Quality factor	2.4	
PIE T	Temperature Factor	307.55	
PIE E	Environmental Factor	1	
MTTF	Mean Time To Failure	8.7 Years	

Table 31: 12V Voltage Regulator MTTF Summary

As you can tell from the completed analyses, the core units within our system will be viable anywhere from 10 to 25 years. As these parts are relatively common, if any failures did rise we would be able to replace them with ease. With the Oval-Mate having its modules hooked up in series, the total system MTTF is the summation of the individual components omega value. This leads to the system MTTF to be 3.9 years. The system MTTF can be increased drastically if a different voltage regulator is used or a different power source.

Safety Analysis

According to IEEE standards applicable safety requirements under section C95.1, our device could potentially cause a hazard to humans exposure to electricity. As of now, the outer switch that provides power to our device needs to be covered properly in order to avoid any possibility of contact with the user. To prevent that to happen, we will either design a 3D cover that will cover the switch, or we will safely wrap the switch with plastics. Second, the power management board could potentially cause a hazard to humans. Precisely, the inductors. With 24V going into the power management , the user can easily get in contact with the inductors on the board. In order to prevent that from happening, we will cover the power management board.

Additionally, the functionality of the XY plotter can cause a hazard. To prevent the XY plotter from running into the sides and not stopping, we have added switches on each side. For instance, if the one switch is closed, the stepper controlling the direction going toward that side will stop running. If two switches get closed, the pen will stop moving. Also, if the XY plotter is behaving unexpectedly, we added an emergency button that will stop the XY plotter from running. Lastly, we added one indicator that will show the state of the microcontroller. It's a seven segment display that will show a value when the XY plotter will be running as expected, and will show a different value otherwise.

Failure Mode, Effects, and Criticality Analysis (FMECA)

Regarding criticality levels and assumptions relating to the FMECA worksheet in Appendix B, here is the rationale for these decisions.

For the function mode "Driving Stepper Motors," the client will be able to configure a maximum and minimum frequency for their device. It is advised to keep the minimum at 1KHz and the maximum below 10KHz, but clients are free to set these frequencies. The chance of providing too high of a frequency is highly unlikely. The maximum frequency the motors can handle was calculated at 5.7MHz and the motor controllers can handle up to 250MHz. Nearing these values would be almost never done. Giving it too low of a frequency is much easier. The motor will start to stutter if it is given too low of a frequency. The torque from this stuttering could damage the motor or other parts and is more likely if warnings aren't heeded. Configurability leaves this as a 2 & 3 based on ease of falling outside respective ranges.

For the function mode IR Circuit transmission to µC's ADC, this problem is not one that clients could easily produce, given our circuitry this will not occur barring a bridged pin or electrical surge. Infrequency of this occurring leaves this as a 1.

For the function mode Power Entry & Power Supply, The potential for a human to touch these components will produce a shock. The power supply is contained in a metal shroud that is grounded, but the power entry module is currently exposed. Developing a case for these two modules could prevent harm. Should harm come, it won't be life threatening or limb threatening, but could leave a burn. Potential harm to humans, in its current state, gives this a 6.

For the function mode Power Management Board Diodes, these diodes are switching as part of the buck-boost converter. This leaves them as a potential point of failure, resulting in improper voltage being delivered to board. To extend the life of these components, keeping the machine switched off when not in use can be beneficial. The power management board is also not a terribly complex circuit to reproduce, leading to a cheap repair. Potential damage brings this to a 3.

For the function mode Servo Motor Angle of Rotation, the servo motor requires a specific duty cycle of 5-10% (5% = -90 degrees, 7.5% = 0 degrees, 10% = 90 degrees). Outside of this range, the servo doesn't move. This duty cycle is configurable but there are warnings explaining this restriction. For that, a 1 is accurate.

Social/Political/Environmental Impact

Introduction

The main environmental issue related to our device's life-cycle will be the outcome of elections. Since our device will be used to mark ballots and those ballots will be used to test the accuracy of the machines validating those ballots. The result of these tests will determine if those machines will be used to validate ballots during any election. The result of the election will decide who will get elected and these people getting elected will be responsible or will decide how the environment will be handled. Additionally, since elections always happen in the USA, each election will elect or reelect people, then the environment will always be handled by the people elected. Additionally, the main ethical issue will be the possibility of an electric shock. Our boards are currently next to each other with the power management board. This proximity can cause a hazard to the user and can get an electric shock.

Social Responsibility and Ethical Impact Analysis

The product currently faces several ethical issues before marketing could be done. The power entry module, which takes in power from an outlet, is in the same space as the PCBs. While the PCBs being readily accessible was a convenient choice for the engineers in this field, the power components ought to be shielded and not be accessible in the same space as the PCBs.

The power management board is carrying a far lower danger to people, but should also likely be kept further away than the main board and motor controller boards.

The risk of being pinched by the device as it moves the arms in the XY-plotter exists but no warning labels exist, of any kind, to inform about the particular dangers the device has. Adding warning labels for operational problems, such as pinching, as well as debugging problems, such as coming into contact with the PCB boards, would inform users to take the necessary precautions when interacting with these capabilities.

Stopping the machine mid-process to avoid damaging it or in the event of another need to stop the device is provided via the emergency button and the power switch out the outside of the 3D printed housing.

Political Impact Analysis

Oval-Mate is being developed for Election Systems & Software. At its core ES&S are responsible for creating technologies that can and will be used for voting during elections. Our product is going to be used to mark testing ballots which will then be run through their certification machines. This poses certain questions when the idea of a machine that marks ballots is brought up.

The first is how this could affect any political elections. While we are creating a machine that autonomously marks ballots, it will never be used outside of ES&S facilities. This ensures that no one could tamper with it and use it for their own political gain.

The second is how is this going to help with voter accessibility? With ballot marking and testing being a time consuming task at ES&S it takes a lot of time away from the engineers to be working on their products. With the introduction of Oval-Mate this burden will be relieved and allow for more time to be spent perfecting their products that potentially millions of people will be using. Though not directly, we believe this small impact could make a ripple effect and allow the processes at ES&S to run faster and smoother, allowing them to create products that will increase voter accessibility in the end.

Environmental Impact Analysis

During the manufacturing process there are a few concerns that arise. The aluminum used in the structure of the XY plotter does create a lot of waste to manufacture. This is in the form of strip mining which reduces habitat and leaves the Earth scared. Manufacturing plants create chemical waste that affects the environment such as aquatic animals. The 3D printed plastic parts that we use in our prototype does create some waste but the support material is water soluble with Oxi-Clean and is biodegradable. The wood used is a glue based press board which has some environmental impacts during the manufacturing of the glue. The various circuit boards and various electronic components also create waste from the various heavy metals used to create them.

The normal use of the Oval-mate doesn't create a lot of waste other than the ink pens. When the pens run out of ink, they are not refillable and must be disposed of. The energy consumption of the Oval-mate is low at using only 50 watts of power during operation and less than 5 watts when idle.

The Oval-mate should have a considerably long life as the components used are of high quality and have a high MTTF. But when it does need to be recycled, the aluminum will be able to be recycled and reused as it does not degrade. There is more than 75% of produced aluminum still in use today through recycling. The pressed wood could be reused for another project but won't be able to be recycled due to the chemicals used to create it. The circuit boards can be recycled to recover copper and other rare metals. This includes reusing components on the boards themselves.

Using a solid wood base would make for a better material in the long term of the Oval-mate. It would allow for easier reuse and recycling, though it is much more expensive. Using metal to replace the 3D printed parts will significantly help with the amount of material that can be recycled. This includes the enclosure around the PCBs and additional mounting brackets that needed to be created to hold cable management features. The PCBs would need to be sent to a recycling center that specializes in dismantling electronic circuit boards. The use of aluminum is a good choice to use as it can be 100% recycled. And if the aluminum can be sourced that has been recycled during the manufacturing process, that would complete the cycle of sustainability. As far as electrical use, we believe that there are efficiencies that can be done to lower the power consumption. Finding 90+% efficient voltage regulators would help as we are using mid-80% regulators currently.

Discussion, Conclusions, and Recommendations

Team 110 has been sponsored by Election Systems & Software (ESS) to create a ballot marking test unit for application in their facilities. Election Systems and Software is looking to save time and money when creating hand marked test decks. This project will automate the marking of ballots with speed and precision. The main point of our project was to create a plotting device that completely marks testing ballots in under 7 minutes so that ESS can use the data to make internal decisions about the design and functionality of their products. The approach that was taken to realize this project was using the LPC5512GBD100E to interface with a windows application via USB to send the configuration selected and stored by the user, with two stepper motors via GPIO that controlled the XY plotter along with the pen and the infra-red light sensor, and the bump switches via GPIO to monitor the movements of the XY plotter. To be explicit, The IR sensor will be our method of distinguishing white and black on the ballot. It is attached to the head of the plotter but must remain 3 millimeters away from its target for optimal readings. The microcontroller we are using is equipped with a 16-bit ADC (with several channels), so distinction will have to be made within that space. The IR sensor's sampling rate is modifiable, but a rate of 12MHz will be used for sampling.

The windows application will collect the ovals that need to be marked using a .NET framework application presenting a form on a Windows computer. After the user's oval selection, they can press "apply" to send the information to the microcontroller. This will happen over USB, where our microcontroller is driven by the winusb.sys windows generic USB driver. Once the data is on the microcontroller, the IR sensor will inform the controller as it moves towards each location and marks ovals. The windows application requires a Windows 10 PC (has not yet been tested on Windows 11 or earlier versions). To interface, the PC will need at least 1 USB 1.0 (or above) output.

The microcontroller being used has up to 80kB of RAM and 128kB of ROM. Estimates, assuming worst case data consumptions (using 32 bit floats for each coordinate, all ovals needing to be marked, and wrapping data in JSON), suggested 40kB of RAM needed. From our current plan, usage would be around 10kB. Our microcontroller has two ports (1 and 2) with up to thirty-two pins individually. Out of this sixty-four pins total,we will be using twenty-four GPIOs for five switches, seven GPIOs for a seven segment display, and 12 GPIOs for the stepper motor control. The first four switches are the ones on the XY plotter (left, right, up, and down), the fifth one will be the emergency switch, the seven GPIOs used will be to light up the LEDs on the seven segment display, and the last 12 switches will be used to control the stepper motors integrated circuit (DR8824). The first four switches will be used to determine if the pen has reached any sides of the XY plotter, if the pen reaches one of the sides, then the pen will go back to the origin. The fifth switch will be used in case there is an emergency and the XY plotter needs to stop operating. The seven segment display will have internal resistors to set the current limit on the LEDs and will be used to display the status of the microcontroller. We used three GPIOs as timers for the PWM (Pulse with modulation). The first two GPIOs will be used to control the steps of the motors, and the third one will be used to control the pen. We also used one GPIO as ADC to get the data from the IR sensor. Last, our microcontroller has an operating voltage range of 1.8 to 3.3v and an operating current range of .9 to 5 mA.

To make our design efficient, we designed three boards. The first one is the one holding the microcontroller, a seven segment display status indicator, and LEDs indicating the data being sent to the steppers and the bump switches. The second board is the stepper driver motor. We design one board used for each stepper. One represents X and the other represents Y axis of the plotter. The third and last board is the power management board that produces power to the whole circuit. Having boards for the main components reduces the amount of work needed to debug and find bugs then increases the efficiency of our overall device.

For recommendation, if any of the devices stop working for any reason, first, check the power management board. In order to make sure the device has power, check the LED indicators on the power management board for the different voltages (3.3v , 5v, and 12v). The same method can also be used to check if the main board and the stepper motor board has power. If power is sent from the power management board and the LED lights are off on other boards, check the wiring between each board from the power management board. If all boards receive power and one of the stepper motors is dysfunctioning, use the LED indicator on the main board to see if data is being sent to the dysfunctioning board. LEDs indicators are used with the main component on this project to facilitate fonctionnement of all components.

While doing this project, we learned many lessons. First, we learned that when the team communicates freely and accepts any idea that makes the project better even though that will require additional work should be welcomed. The next lesson was writing and testing small portions of software to test devices like stepper motors, infrared light sensor, and servo for the pen was beneficial and time saving. Before our custom made boards were designed, we were ahead with a significant knowledge on how we will interface with these devices. Additionally, being able to have access to all the pins of the microcontroller was one of the most important things that allowed us to use pins that we did not originally think about using. Overall, our team put considerable effort and stuck together in both easy and hard situations with the main focus of getting this project done.

Project Audit

System Integration

Was the original scope maintained throughout?
The original scope of the project was maintained throughout the duration. This was due to our laser focus on what must be done at the end of the project. All of our PSSCs have been completed with appropriate evidence.

Were all changes documented?
With the original scope maintained, no changes were made.

Were processes updated to reflect lessons learned?
Yes, they were. If a process needed to be streamlined we made sure to address the issue and take corrective action.

What changes in the design process will make for a more successful next project?
Having more time dedicated to researching devices or software that we are not familiar with would be beneficial. Becoming familiar with a device and its quirks during the testing process can lead to board redesigns which could have been eliminated with more research. More subtasks in the WBS to have more visibility to small tasks that need to be accomplished will help as well. The days given on the AON will be better next time as we have experience to gauge how much time certain tasks will take.

Scope Management

Were the original requirements met by the final product?
The original requirements were met by the final product. The time taken to define our scope really helped us stay on track. The PSSCs are tested and completed.

Does documentation trace the requirements from planning through design to implementation?
Yes. Because of a thorough problem definition and planning stage, we were able to follow through with our original design with very little modifications.

What changes in requirement management would increase the chance of success?
Extra time on requirement analysis is time well spent. It allows all parties involved to know what is expected of them and how the device should operate at the end of the project.

Time Management

Does the final version of the original proposal document the actual schedule performance?
The schedule performance of the original proposal does not reflect on how the schedule was executed. There were times when the order of execution was incorrect, this was due to what parts were available at the time. Even with these slight changes this didn't affect the critical path timeline.

What estimates were incorrect? Were these factors documented?
Getting our PCBs designed and parts ordered took a bit longer than expected. This made us almost miss our milestone of developing algorithms. To develop algorithms we needed functioning boards to do this. This was documented as a risk and we mitigated it by also buying development boards for the main components used in the project. Then when our boards came in we were able to test and integrate them into the project.

How can these lessons be applied to other projects?
More time is needed on the hardware side of the project for designing and purchasing everything needed. A good lesson learned was that the prototype boards helped us maintain our timeline because it gave the software something to develop with.

Cost Management

Does the final budget document all expenses? Are all component selection changes included?
The final budget does document all out of pocket expenses incurred during this project. The BOM lists out all the parts used in the Oval-Mate project.

Are incorrect estimates documented? Are the reasons for incorrect estimates included?
Our overall estimate of cost was low but we stayed within budget. The increase in the actual cost compared to the estimated cost was due to not fully understanding the cost of getting a PCB printed and how expensive components are currently.

What lessons can be applied to future projects?
Knowing that PCBs and components are much more expensive than a few years ago, the estimated cost will be even closer to actual cost.

Quality

Have all changes made because of quality considerations been documented? What is the overall MTTF?
The overall MTTF is 3.9 years based on the analysis provided in this report. The main factor to that is our switching voltage regulators. If different regulators are selected or a power supply that provides the voltages needed by the Oval-Mate directly, then the MTTF would go up.

Human Resources

Has each member of the team been informed of closeout assignments; of exceptional performance; of behaviors that have been detrimental to team and project operations?
Throughout the project we all have been supportive of each other on small and major accomplishments, even if they didn't relate to the project. We knew this was going to be a semester where any support would go a long way. As we are wrapping up the project, we have met multiple times to assign tasks that need to be completed before we turn in this report and present our project to our SPO. We have been very fortunate to have no behaviors or incidents that created issues along the way.

Communication

Have all stakeholders been informed of project results and documentation?
ES&S has signed off on the project. A closure meeting was held with them on 4/20/22 to give a demonstration of the Oval-Mate. Documentation was also discussed on what is provided. A USB drive will be generated for ES&S with all documents created to allow them to continue development of the Oval-Mate.

What improvements will increase the chances of success on the next project?
During the design stage of the project we had multiple meetings with ES&S to discuss what requirements and deliverables were to be provided. This allowed us to know exactly what was expected of us and for the closure meeting to be a simple handoff of the project.

Risk

Have all issues and risks been closed with appropriate documentation?
The table below shows the risks that we had identified at the beginning of the project. Each one has a risk level and what we did to close the risk.

Risk	Closer Documentation	Risk Level
1. Expectation that all members are able to participate and do so by creating quality work	Meeting consistently and working to maintain the team was vital to keeping the team motivated and together	High
2. An assumption that rooms, spaces, and equipment will be available at the times we'll plan to use them	Discord was used for virtual meetings. Utilized the ESS labs from our sponsor	Low
3. Assumption that our team can find a sponsor	We found a sponsor in ESS that will buy our parts to eliminate the financial burden	Low
4. Assumption that this project is feasible given our skillset	Narrowed down focus to align with skillset	Medium
5. Assumption that we can meet during the pandemic	Meetings were be done virtually via Discord and in person	Medium
6. Assumption that in-class learning will be consistent	We never had a closure of campus, so we were able to meet in class every week.	Low
7. Assumption that transportation will never be an issue	No team members' cars broke down, so we were able to meet up when scheduled.	Medium
8. Mechanical portion of project (XY Plotter)	A XY plotter was purchased that was able to perform to expected level.	Low
9. Assumption that all materials, such as processors or circuit components, will be available on the market for purchase by our team or sponsor	Purchasing readily available parts and using components from our sponsor. Purchasing many of each part was critical to avoid problems buying replacement parts	Medium
10. Assumption that replacement parts are available and that any particular component can be purchased with replacements	Extra parts were purchased. The extra parts will be used to build 2 units after the project is complete	Low

Table 32: Assumptions, Risks, and Mitigations

What assumptions can be avoided on future projects to mitigate associated risks?
With our next projects going to be in a professional setting, we will have better transportation options available to us which will eliminate this risk. We also will have a dedicated space to do the project at our place of employment, which will eliminate this risk as well.

Procurement and Operations

Have all procurement documents (BOM, budget) been updated appropriately?
All procurement documentation is updated to parts purchased for the project.

Have all operational documents (user's manual, manufacture, maintenance & repair) been updated?
The user manual has been created and reviewed by team members.

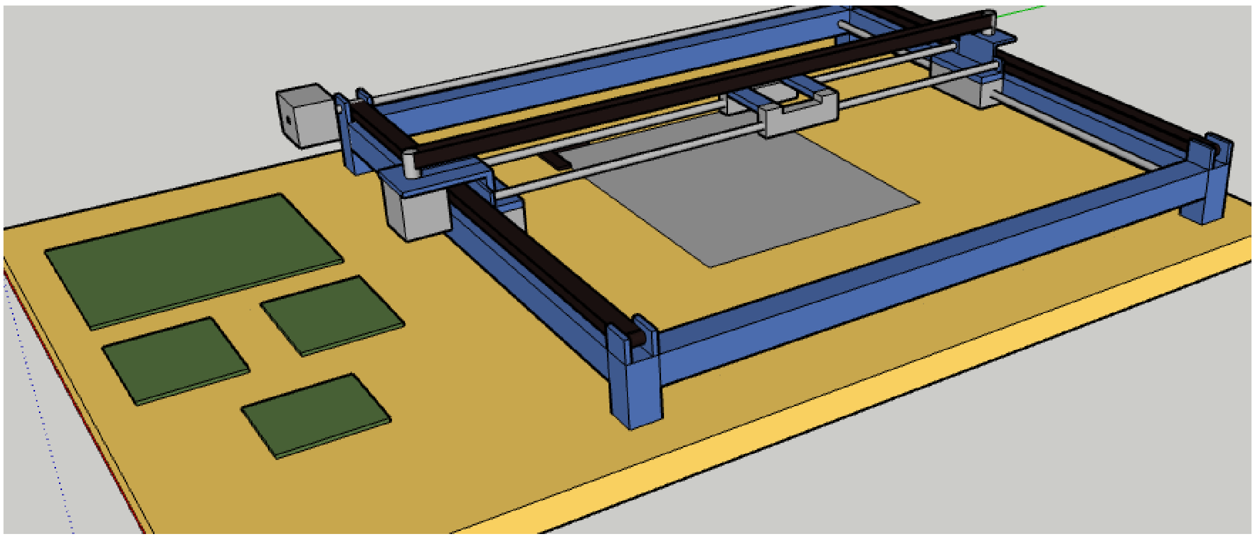
Identify both the positive and negative lessons learned from the project.
One negative lesson that we learned as a team was that it is a lot harder to follow an AON, Gantt Chart, and LRC than we realized. Some tasks took longer than they should have and some took less time than expected. Also, assigned tasks sometimes involved others and responsibilities were more flexible.

Out of the previous lesson we learned a valuable positive one. As a team we learned we could trust and rely on one another when help was needed. We were aware of each other's strengths and could ask for help at any time.

Identify recommended corrective actions for the negatively based observations that should be considered for future projects. Consider the cost, resources, schedule, communication, and work activities of the project.
Now that we have a project under our belt, we will be able to estimate our time better for the various tasks required. The cost of the project was kept under budget but our estimates didn't take into account inflation of PCBs and components that have occurred. With that we will be able to have a much closer estimate of cost. Having each of the subtasks broken down into smaller tasks will also help us keep track of what is needed to complete the tasks more efficiently. With each task we can more easily assign various people to work on it to keep the schedule from slipping. Also knowing more now on how the workflow of hardware to software works, we will be able to schedule tasks more efficiently.

Installation and User Instructions

Oval-Mate



Written by:

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April 2022
Version 1.0

Intended use

Oval-Mate is a device that utilizes an XY plotter and a complementary windows application to mark ballots used for internal testing in Election Systems and Software’s facilities. The use of this product on any documents besides designated testing ballots is prohibited.

Installation instructions

To install the Oval-Mate and begin use first find a space for the plotter to sit. The overall size of the machine is roughly 2 x 3 feet and can take up a large amount of desk space. It is recommended that the plotter is placed somewhere it can be easily accessed and also where it will stay. Though the plotter can be moved it is better to leave it where it will be used.

Next you must install the Oval-Mate windows application to operate the machine. Unzipping the download and double clicking the Setup.exe will install the application for use. Once the application is installed, the machine is plugged into the wall and connected to a computer via USB connection. Upon completion, Oval-Mate is ready to be used.

Features/accessories

The Oval-Mate product features a wide range of unique accessories that allow the system to operate within its specified tasks. First, to make things simple, Oval-Mate utilizes a Two Menu windows application with USB connection to select desired ovals and send the data to the plotter. These menus can be seen below in Figures 1 and 2.

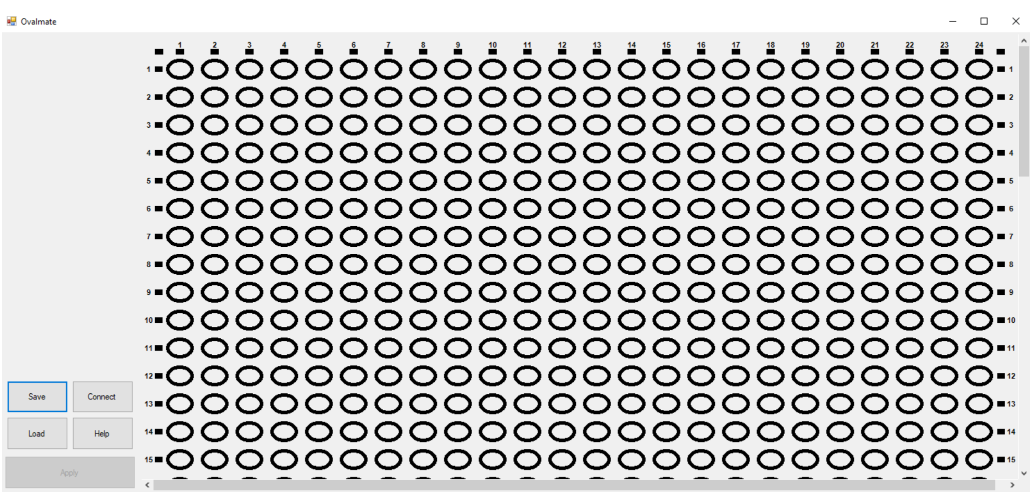

Figure 13: Main Menu

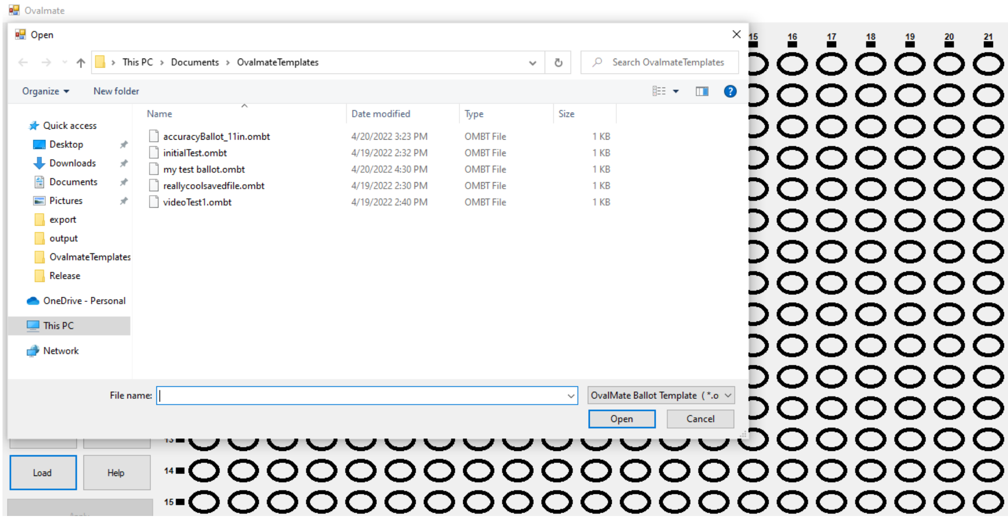

Figure 14: Save/Load Menu

In addition to the application menus, Oval-Mate features many other useful accessories. These include:

- A stand alone Reset Button for quick disengagement
- A 3D printed casing with Plexi-Glass cover to house the electronic components
- Ballot Guides and Clamps to keep the ballot in place when marking
- Mounted Cable rails to house wires and provide a clean looking design model
- Save/Load Options included in the two menu application
- Troubleshooting Menu providing information through the use of a “Help” button

Description of Main Product Elements

The Main elements that make up the Oval-Mate are the XY plotter itself and the Windows application which operates the machine. Pictured below in Figure 3 is a top-down view of the main unit. Pictured on the left is the 3D printed casing which encloses the electronic components and right above that is the emergency stop button. On the plotter side, The cable mounts can be seen along the x and y axes which house the wires coming from the plotter. In the middle space you can see the ballot clamps and guides which were designed to hold the ballots in place during marking to ensure there is no movement.

In addition to the plotter, referring back to Figures 1 and 2 above is the Two Menu Application. Figure 1 displays the main menu where you can connect to the plotter, select ovals, and send the data to the plotter to be marked. Also, there includes a save and load option to access previously created ballot marking configurations. These Menus are displayed in Figure 2.

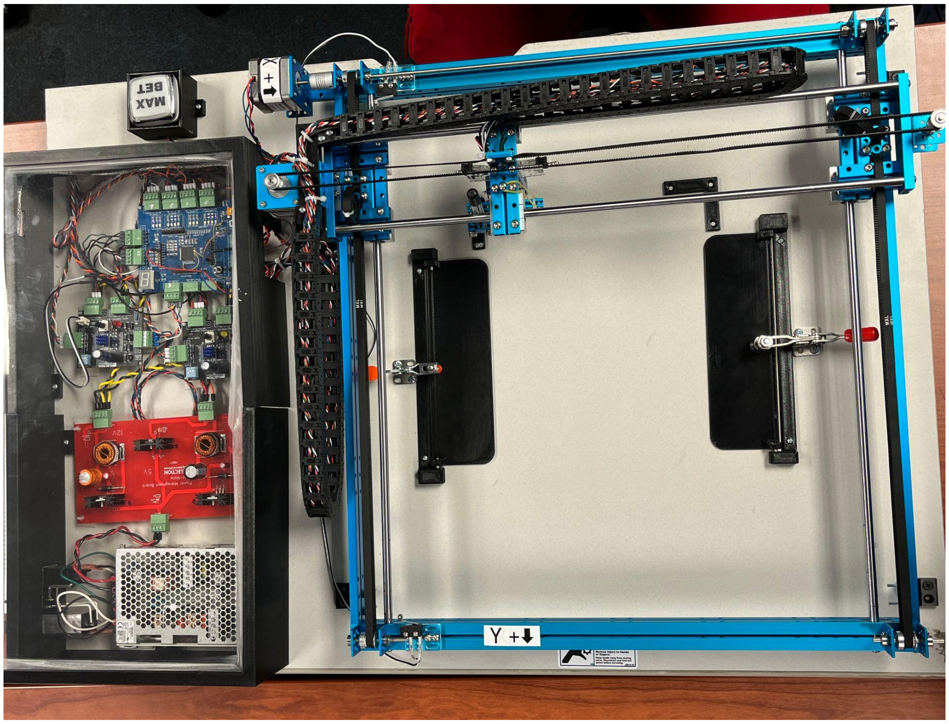

Figure 15: XY plotter and Hardware

Safety warnings

The Oval-Mate is a mechanical system which features moving parts along the x and y axes. Included on the packaging are safety warnings and indicators which inform the user to not handle the device during operation. Also, under the glass enclosure are electronics and a power supply which should not be handled without proper training and knowledge of the system.

Description of how to use/operate the product

This section provides detailed instructions of how to use the Oval-Mate to mark ES&S testing ballots. The steps are outlined below in Table 1.

Step 1	Plug in and Turn ON the plotter	On the bottom left side of the plotter enclosure is an AC adapter which plugs into the wall. Once plugged in, flip the switch on the side to the ON position.
Step 2	Open Windows Application	Open the Oval-Mate application on a desktop or laptop
Step 3	Connect Plotter via USB cable	Through the smaller side hole on the left side of the enclosure run a USB cable through and plug it in to the main board and the computer
Step 4	Load Ballot onto plotter	Unfasten the clamps on the plotter and slide in a ballot aligning it with the square guides. Once positioned, fasten the clamps and make sure the ballot is secured and doesn't move.
Step 5	Select desired Ovals or Load a pre-saved selection option	On the main menu select the ovals which you want to mark on the ballot. If there are any saved configurations, use the "Load" button to select one.
Step 6	Save if applicable	Once the ovals are marked, if this is a new selection configuration click the "Save" button.
Step 7	Click Apply	Finally, click "Apply" to send the data to the plotter and mark the ballot
Step 8	Flip ballot and repeat steps 4 through 7	If another side needs to be marked flip the ballot and repeat steps 4 through 7

Table 33: Steps to Mark A ballot using the Oval-Mate

Troubleshooting

Located on the main board in the enclosure is a Seven-Segment display which provides status updates and codes for any problems or issues that arise. On the main menu there is a "Help" button which, if pressed, will provide a detailed explanation of the displayed codes. An example of this menu can be seen below in Figure 4. The details of each error and status update can be found in the appendix.

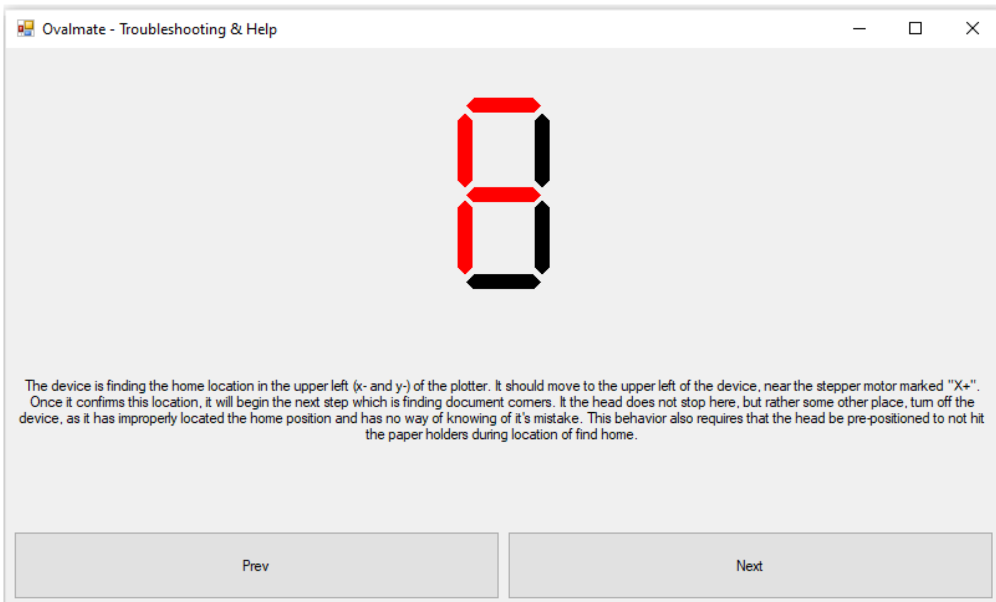

Figure 16: Troubleshooting & Help Menu

Maintenance information

Maintenance of the Oval-Mate electronics should only be performed with training and knowledge of the component parts. Provided on the main board are LED status indicators which can identify any potential maintenance issues.

The most common maintenance which will be needed to perform is the pen replacement. Over time the pen used for marking the ballots will run out of ink and therefore be replaced. Located on the central part of the machine there is a clamp which is bolted over the pen to keep it in place and steady. When replacing the pen the new one should be put in while the arm holding it is level to the ground to ensure when the servo motor lifts and drops it, it is in the right location.

Information on disposal of the product and packaging

When discarding the Oval-Mate plotter certain measures must be taken to ensure an environmentally friendly disposal. First all of the plastic and wood components can be recycled in a traditional way. The plotter itself is aluminum so it can be recycled as well. For the electronics, they must be taken to an appropriate place of service that can dispose of them correctly or recycle them if applicable.

Technical specifications

In the following table the technical specifications are listed and detailed.

24 V Power Supply	This power supply takes power from the outlet and converts it to 24 V to be supplied to the Power Management Board
Power Management Board (PMB)	This PCB takes the 24 V from the power supply and distributes it to the rest of the system using voltage regulators. The PMB supplies 3.3V, 5V, and 12V
Stepper Motors and Drivers	Two stepper motors are used to drive the marking pen along each axis. There are two separate motor driver PCBs that take 12V from the PMB to drive the motors.
Servo Motor	A servo motor is used along the pen mount to raise and lower the pen when making marks. The servo uses 5V
IR Sensor	An IR sensor is used to locate the corners of the ballot and selected ovals. The IR sensor uses 3.3 V
Bump Switches	Bump Switches are used to observe the limits on the axes of the plotter. The bumps use 3.3V
Microcontroller and USB	The microcontroller on the main board drives the whole system and sends data to the motors and collects data from the IR. It connects to the PC via USB connection
Oval-Mate Windows App	The Windows App is used to select ovals and send data to the microcontroller

Table 34: Technical Specifications

Appendix

Ovalmate errors:

Failed to configure peripherals(E):
The Config file failed to initialize on the Oval-Mate microcontroller. Please call Alex Wissing for assistance.

Failed to find home position(1):
The print head didn't find home position correctly. Please turn off the Oval-Mate and move the print head manually to the top left ballot guide. Then turn Oval-Mate back on and retry the print job. If the error is persistent, contact Hardware Support for further assistance.

Failed to find Document corners(2):
The ballot corner next to the ballot guide is most likely not flat against the surface. Press the ballot down flat and restart the print job. If the error is persistent, contact Hardware Support for further assistance.

Ovalmate normal operation states:

Finding Home(H):(0b1110110)
Oval-Mate is finding the top left corner of the XY plotter. This is considered its starting position.

Finding Top Left Document Corner(L):
Oval-Mate is finding the top Left corner of the ballot.

Finding Top Right Document Corner(R):
Oval-Mate is finding the top Left corner of the ballot.

Driving to Next Oval Position(n):
The Oval-Mate is moving to the next oval location it needs to mark.

Marking Oval Position(O):
Oval-Mate is marking the oval location selected.

Waiting for USB input(U):
USB connection has not been established. Please plug in USB to the host PC.

Appendices

A) Notes

All references used in this document are referred to in the References section of the report.

B) Acceptance Testing

PSSC 1: Conforming to IEEE standard 1220

To adhere to this standard, the team will need to perform a functional analysis on our design and our prototype. The functional analysis on the design has already been done and listed below.

Functional Analysis

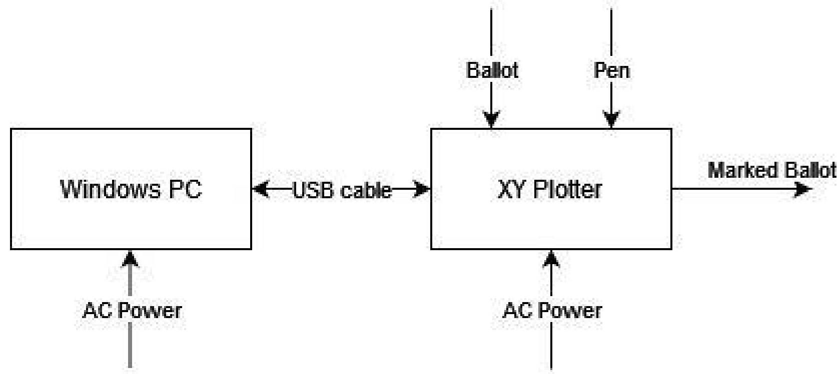

Figure 17: Level 0

Module	Windows PC
Inputs	• AC Power
Outputs	• USB communication
Functionality	Provide user selected oval locations to be marked by XY Plotter

Table 35: Windows PC Functional Analysis

Module	XY Plotter
Inputs	• AC Power • USB communication • Ballot • Pen
Outputs	• Marked Ballot

Functionality	Will mark a ballot based on the positions provided by the Windows PC. A ballot and pen will need to be manually placed in the device.

Table 36: XY Plotter Functional Analysis

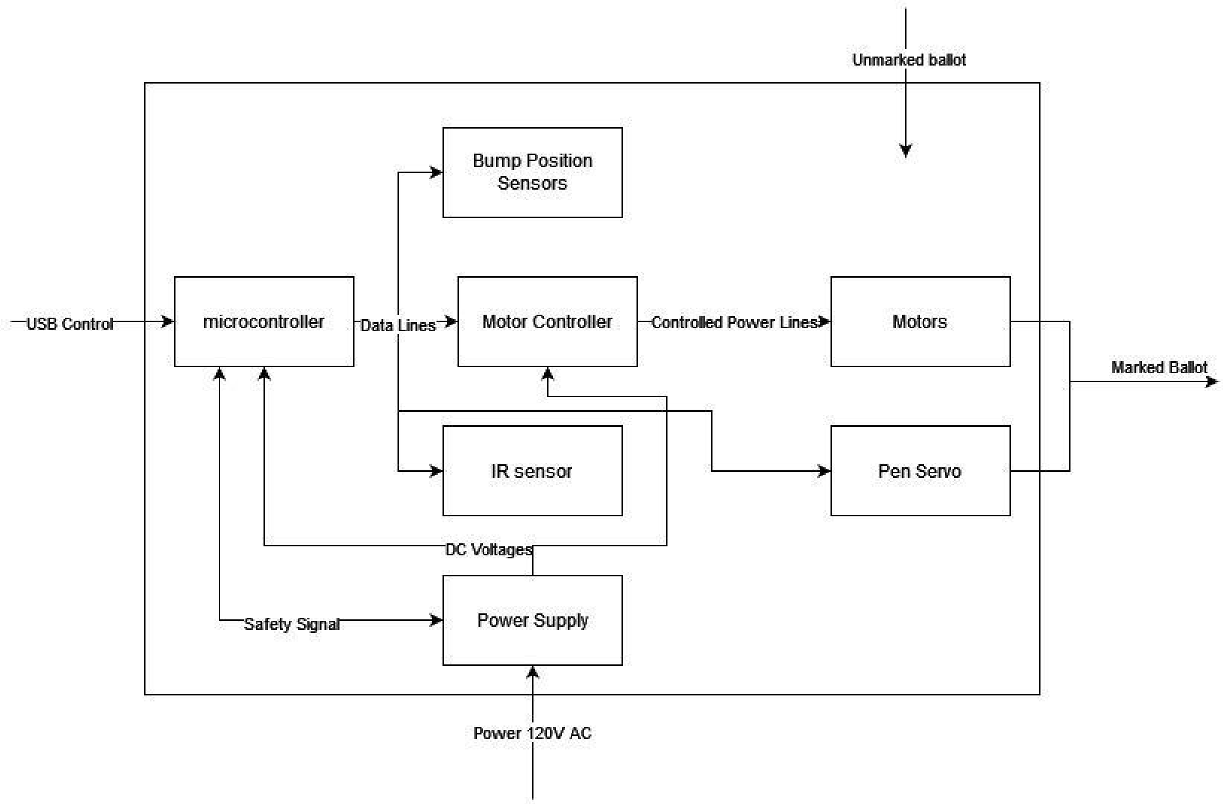

Figure 18: Level 1: XY Plotter

Module	Microcontroller
Inputs	● USB Control ● Power Supply Safety Signal ● DC Power ● Sensor Signals (Both analog and digital)
Outputs	● Status back to Windows PC ● Motor Control ● Servo Control
Functionality	Responsible for calculating motor movements based on current location and next target oval. Will also execute a mark oval function which will activate the servo to place pen on paper and fill in the oval. Analog IR data will need to be fed into an ADC to locate black box landmarks on the ballot so position error correct can be calculated. The bump sensors will act as the zero position for the stepper motors.

Table 37: Microcontroller Functional Analysis

Module	Bump Position Sensors
Inputs	• Digital ‘High’ DC
Outputs	• Digital High/Low
Functionality	Will provide zero position indication for the stepper motors.

Table 38: Bump Position Sensors Functional Analysis

Module	Motor Controller
Inputs	• Motor Direction • Motor Step Pulse • Motor Mode Selection • High Power DC Voltage
Outputs	• Controlled Power Lines to Motors
Functionality	Will take microcontroller inputs to move the motors in correct direction, mode, and pulse speed. DC power will be calculated based on motors selected but in general will be of a higher voltage than the microcontroller and will require a few amps of current capability.

Table 39: Motor Controller Functional Analysis

Module	IR Sensor
Inputs	• DC Voltage
Outputs	• Analog Data Line
Functionality	An IR LED will shine on the paper to detect the black square landmarks on the ballot for oval location calculations. The output will be an analog signal from a phototransistor that will receive reflected IR to the base of the transistor.

Table 40: IR Sensor Functional Analysis

Module	Power Supply
Inputs	• AC Power
Outputs	• Multiple DC levels • Safety Signal
Functionality	DC levels will be determined once components are picked out but at least two voltages will need to be created. The higher-level DC voltage will also need to source a few amps of current to drive the stepper motors. The safety signal will be used to tell the microcontroller to stop and shutdown as there is a problem with one or more of the DC voltages.

Table 41: Power Supply Functional Analysis

Module	Motors
Inputs	● Controlled Power Lines
Outputs	● Moves Pen on XY print rails
Functionality	Motors will drive the print head with a pen attached to not only mark the ballot but also use the attached IR sensor to locate landmarks and verify that the pen marked the oval.

Table 42: Motors Functional Analysis

Module	Pen Servo
Inputs	● DC Power ● Control signal
Outputs	● Moves Pen Vertically
Functionality	Pen will be raised and lowered via a servo.

Table 43: Pen Servo Functional Analysis

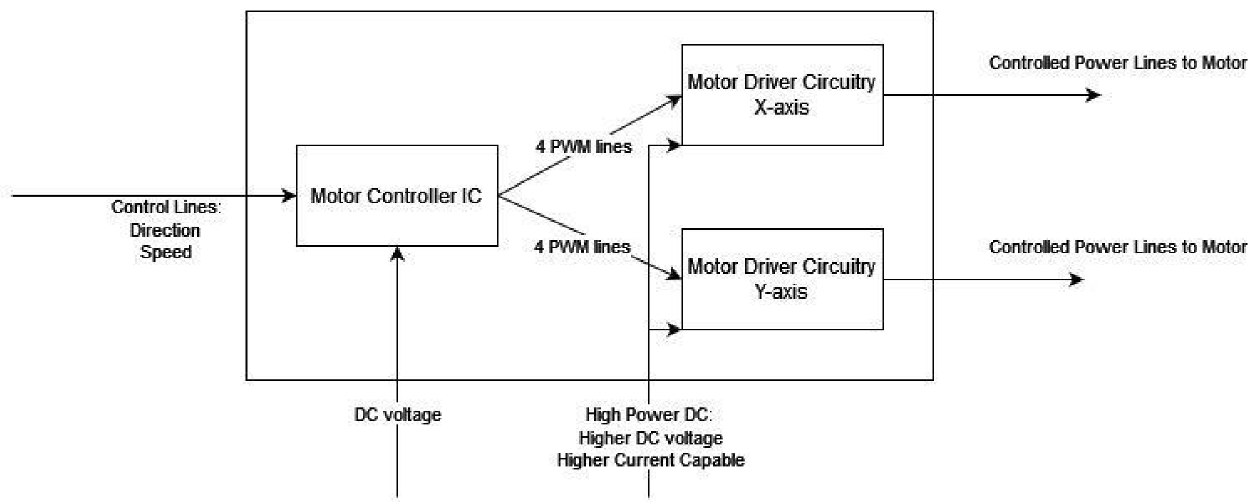

Figure 19: Level 2: Motor Controller

Module	Motor Controller IC
Inputs	● DC Power ● Control Signals
Outputs	● Four PWM lines
Functionality	Takes the control signals from the microcontroller and turns them into PWM signals to drive the stepper motor driver circuit. This will allow for current chopper operation to get maximum torque out of the motors for excellent accuracy. Micro stepping features built into the IC will also allow for greater control of stepper motor movement.

Table 44: Level 2 Motor Controller IC Functional Analysis

Module	Motor Driver Circuit X and Y Axis
Inputs	● Four PWM Lines ● High Power DC
Outputs	● Controlled Power Lines to Motor
Functionality	High Power DC will drive power MOSFETs which will connect to the windings of the stepper motor. The four MOSFETs will be pulsed by the PWM to 'step' the motor at the rate and direction needed.

Table 45: Level 2 Motor Driver Circuit Functional Analysis

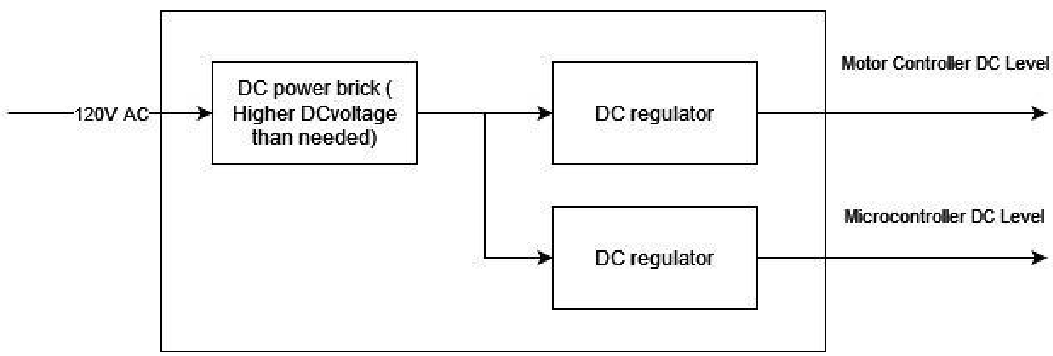

Figure 20: Level 2: Power Supply

Module	DC Power Brick
Inputs	● 120V AC
Outputs	● DC Voltage
Functionality	A power brick will be used with an appropriate voltage needed for the selected motors. The power brick was chosen because of the high current demands needed by the stepper motors. Stable power is essential to get accurate steps from the motors.

Table 46: Level 2 DC Power Brick Functional Analysis

Module	DC Regulators
Inputs	● DC Power
Outputs	● Regulated DC Level
Functionality	High level DC voltage will be regulated down to the levels needed.

Table 47: Level 2 DC Regulators Functional Analysis

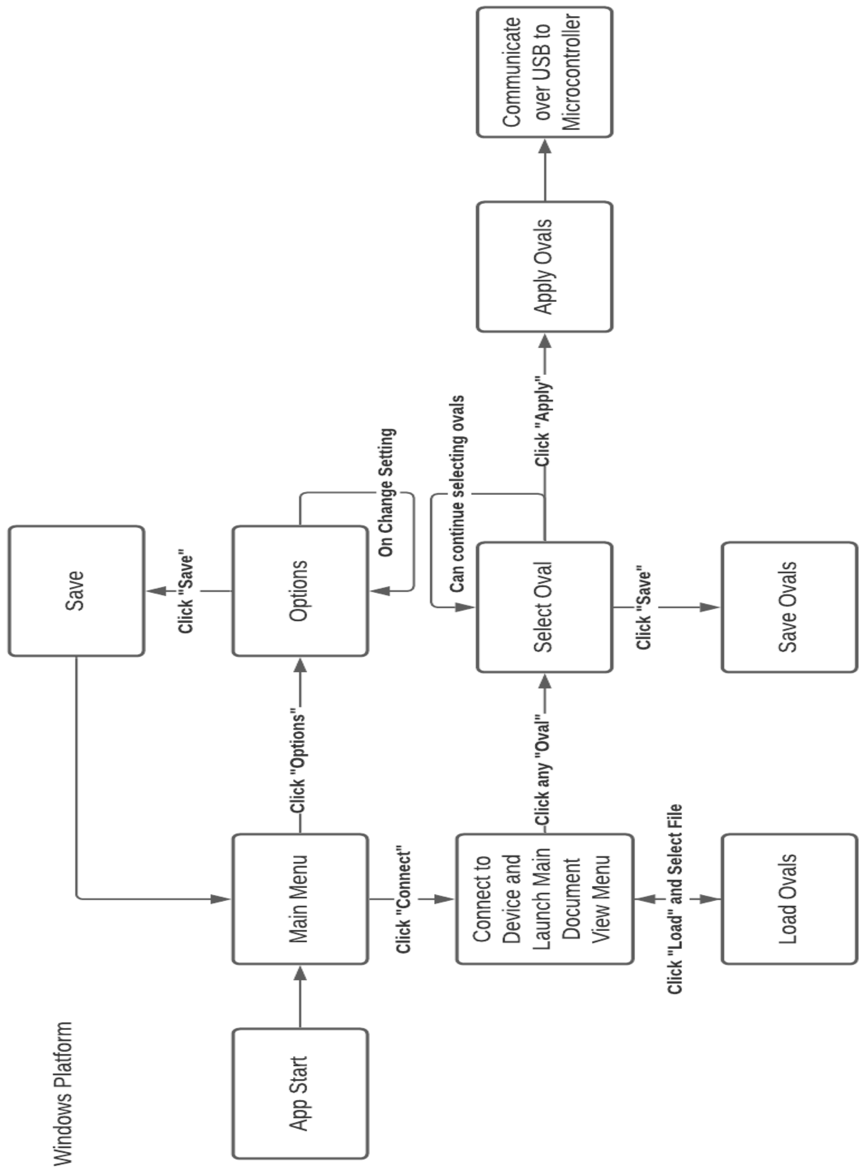

Figure 21: Data Flow Chart

PSSC 2: Completely mark a test ballot in 7 minutes

Video of Oval-Mate marking a ballot: https://youtu.be/soO_XK59jR0

PSSC 3: In a 2 Menu application, the user will be able to save and load more than 100 different ballot configurations to the device and the LED status indicators will display progress

LEDS: https://youtu.be/soO_XK59jR0?t=63 video shows LEDs and 7-segment display changing

100 ballots that can be saved and loaded:

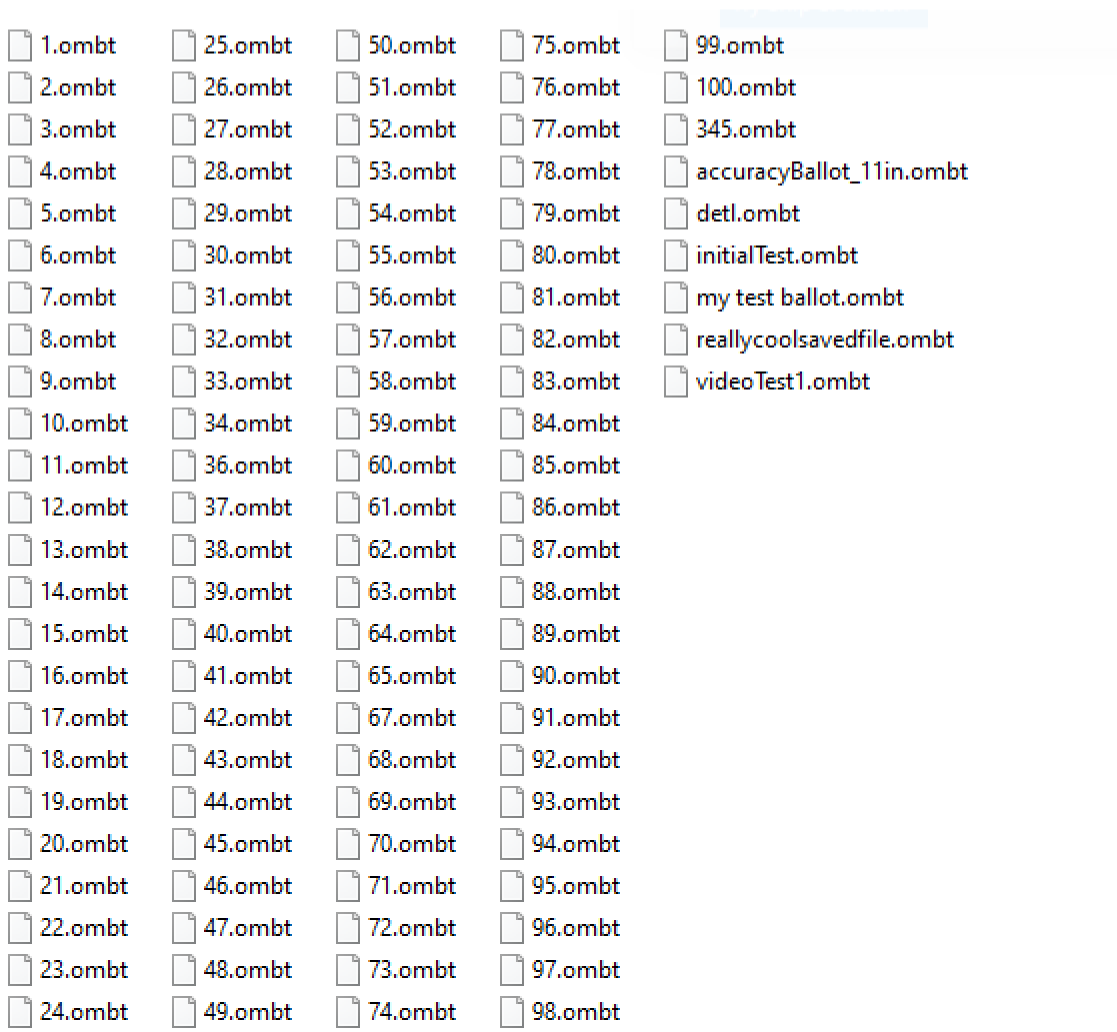

Figure 22: 100 Ballot Configurations

2 Menu Application (form filling window and troubleshooting/help window):

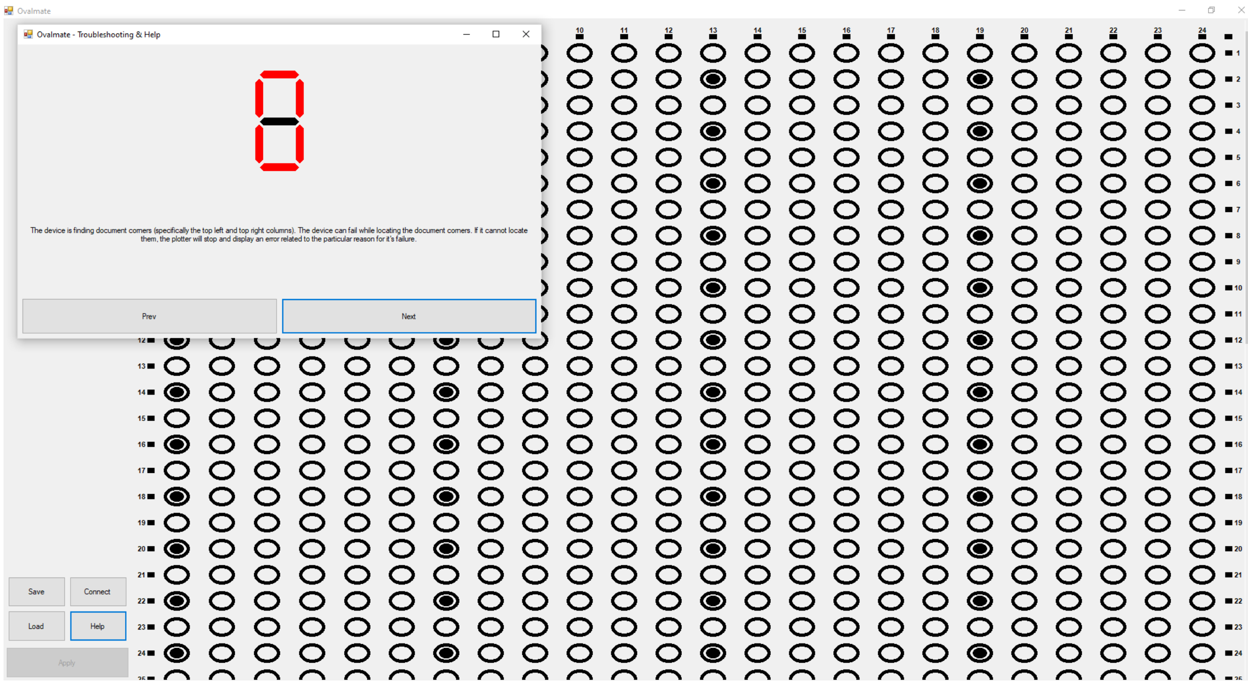

Figure 23: Two Windows Application

PSSC 4: Tabulate 20 marked ballots in ESS tabulator and verify results.

Video of DS950 processing 20 ballots marked by Oval-Mate: https://youtu.be/1vZayvk7oKA

Below are pages of the Zero and Detail Report that the DS950 generates. The Zero Report shows that the machine started with Zeros for all oval locations. The Detail report shows that every other oval that was marked by the Oval-Mate tabulated correctly. If there would have been an issue with one of the marks, the DS950 would have not counted it and flagged it for review.

Detail Results

Machine ID: A Machine #: 9521060545

Accuracy
DSACC11
12/31/2022

04/11/2022 13:56:20

First Ballot Date Time:	04/11/2022 13:55:54	Total Sheets Processed:	20
Last Ballot Date Time:	04/11/2022 13:56:10	Total Ballots Cast:	20
		Blank Sheets Cast:	0

Contest	Votes
Office1	
(Vote For 25)	
C 1	20
C 2	0
C 3	20
C 4	0
C 5	20
C 6	0
C 7	20
C 8	0
C 9	20
C 10	0
C 11	20
C 12	0
C 13	20
C 14	0
C 15	20
C 16	0
C 17	20
C 18	0
C 19	20
C 20	0
C 21	20
C 22	0
C 23	20
C 24	0
C 25	20
C 26	0
C 27	20
C 28	0
C 29	20
C 30	0
C 31	20
C 32	0
C 33	20
C 34	0
C 35	20
C 36	0
C 37	20
C 38	0
C 39	20
C 40	0
C 41	20
C 42	0
C 43	20

Figure 24.1: Details Report

Detail Results

Machine ID: A   Machine #: 9521060545   Accuracy
DSACC11
04/11/2022 13:56:20   12/31/2022

First Ballot Date Time:	04/11/2022 13:55:54	Total Sheets Processed:	20
Last Ballot Date Time:	04/11/2022 13:56:10	Total Ballots Cast:	20
		Blank Sheets Cast:	0

Contest	Votes
C 44	0
C 45	20
C 46	0
C 47	20
C 48	0
C 49	20
Over Votes	0
Under Votes	0
Total	**500**

Office2
(Vote For 25)

C 101	20
C 102	0
C 103	20
C 104	0
C 105	20
C 106	0
C 107	20
C 108	0
C 109	20
C 110	0
C 111	20
C 112	0
C 113	20
C 114	0
C 115	20
C 116	0
C 117	20
C 118	0
C 119	20
C 120	0
C 121	20
C 122	0
C 123	20
C 124	0
C 125	20
C 126	0
C 127	20
C 128	0
C 129	20
C 130	0
C 131	20
C 132	0
C 133	20

Figure 24.2: Details Report

Detail Results

Machine ID: A Machine #: 9521060545 — Accuracy
DSACC11
04/11/2022 13:56:20 — 12/31/2022

First Ballot Date Time:	04/11/2022 13:55:54	Total Sheets Processed:	20
Last Ballot Date Time:	04/11/2022 13:56:10	Total Ballots Cast:	20
		Blank Sheets Cast:	0

Contest	Votes
C 134	0
C 135	20
C 136	0
C 137	20
C 138	0
C 139	20
C 140	0
C 141	20
C 142	0
C 143	20
C 144	0
C 145	20
C 146	0
C 147	20
C 148	0
C 149	20
Over Votes	0
Under Votes	0
Total	**500**

Office3
(Vote For 25)

C 201	20
C 202	0
C 203	20
C 204	0
C 205	20
C 206	0
C 207	20
C 208	0
C 209	20
C 210	0
C 211	20
C 212	0
C 213	20
C 214	0
C 215	20
C 216	0
C 217	20
C 218	0
C 219	20
C 220	0
C 221	20
C 222	0
C 223	20

Figure 24.3: Details Report

Detail Results

Machine ID: A Machine #: 9521060545

Accuracy
DSACC11
12/31/2022

04/11/2022 13:56:20

First Ballot Date Time:	04/11/2022 13:55:54	Total Sheets Processed:	20
Last Ballot Date Time:	04/11/2022 13:56:10	Total Ballots Cast:	20
		Blank Sheets Cast:	0

Contest	Votes
C 224	0
C 225	20
C 226	0
C 227	20
C 228	0
C 229	20
C 230	0
C 231	20
C 232	0
C 233	20
C 234	0
C 235	20
C 236	0
C 237	20
C 238	0
C 239	20
C 240	0
C 241	20
C 242	0
C 243	20
C 244	0
C 245	20
C 246	0
C 247	20
C 248	0
C 249	20
Over Votes	0
Under Votes	0
Total	**500**

Office4

(Vote For 25)

C 301	20
C 302	0
C 303	20
C 304	0
C 305	20
C 306	0
C 307	20
C 308	0
C 309	20
C 310	0
C 311	20
C 312	0
C 313	20

Figure 24.4: Details Report

Detail Results

Machine ID: A Machine #: 9521060545

Accuracy
DSACC11
12/31/2022

04/11/2022 13:56:20

First Ballot Date Time:	04/11/2022 13:55:54	Total Sheets Processed:	20
Last Ballot Date Time:	04/11/2022 13:56:10	Total Ballots Cast:	20
		Blank Sheets Cast:	0

Contest	Votes
C 314	0
C 315	20
C 316	0
C 317	20
C 318	0
C 319	20
C 320	0
C 321	20
C 322	0
C 323	20
C 324	0
C 325	20
C 326	0
C 327	20
C 328	0
C 329	20
C 330	0
C 331	20
C 332	0
C 333	20
C 334	0
C 335	20
C 336	0
C 337	20
C 338	0
C 339	20
C 340	0
C 341	20
C 342	0
C 343	20
C 344	0
C 345	20
C 346	0
C 347	20
C 348	0
C 349	20
Over Votes	0
Under Votes	0
Total	**500**

Office5
(Vote For 25)

C 401	0
C 402	0
C 403	0

Figure 24.5: Details Report

Zero Report

Machine ID: A	Machine #: 9521060545	Accuracy DSACC11
04/11/2022 13:54:25		12/31/2022

First Ballot Date Time:	Total Sheets Processed:	0
Last Ballot Date Time:	Total Ballots Cast:	0
	Blank Sheets Cast:	0

Contest	Votes
Office1	
(Vote For 25)	
C 1	0
C 2	0
C 3	0
C 4	0
C 5	0
C 6	0
C 7	0
C 8	0
C 9	0
C 10	0
C 11	0
C 12	0
C 13	0
C 14	0
C 15	0
C 16	0
C 17	0
C 18	0
C 19	0
C 20	0
C 21	0
C 22	0
C 23	0
C 24	0
C 25	0
C 26	0
C 27	0
C 28	0
C 29	0
C 30	0
C 31	0
C 32	0
C 33	0
C 34	0
C 35	0
C 36	0
C 37	0
C 38	0
C 39	0
C 40	0
C 41	0
C 42	0
C 43	0

Figure 25.1: Zero Report

Zero Report

Machine ID: A	Machine #: 9521060545		Accuracy DSACC11 12/31/2022
04/11/2022 13:54:25			

First Ballot Date Time:	Total Sheets Processed:	0
Last Ballot Date Time:	Total Ballots Cast:	0
	Blank Sheets Cast:	0

Contest	Votes
C 44	0
C 45	0
C 46	0
C 47	0
C 48	0
C 49	0
Over Votes	0
Under Votes	0
Total	**0**

Office2

(Vote For 25)

C 101	0
C 102	0
C 103	0
C 104	0
C 105	0
C 106	0
C 107	0
C 108	0
C 109	0
C 110	0
C 111	0
C 112	0
C 113	0
C 114	0
C 115	0
C 116	0
C 117	0
C 118	0
C 119	0
C 120	0
C 121	0
C 122	0
C 123	0
C 124	0
C 125	0
C 126	0
C 127	0
C 128	0
C 129	0
C 130	0
C 131	0
C 132	0
C 133	0

Figure 25.2: Zero Report

3 of 10

Zero Report

Machine ID: A Machine #: 9521060545

Accuracy
DSACC11

04/11/2022 13:54:25 12/31/2022

First Ballot Date Time:		Total Sheets Processed:	0
Last Ballot Date Time:		Total Ballots Cast:	0
		Blank Sheets Cast:	0

Contest	Votes
C 134	0
C 135	0
C 136	0
C 137	0
C 138	0
C 139	0
C 140	0
C 141	0
C 142	0
C 143	0
C 144	0
C 145	0
C 146	0
C 147	0
C 148	0
C 149	0
Over Votes	0
Under Votes	0
Total	**0**

Office3
(Vote For 25)

C 201	0
C 202	0
C 203	0
C 204	0
C 205	0
C 206	0
C 207	0
C 208	0
C 209	0
C 210	0
C 211	0
C 212	0
C 213	0
C 214	0
C 215	0
C 216	0
C 217	0
C 218	0
C 219	0
C 220	0
C 221	0
C 222	0
C 223	0

Figure 25.3: Zero Report

Zero Report

Machine ID: A Machine #: 9521060545 Accuracy
DSACC11
04/11/2022 13:54:25 12/31/2022

First Ballot Date Time:		Total Sheets Processed:	0
Last Ballot Date Time:		Total Ballots Cast:	0
		Blank Sheets Cast:	0

Contest	Votes
C 224	0
C 225	0
C 226	0
C 227	0
C 228	0
C 229	0
C 230	0
C 231	0
C 232	0
C 233	0
C 234	0
C 235	0
C 236	0
C 237	0
C 238	0
C 239	0
C 240	0
C 241	0
C 242	0
C 243	0
C 244	0
C 245	0
C 246	0
C 247	0
C 248	0
C 249	0
Over Votes	0
Under Votes	0
Total	**0**

Office4
(Vote For 25)

C 301	0
C 302	0
C 303	0
C 304	0
C 305	0
C 306	0
C 307	0
C 308	0
C 309	0
C 310	0
C 311	0
C 312	0
C 313	0

Figure 25.4: Zero Report

5 of 10

Zero Report

Machine ID: A Machine #: 9521060545

Accuracy
DSACC11
12/31/2022

04/11/2022 13:54:25

First Ballot Date Time:		Total Sheets Processed:	0
Last Ballot Date Time:		Total Ballots Cast:	0
		Blank Sheets Cast:	0

Contest	Votes
C 314	0
C 315	0
C 316	0
C 317	0
C 318	0
C 319	0
C 320	0
C 321	0
C 322	0
C 323	0
C 324	0
C 325	0
C 326	0
C 327	0
C 328	0
C 329	0
C 330	0
C 331	0
C 332	0
C 333	0
C 334	0
C 335	0
C 336	0
C 337	0
C 338	0
C 339	0
C 340	0
C 341	0
C 342	0
C 343	0
C 344	0
C 345	0
C 346	0
C 347	0
C 348	0
C 349	0
Over Votes	0
Under Votes	0
Total	**0**

Office5
(Vote For 25)

C 401	0
C 402	0
C 403	0

Figure 25.5: Zero Report

PSSC 5: Fill more than 90% of oval space with mark by measuring oval with micro ruler

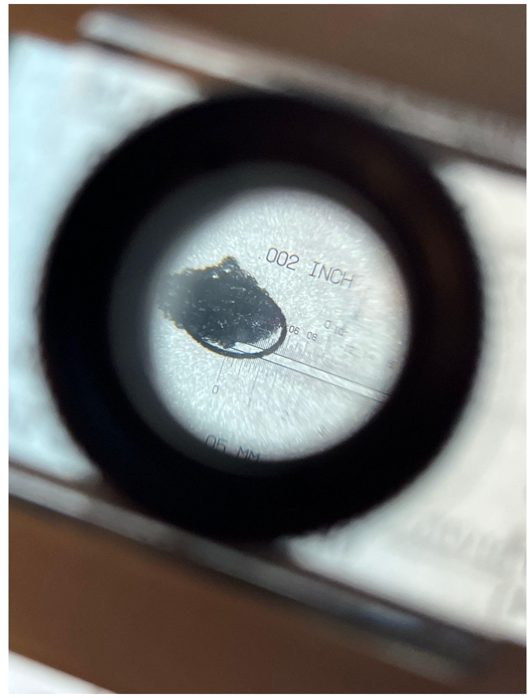

Figure 26: Micro Ruler Measurements

Test Writer: Adam Krajicek			
Test Case Name:	Percentage of Oval Space Marked	Test ID #:	0002
Description:	Measure the percentage of space marked within the printed oval space. Oval-mate will mark 90% or more of oval space with mark on ballot.	Type:	White Box
Tester Information			
Name of Tester:	Alex Wissing	Date:	4/15/22
Hardware Ver:	1.0	Time:	13:00
Setup:	Oval-mate will print nine ovals. Ovals will be placed in the four corners, then single ovals centered between the four corners which will count for four more ovals. Then the last oval will be in the center of the ballot. This will test for all skew or slippage that would occur during printing. A micro ruler will be used to measure mark coverage of the oval.		

Step	Action	Expected Result	Pass	Fail	N/A	Comments
1	Measure width of white space of oval	Record measurement				1mm
2	Measure height of white space of oval	Record measurement				0.3mm
3	Multiply H x W to get area of white space	Area must be 0.6mm or less	X			0.3mm^2
Overall test result:			X			Oval-Mate passed this test.

Table 48: Test Case 0002

As per Test Case 0002:

White space = 1mm * 0.3mm = 0.3 (mm^2)

Total space = 3mm * 2mm = 6 (mm^2)

Percent white space = White space / Total space = 0.05 = 5%

5% < 10% => PSSC 5 Complete!

C) Electrical Specification

1. Schematics

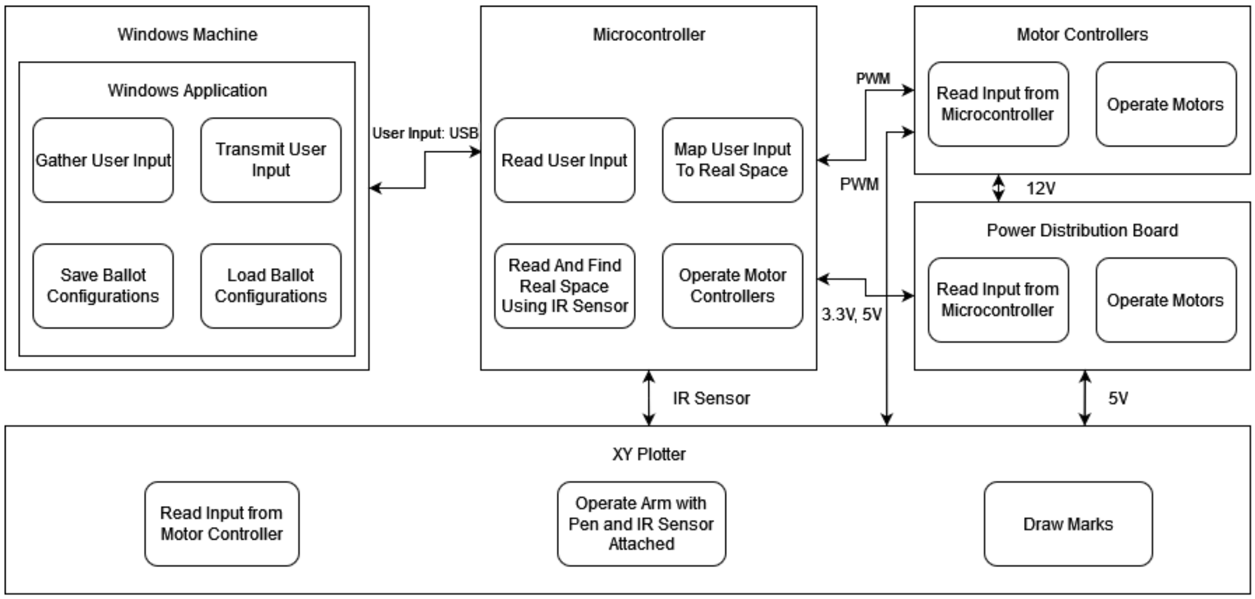

Figure 27: Block Diagram of Theory of Operation

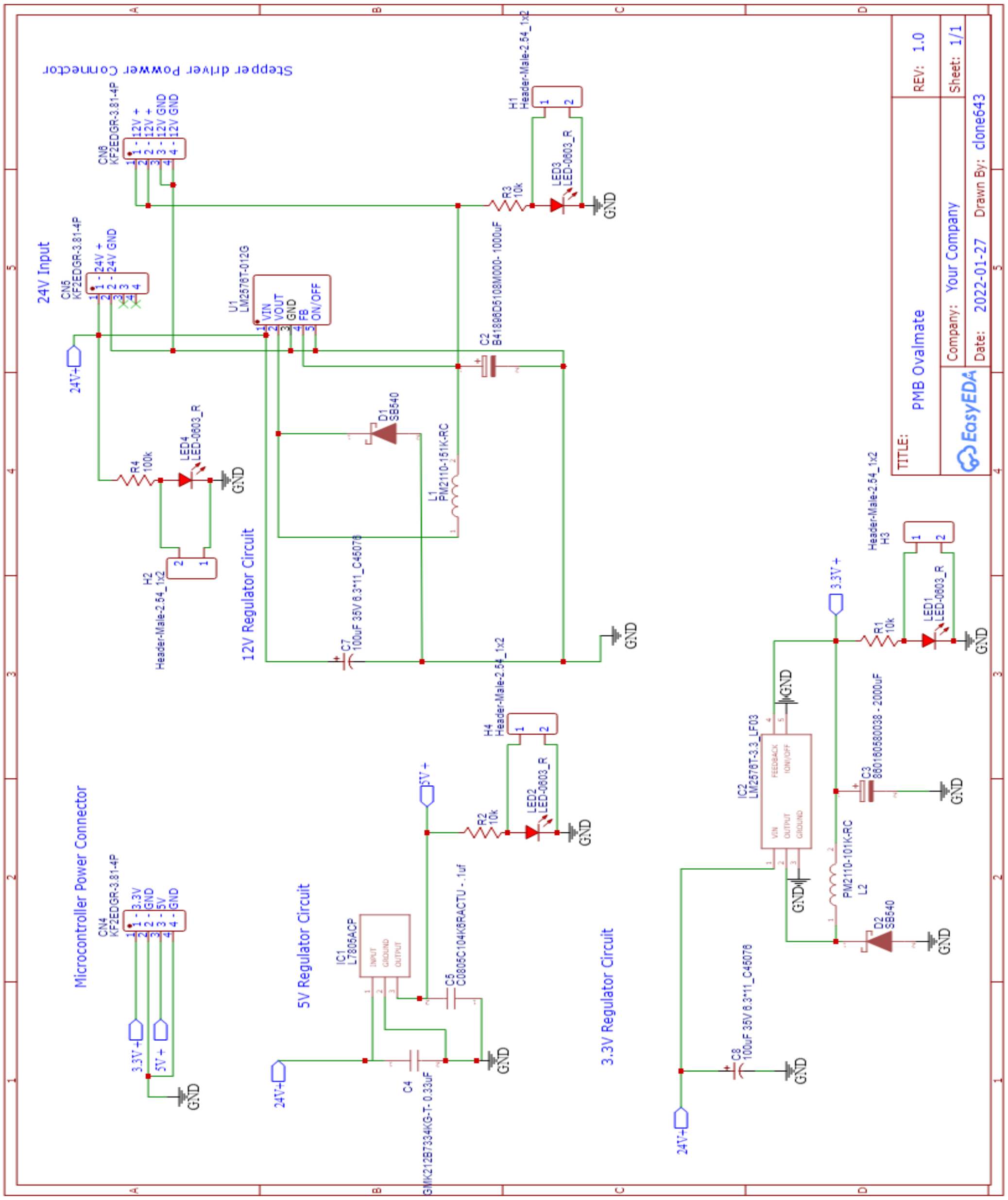

Figure 28: Power Management Board Schematic

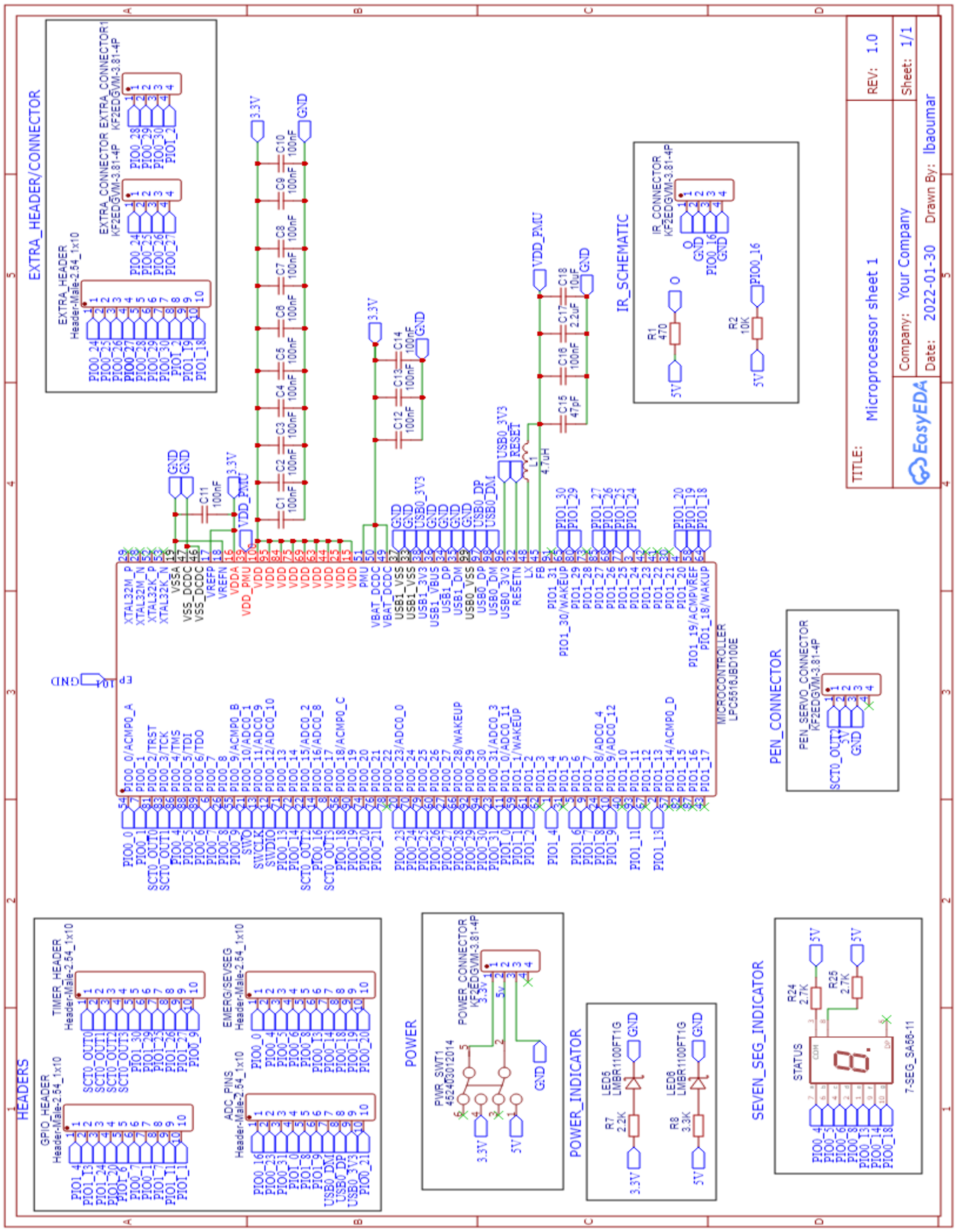

Figure 29.1: Microcontroller Schematic

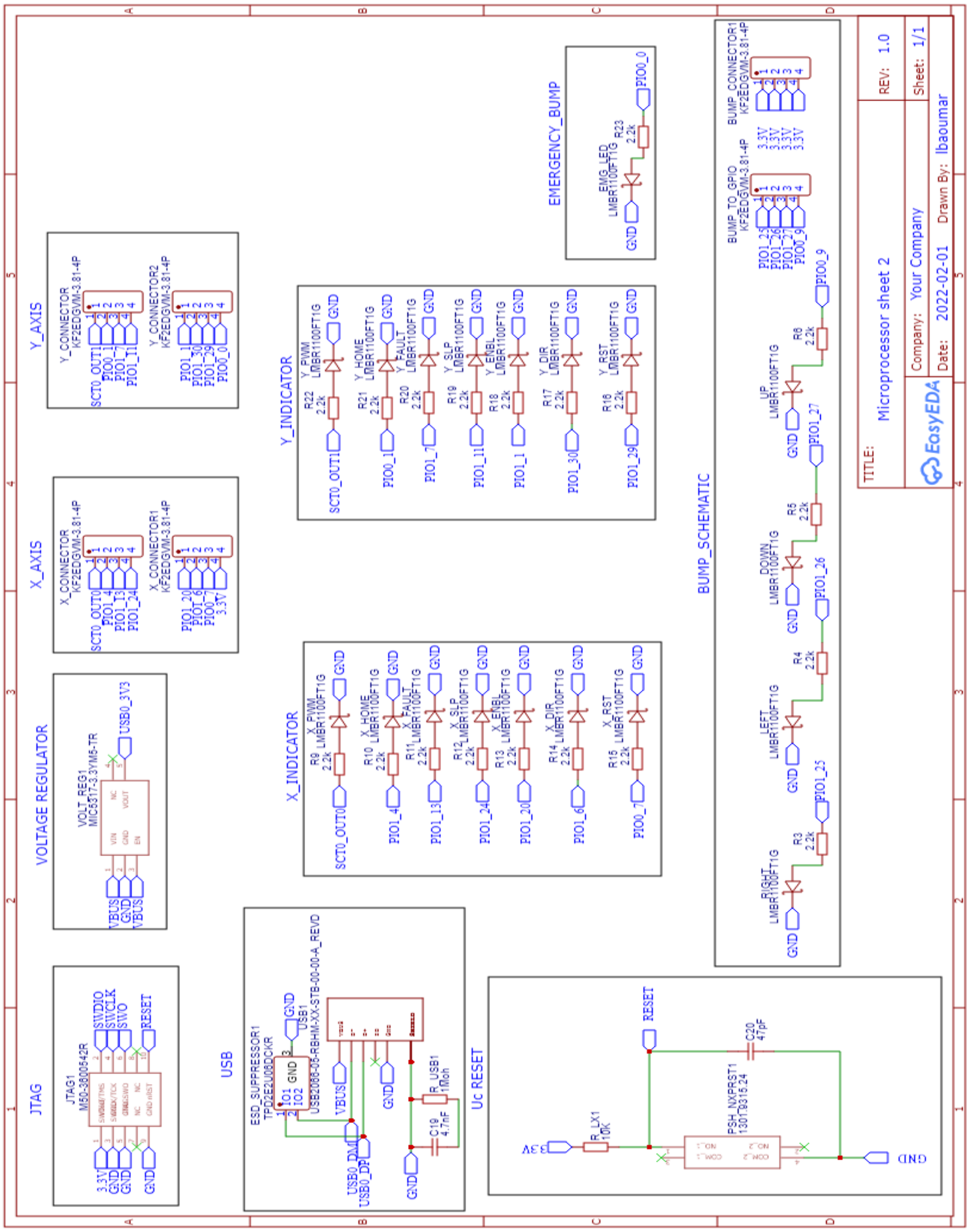

Figure 29.2: Microcontroller Schematic cont'

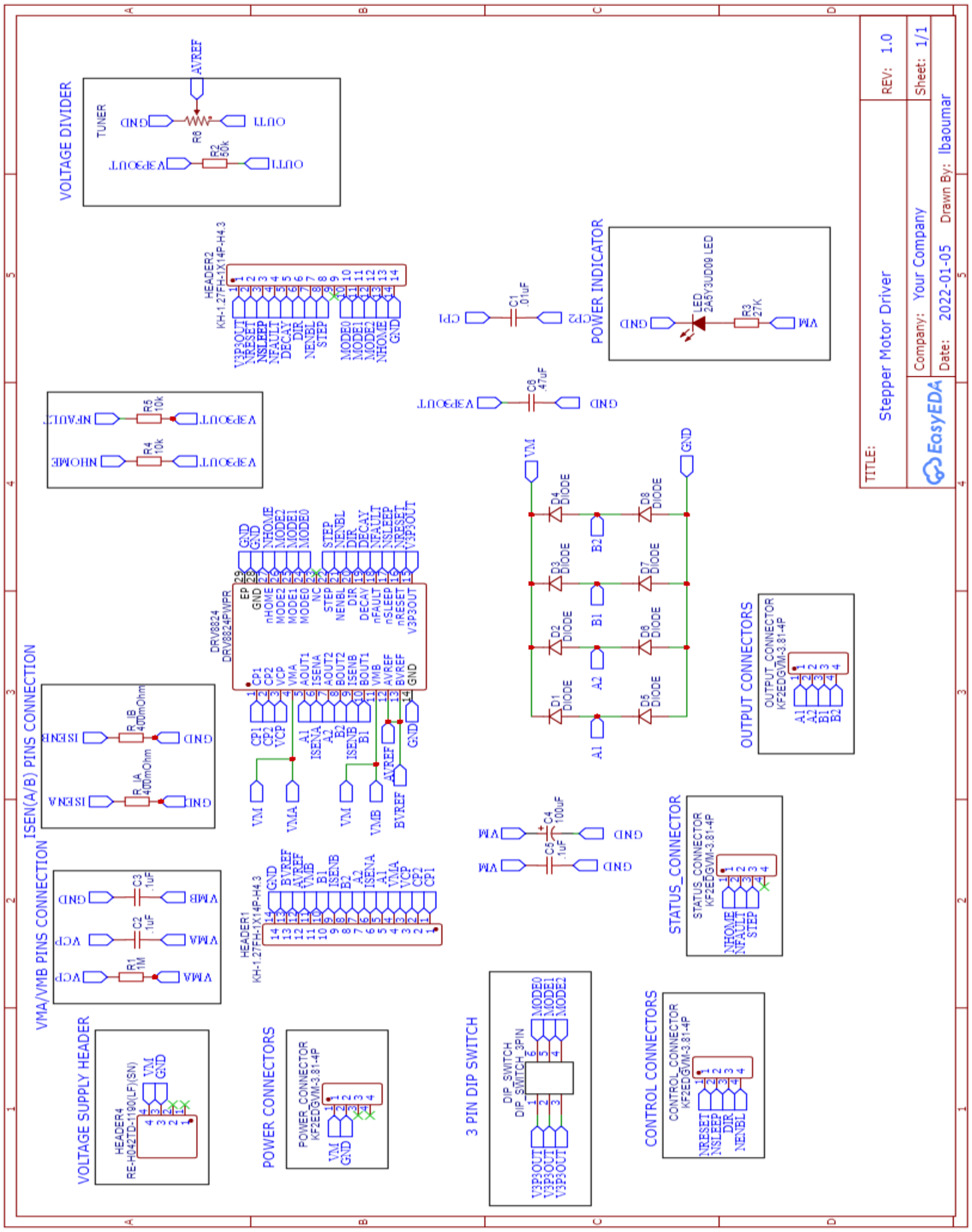

Figure 30: Stepper Motor Driver Schematic

2. Timing Analysis

Components that utilize timing elements include the stepper motor drivers, the servo motor, the analog-to-digital converter which is used to interpret the infra-red sensor, and the USB communication bus. Three internal clocks of the LPC5512JBD100E microcontroller were used to obtain the initial frequency of 1MHz, 12MHz, and 96MHz.

The stepper motor drivers require 7 signals from the microcontroller, but only the step line utilizes timing requirements. To indicate a step, a high pulse and a low pulse are required. The frequency of these signals must be below 250KHz and have a minimum pulse size of 1.9 microseconds. The later requirement can be avoided entirely by keeping the period at a 50% duty cycle. The two speeds that the plotter operates between are 2.6KHz and 10KHz.

The servo motor, a Micro Servo 9g SG90, requires a 50Hz signal with a duty cycle between 5% (-90 degrees) to 15% (90 degrees). To achieve this frequency, the 1MHz clock is used to drive a general purpose timer (CTIMER) at two alternating match values.

The ADC operates, according to the LPC551x/LPC55S1x datasheet, at 48MHz which offers upto 2 million samples per second. The same 48MHz signal as used with the FSUSB module is used to power the ADC. The microcontroller also offers hardware averaging of samples in order to prepare averaged samples before they are needed by the software. The ADC was set to do hardware averaging for 128 samples.

The USB communication bus for FullSpeed USB (FSUSB) operates at 48MHz according to the datasheet for the LPC551x/LPC55S1x microcontrollers. Transfer rate is 12Mbps in accordance with the FSUSB specification. The 96MHz clock was divided to access the 48MHz desired frequency.

3. Loading Analysis

The loading analysis was performed as part of the initial part selection of the power supply and power management board components. Each stepper motor is capable of drawing 1A @12V, which is regulated by the onboard current limiting circuit. With the two stepper motor driver boards being the only two boards needing 12V, we needed a minimum of 2A. With a 50% safety margin, we selected a 12V buck boost voltage regulator that is rated for 3A @12V. The servo motor is the only device that requires 5V to operate and it consumes 100mA when idle and while in operation 400mA. Again with a 50% safety margin we selected a 1A 5V linear regulator. This allowed us to add an additional button that lights up with 10mA of current, which still keeps us well within the safety margin. The microcontroller uses up to 2A of current @3.3V based on its datasheet. The seven segment display, IR sensor, and bump switches also use 3.3V. The seven segment display only uses 50mA, the IR sensor LED uses 20mA, the phototransistor uses 50uA, and the bump switches use 66uA. With these additional 3.3V powered peripherals, we chose a 3A, 3.3V buck boost voltage regulator. This gives a safety margin of 40%. With these voltage regulators selected we also knew that we wanted a 24V power supply because the regulators are more energy efficient with higher supply voltages. The total power needed by the system based on the above figures is 51 watts. We selected the 24V power supply on the fact that it has more than enough power capability and was already purchased by ES&S.

Below are the voltage and current ratings measured while the Oval-Mate was actively marking a ballot.

Voltage	Min Amps	Max Amps	Max Power Needed
3.3V	20.2mA	22.7mA	74.9mW
5V	62mA	522mA	2.61W
12V	18mA	372mA	4.46W
24V	112mA	581mA	13.94W

Table 49: DC Power Analysis

4. Specification Sheets

The following are the main components used to make Oval-mate operational and links of the datasheets.
Microcontroller: LPC5512JBD100E
https://www.nxp.com/docs/en/nxp/data-sheets/LPC55S1x_LPC551x_DS.pdf

Stepper driver: DVR8824
https://www.ti.com/lit/ds/symlink/drv8825.pdf?ts=1650782803993&ref_url=https%253A%252F%252Fwww.google.com%252F

Infra-red light sensor: QRE1113
https://www.sparkfun.com/datasheets/Robotics/QR_QRE1113.GR.pdf

Servo motor:
https://media.digikey.com/pdf/Data%20Sheets/DFRobot%20PDFs/SER0006_Web.pdf

XY plotter:
https://www.instructables.com/How-to-make-a-XY-plotter-with-Makeblock/

5. Signal Quality Analysis (SQA)

The signal quality for FS USB and our PWM signals are the most concerning considering their high frequency. Using the logic analyzer at UNO, the following readings were gathered to show the signals not degrading.

Figure X, pictured below, displays the 50% duty cycle at 2.6KHz of both the X and Y stepper motor controller step pins. Later in the image, both motors are stopped because a wall was hit during FindHome. The wall was the top wall, so the Y motor stays stopped and the X continues.

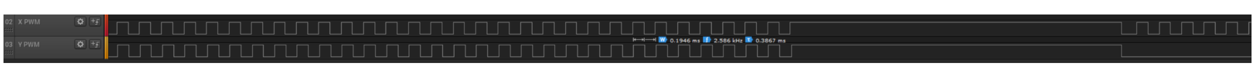

Figure 31: Stepper Motor PWM X & Y

Figure X shows the beginning of the manufacturer code "Team 110, University of Nebraska at Omaha" being transferred to the attached Windows computer. FS USB operates at 12Mbps and is driven by a 48MHz clock in the microcontroller.

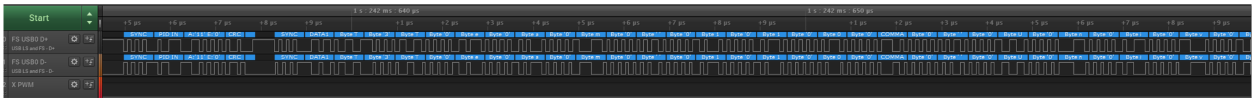

Figure 32.1: FS USB D+ & D- (1/3)

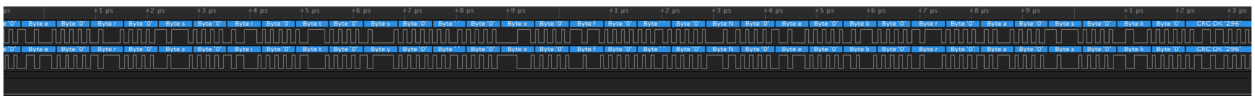

Figure 32.2: FS USB D+ & D- (2/3)

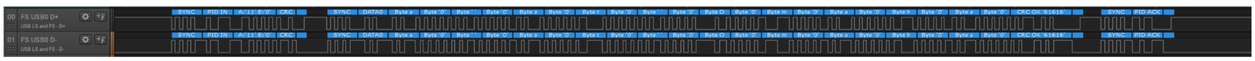

Figure 32.3: FS USB D+ & D- (3/3)

6. Safety/Electrical Hazard Checklist

The Oval-Mate has an electrical hazard sticker on the plexiglass cover on the PCB enclosure to warn users that electrical shock hazards are enclosed. The Oval-Mate itself only has a standard NEMA 5-15P to IEC 320-C13 power cord that plugs into the power entry module. The power entry module is fused to protect from short circuits or unexpected electrical loads. The power switch is on the power entry module. The PMB, power supply, and power entry module are all an electrical risk that can result in shock. The inductors for the Buck-Boost converter of the PMB are not contained, however the power supply is enclosed in a grounded metal.

The Oval-Mate also has a warning sticker near the frontside of the module that warns of the potential for users to be pinched by the plotters arms as it moves. Below are pictures of the safety stickers.

Figure 33: Electrical Shock Hazard Label

Figure 34: Pinch Hazard Label

7. Accuracy Certification

An ES&S DS950 Central Tabulator (DS9521060545) was used to tabulate twenty marked ballots by the Oval-Mate. The election that matches the ballots was loaded onto the tabulator and Zero Report was printed. This Zero Report shows that the tabulator has nothing processed on it. Then the twenty marked ballots were run through the DS950 and the ballots were saved. A Detailed Results Report was printed to show that all marks were tabulated correctly by the DS950. If there would have been an error or unacceptable mark produced by the Oval-Mate, the DS950 tabulator would have not tabulated that particular ballot and flagged it for review.

A microruler (P/N 300MLA0027-004) was used to measure the amount of unmarked area in a particular oval. Each oval marked of a particular ballot was examined so an oval didn't show $0.6mm^2$ of white area. This was quite time consuming however once a rhythm was established and knowing what area of white space you were looking for made the process easier. As for the time requirement a cell phone timer was used as soon as the print command was pressed. Then the end time was when the last oval was filled in.

D) Software

The software produced for the Oval-Mate project is written in C# and C, where C# is the language of the Windows Application and C is the language of the microcontroller driver.

1. Flowcharts

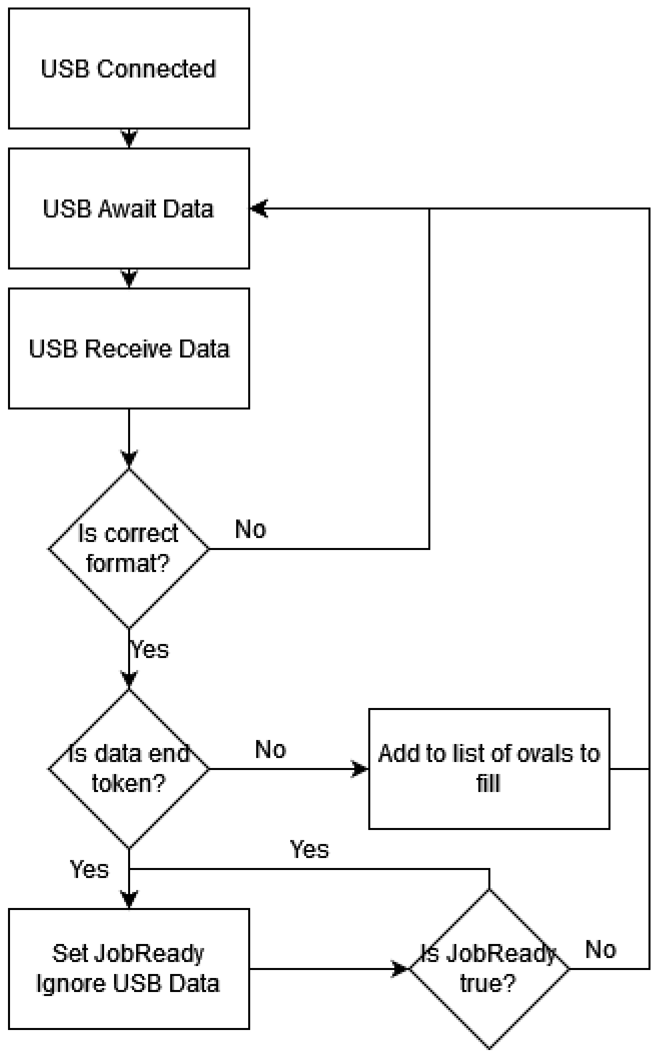

Figure 35: USB Communication Flowchart

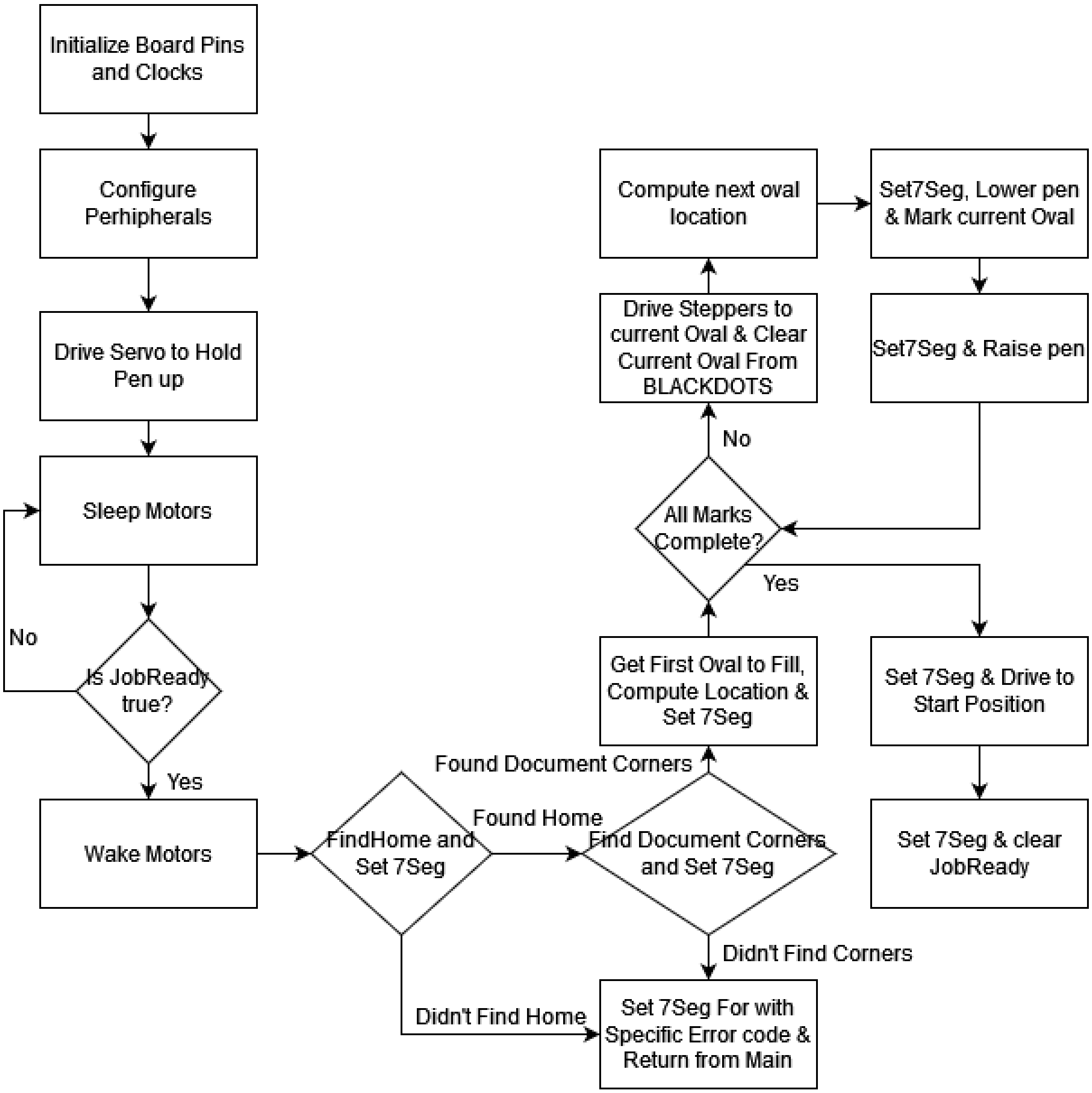

Figure 36: Main Program Execution

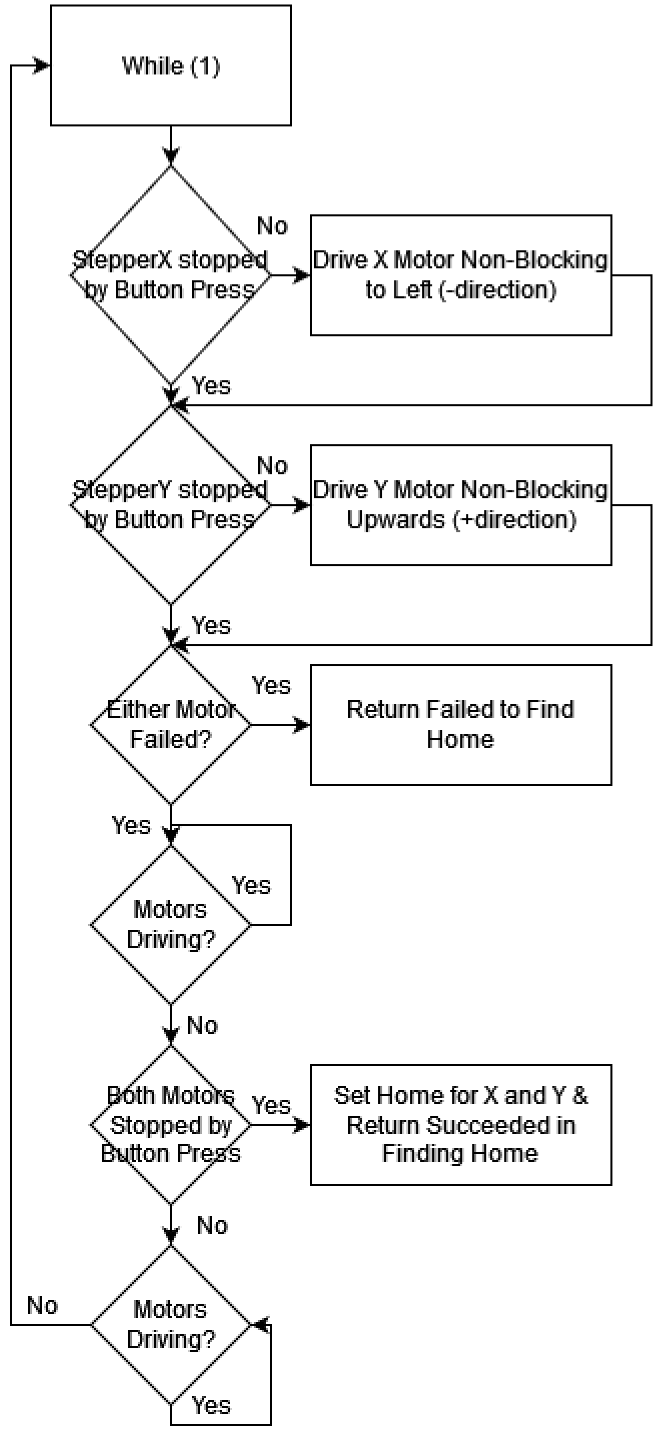

Figure 37: Find Home

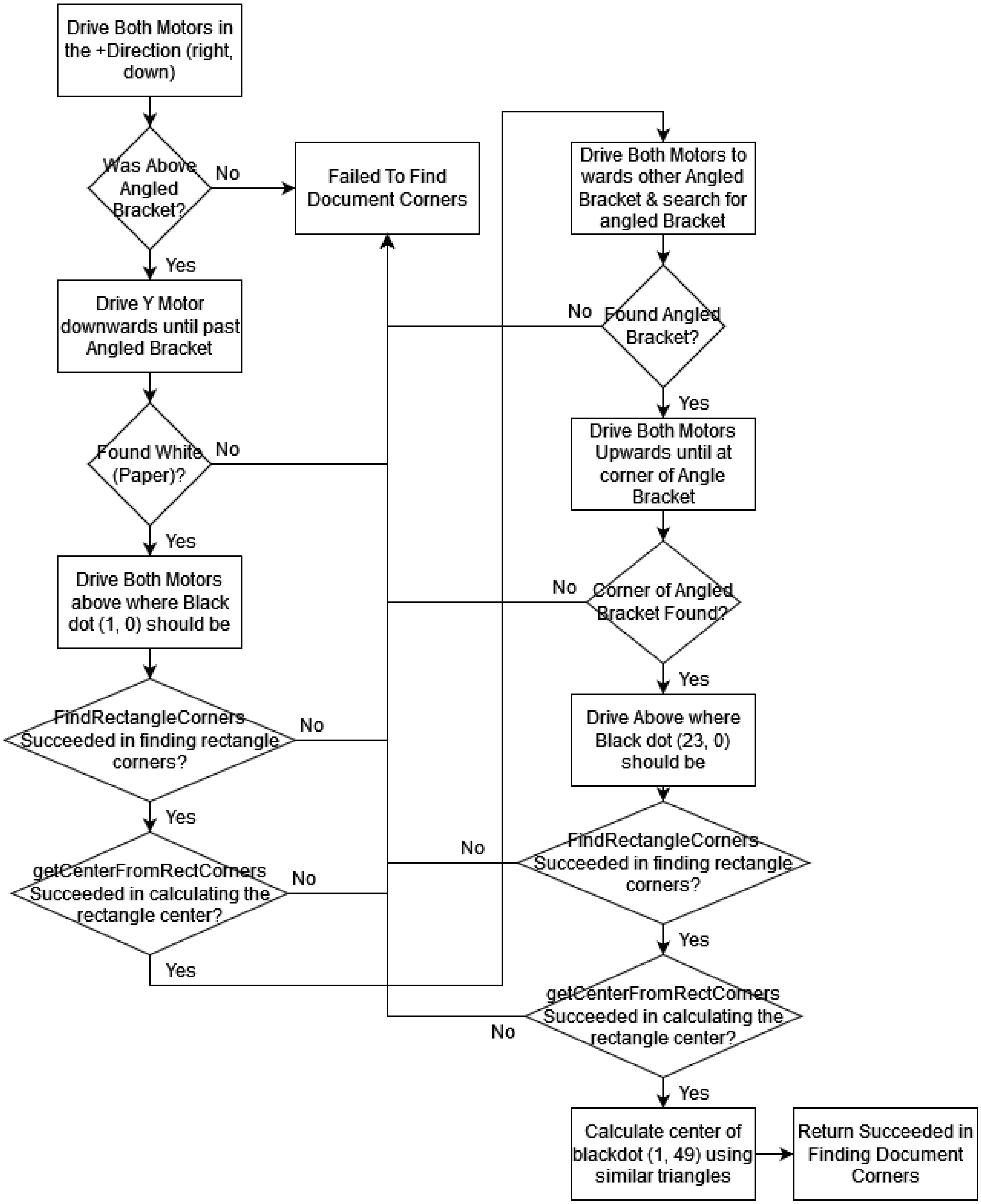

Figure 38: Find Document Corners

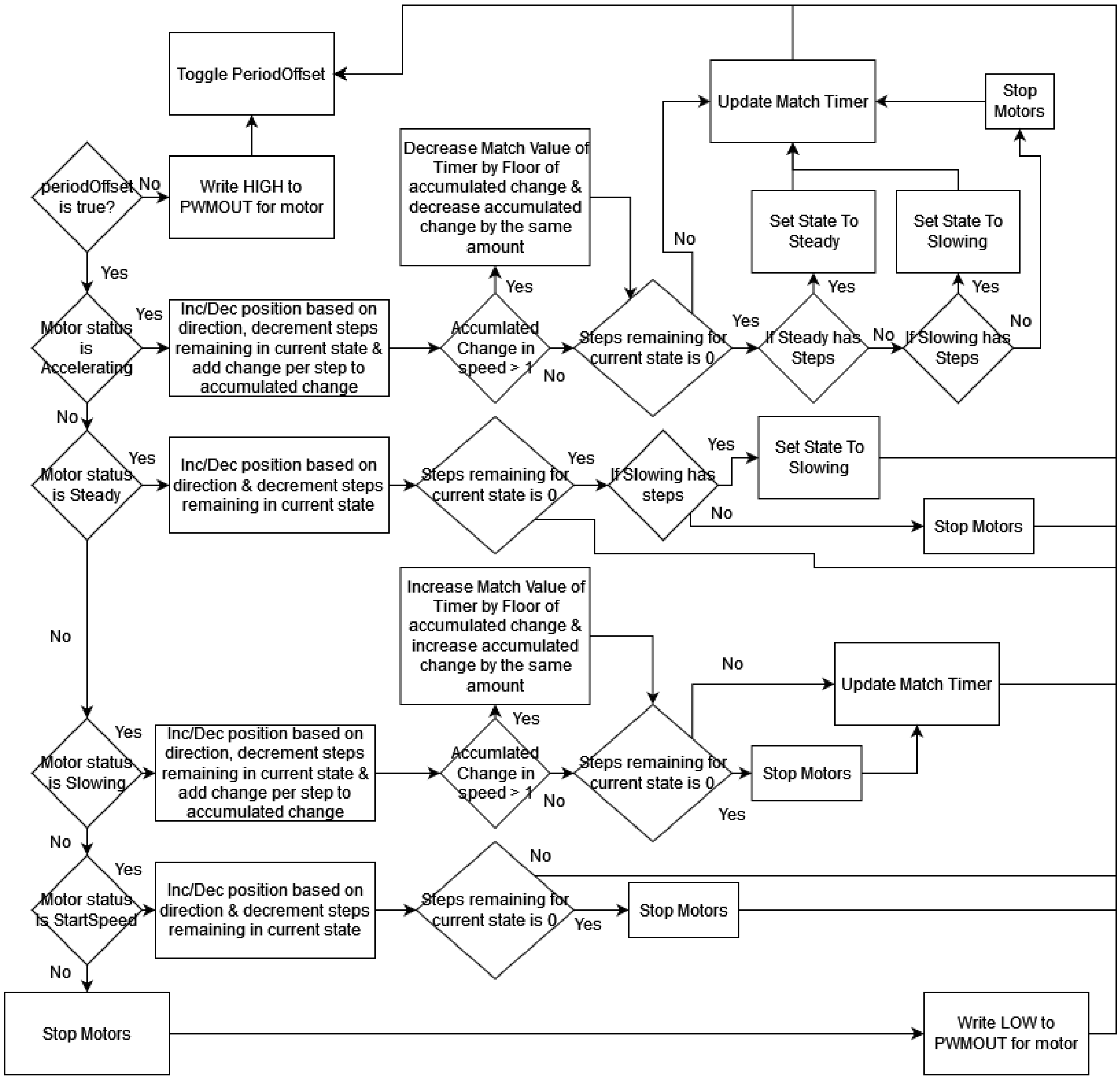

Figure 39: Stepper Motor Timer Interrupt Handler

2. Programing Lists
    a. Oval-Mate UI (https://github.com/silvercorked/OvalMateUI) is the code base for the .Net Framework-based Windows Application. It can be published (turned into an installable form) via Visual Studio and can be installed on computers running Windows 10. The UI takes user input in the form of which ovals that user would like filled. It can save and load these choices, provide troubleshooting/information, and send choices to the Oval-Mate Plotter.
    b. Oval-Mate (https://github.com/silvercorked/OvalMate) is the code base for the LPC55S1x/LPC551x-based microcontroller driver for the main board. It can be flashed to the main board of the Oval-Mate plotter via the JST connector and the

LPC-Link2 board from NXP. The code operates the plotter by awaiting for USB input, finding home, finding document corners, and marking oval locations based on selections made in the Oval-Mate UI.

E) Resource Expenditure Analysis

1. Cost and Labor Hour Analysis

Estimated Engineer's Salary	$80,000
Hourly rate	$41.03
Nick Guida	274 Hours
Adam Krajicek	310 Hours
Alex Wissing	390 Hours
Lloyd BaOumar	290 Hours
Total Engineering Hours	1,264
Total Hours Costs (Hours Spent x Hourly rate)	$51,861
Total Spent	$810
Total Monetary Investment (Total Hours Costs + Total Spent)	$52,671
Money Saved from each Ballot (Hourly rate / 4 = 15 minutes)	$10.26
Number of ballots to break even (Total Investment / Money Saved)	5,133 ballots
Time saved (Number of ballots x 15 minutes)	1,283 Hours

Table 50: Economic Break Even Analysis

2. Parts List

Stepper Motor Board			
ID	**Name**	**Designator**	**Quantity**
1	.01uF	C1	1
2	.1uF	C2,C3,C5	3
3	100uF	C4	1
4	.47uF	C6	1
5	KF2EDGVM-3.81-4P	CONTROL_CONNECTOR,OUTPUT_CONNECTOR,POWER_CONNECTOR,STATUS_CONNECTOR	4
6	DIODE	D1,D2,D3,D4,D5,D6,D7,D8	8
7	DIP_SWITCH_3PIN	DIP_SWITCH	1
8	DRV8824PWPR	DRV8824	1
9	KH-1.27FH-1X14P-H4.3	HEADER1,HEADER2	2
10	RE-H042TD-1190(LF)(SN)	HEADER4	1
11	2A5Y3UD09 LED	LED	1
12	1M	R1	1
13	50k	R2	1
14	27K	R3	1
15	10k	R4,R5	2
16	TUNER	R6	1
17	400mOhm	R_IA,R_IB	2

Table 51: Stepper Motor Board Parts List

Microprocessor Board			
ID	**Name**	**Designator**	**Quantity**
1	Header-Male-2.54_1x10	ADC_PINS,EMERG/SEVSEG,EXTRA_HEADER,GPIO_HEADER,TIMER_HEADER	5
2	KF2EDGVM-3.81-4P	BUMP_CONNECTOR1,BUMP_TO_GPIO,EXTRA_CONNECTOR,EXTRA_CONNECTOR1,IR_CONNECTOR,PEN_SERVO_CONNECTOR,POWER_CONNECTOR,X_CONNECTOR,X_CONNECTOR1,Y_CONNECTOR,Y_CONNECTOR2	11
3	100nF	C1,C2,C3,C4,C5,C6,C7,C8,C9,C10,C11,C12,C13,C14,C16	15
4	47pF	C15	1
5	2.2uF	C17	1
6	10uF	C18	1
7	4.7nF	C19	1
8	47pF	C20	1
9	LMBR1100FT1G	DOWN,EMG_LED,LED5,LED6,LEFT,RIGHT,UP,X_DIR,X_ENBL,X_FAULT,X_HOME,X_PWM,X_RST,X_SLP,Y_DIR,Y_ENBL,Y_FAULT,Y_HOME,Y_PWM,Y_RST,Y_SLP	21
10	TPD2E2U06DCKR	ESD_SUPPRESSOR1	1
11	M50-3600542R	JTAG1	1
12	4.7uH	L1	1
13	LPC5516JBD100E	MICROCONTROLLER	1
14	1301.9315.24	PSH_NXPRST1	1
15	4.52E+11	PWR_SWT1	1
16	470	R1	1
17	10K	R2,R_LX1	2
18	2.2k	R3,R4,R5,R6,R9,R10,R11,R12,R13,R14,R15,R16,R17,R18,R19,R20,R21,R22,R23	19
19	2.2K	R7	1
20	3.3K	R8	1
21	2.7K	R24,R25	2
22	1Moh	R_USB1	1
23	7-SEG_SA56-11	STATUS	1
24	USB2066-05-RBHM-XX-STB-00-00-A_REVD	USB1	1
25	MIC5317-3.3YM5-TR	VOLT_REG1	1

Table 52: Microcontroller Board Parts List

Power Management Board			
ID	Name	Designator	Quantity
1	B41896D5108M000-1000uF	C2	1
2	860160580038 - 2000uF	C3	1
3	GMK212B7334KG-T-0.33uF	C4	1
4	C0805C104K6RACTU - .1uf	C5	1
5	100uF 35V 6.3*11_C45076	C7,C8	2
6	KF2EDGR-3.81-4P	CN4,CN5,CN6	3
7	SB540	D1,D2	2
8	Header-Male-2.54_1x2	H1,H2,H3,H4	4
9	L7805ACP	IC1	1
10	LM2576T-3.3_LF03	IC2	1
11	PM2110-151K-RC	L1	1
12	PM2110-101K-RC	L2	1
13	LED-0603_R	LED1,LED2,LED3,LED4	4
14	10k	R1,R2,R3	3
15	100k	R4	1
16	LM2576T-012G	U1	1

Table 53: Power Management Board Parts List

3. Other Resources

Our work was primarily conducted at ES&S, which allowed access to some of their technology. Specific items that were used include a 4-channel oscilloscope, soldering equipment, power supplies, a 3D printer (and bath for removing support material), and ordering services. Through ES&S business relationships and due to their funding of the project, components were ordered in their name.

An element that certainly shouldn't be understated is the advice available when working in a space with so many professional engineers. Our team sought guidance in soldering techniques (especially for smaller components), FullSpeed USB implementation, and packaging design.

F) ABET Criterion

F1) Adam Krajicek

1. ABET criterion 1 is about identifying, formulating, and solving complex engineering problems by applying principles of engineering, science, and mathematics. During Capstone, I have been using the book Design for Electrical and Computer Engineers by Ford and Coulston. This book outlines steps needed to design a product. These steps have been followed in a logical path of problem identification, research, requirements specification, concept generation, design, prototype, system integration, final system test and acceptance testing. The Oval-mate project has followed these steps as multiple problems were identified and then researched. The problem selected was saving time for ESS by automating the filling out of ballots with a pen. Then requirements were generated so that a concept could be thought of to satisfy those requirements. These requirements are in the form of our PSSCs. During the design phase I had to find out all the power requirements of our complete system. This was accomplished by reading all the datasheets of major components to see their max operating characteristics. With this I was able to then add a safety margin for losses that happen throughout the system such as cable and passive component losses. System integration I had to use sound troubleshooting techniques to be able to isolate issues that arose from simple wire connection problems to board layout issues that required a change to our schematic. Documenting testing completed is also another item that I've performed during the project. This allows traceability to see where in the process certain boards or a function stopped working.
2. ABET criterion 2 is the ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. This has been accomplished by including a fused AC power entry module. This allows for protection of people and electronics from short circuit situations. Also, the electronics are enclosed so a user cannot accidentally touch sensitive electronic parts. The cables used in the system are UL rated to keep the user safe as well. The power supply and power regulators have high efficiency ratings to maximize the use of the electricity that enters the system. When the motors are not being driven during setup time, the stepper motor drivers are put into sleep mode to reduce idle power consumption. All of these help the environment by conserving energy.
3. ABET criterion 3 is the ability to communicate effectively with a range of audiences. This has been achieved through multiple presentations in Capstone class as well as other academia classes. I've also had the opportunity to present and teach coworkers on multiple products operation and repair at my job. Also at my job there are multiple meetings that I'm in charge of leading and creating agendas. The Robots Fair at the Air Force Museum also allowed me to work with younger individuals.

4. ABET criterion 4 is the ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. This has been achieved by recognizing that there was a conflict of interest with me working at ESS and doing a project for them. I made sure that there was a separation of time so that way there was no way to think I was getting paid to do this project. With this being a prototype to prove out that time can be saved, capital cost is a huge importance. To keep the new capital cost low, I used electronic and physical parts that ESS already had available at their office. This included a power entry module, 24V power supply, plexiglass, particle board and wire.
5. ABET criterion 5 is the ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. This has been achieved by working with my Capstone team. We went from not knowing each other to trusting each other. Each of us gets the tasks completed that we say we are going to complete and also collaborate to ensure work will be cohesive with the project's end goals. Each person has been engaged throughout the process of designing the Oval-mate which has turned into a solid project. I've also been part of multiple teams throughout my academic and professional career.
6. ABET criterion 6 is the ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions. This criterion has been achieved throughout my academic and professional career. One good example is when the stepper motors were not responding to our Microcontroller board but worked when pretesting with an Arduino board. I was able to troubleshoot and interpret the data lines going to and from the Stepper Driver board. After double checking that the Microcontroller board was outputting the correct line level without the Stepper Driver board connected and knowing it worked previously, I went to the datasheet to double check the stepper driver IC to ensure I/O ports were configured correctly. It turned out that I misread the datasheet that the Fault output pin of the stepper IC was an open-drain output and that our LED circuit on its output was drawing too much current and pulling the voltage down. With the voltage pulled down the stepper driver IC thought it was in a fault and wouldn't operate as expected. We pulled the LED circuit off the PCB and the Stepper Driver boards started to operate as expected.
7. ABET criterion 7 is the ability to acquire and apply new knowledge as needed, using appropriate learning strategies. This criterion has been satisfied by learning more about how stepper motors and stepper drivers work together as well as voltage regulators. With stepper motors being the best choice to move the XY plotter, I needed to learn more about it. I was familiar with stepper motors in other classes but needed more information. I used the internet to get basic information about torque and speed requirements. I also talked to engineers that had field experience with stepper motors to get more incite. A major component of how well stepper motors perform is that current

equals how much torque they produce. During the beginning of a step the current can be low, and a miss step can occur. However, this can be eliminated if a current chopping driver is used. This allows max current to be available at the beginning of the pulse. I also learned about micro stepping which I've never heard of before this project. It allows a single 1.8-degree step to be divided into multiple smaller steps to have a greater degree of precision. This is done by not fully energizing a single coil but having a percentage of the power divided between the coils, so the rotor is held in between polls. Voltage regulators are also something that I've never delt with before and learned about the various types and characteristics of each. I ended up choosing a buck-boost voltage regulator as it allowed a cheaper solution to meet our current requirements for this project.

F2) Alex Wissing

1. Application of earlier coursework is clear in the programming of a microcontroller system in the C language (ECEN 1060, CSCI 1620), the design, debugging, and flashing of a microcontroller on a custom PCB (ECEN 4330, ECEN 4350), and the optimization of code to avoid wasted time. That last point can be demonstrated in two particular cases: exploration of disassembled C code to select methods of manipulation in C to reduce total cycles (ECEN 3130), and hiding complex floating point calculations behind blocking stepper motor driving behaviors (ECEN 3130). The second part of this outcome was accomplished in learning C#, the .NET Framework for Windows Application development, and exploring and utilizing example code provided by NXP to expand functionality and achieve the project deliverables.
2. Protecting environments, the public, and users is of the utmost importance. Minimizing electrical footprint is one way that this was accomplished. The stepper motors are operated off of our 12 volt line and while they are stationary (ie waiting for USB to connect) they consume the most power. To avoid this, when the motors are idle, the code will interact with the stepper motor driver and sleep the motor to avoid allowing it to consume too much energy. Creating an easy to use UI which saves files in minimal file sizes also accomplishes savings.
3. I did debate in high school for 4 years. In fact, I still judge high school debate tournaments when they need an extra judge. Through that experience, the speech class that's required at UNO, and the many required presentations that are a part of this curriculum, I've gone from being relatively shy to being outgoing in many ways. While I still don't feel comfortable giving speeches, I can stay focused and work through the nerves to deliver the information I'm supposed to.
4. One element that became apparent as we continued implementing our design was that there seemed to be some issue with our USB. Examining the PSSC's, it actually doesn't

specify that USB needs to be working. However, I felt that it was still my responsibility to get it working. This was part of the reason I didn't give up on getting USB working.
5. Our completed project and PSSC's speak to this. There were several points where I invited the team to help me think about the issues I was facing, especially when the core of the hardware was done and being packaged. We explored a lot of solutions for the different problems.
6. Several tests were developed in order to test each feature and peripheral as they were designed. A few tests for the infrared sensor, which was read through the ADC, revealed it to be outputting near constant values. After checking the output lines on the oscilloscope, we found that the sensor was being powered by 5V, but that the microcontroller's ADC wouldn't take anything past 3.96V for a long duration. We then unpowered the board, grabbed a copy of the infrared sensor and tested it being powered with 3.3V rather than 5V. It functioned fine, so we cut the trace that powered the infrared and powered it with 3.3V instead. After that, the output of the infrared sensor was readable.
7. Before this project, I did not know how to make a windows application. I had to go and read Microsoft's WIN32 API tutorial to get the basics. I then explored for frameworks that exist for developing these sorts of applications and decided to write the application in C#, a language I didn't know, and use the .NET framework. These were the things I had to learn for the windows application. For the microcontroller, I had to explore NXP's examples to learn how to interface with the peripherals provided. I had to do research on HID USB and DC stepper motors.

F3) Lloyd BaOumar

1. Throughout my curriculum in general but particularly in java, microcontroller design, and capstone. I have been trained and taught to acquire the ability to identify, formulate, and solve complex engineering, science, and mathematics. Taking capstone gave me the opportunity to apply the principles of engineering, science, and mathematics to solve a problem. After selecting Oval-Mate as our project, we used the engineering design process to plan how to get it done. We first identified the problem that ES&S was going through. The problems identified were the effort and time that engineers from ES&S had to fill up ballots and test their machines. After identifying the problem, we did a lot of research to come up with a solution following the engineering design process.
2. In order to get this project, we used the engineering design process. The first step was the identification of the problem. The problem was the amount of time and effort that engineers from ES&S were putting into filling up ballots to test their tabulating machines. The next step was doing research to find a solution that will meet the minimum requirement of saving time and effort. We came up with the idea of purchasing an XY plotter that will be driven with our own custom made embedded system. The next step was to find a microcontroller that was able to interface with the devices needed to detect

and mark up the ovals on the ballots. After designing our own boards, PCB, and implementing the software, we tested our prototype and made sure it met the needs of our client. The first need was safety. To make sure the user was safe while using the device, we designed a package that covered any susceptible side that could cause an electric shock to the user. Additionally, we added warning stickers to warn users of any possibilities of accidents.

3. Throughout my four years of getting my degree, I was exposed to communicating with different people from different places in general. I was also exposed to communicating in front of a considerable amount of people in public speaking and capstone. Working with my capstone team was extremely helpful because each of them gave me different areas that I needed to improve for better communication in front of an audience and had me practice before any presentation.
4. Since engineers are those responsible for the safety and wellbeing of humans and development, it is important that we are able to recognize ethical and professional responsibilities in any engineering situations and make informed judgements. Our implication in solving any issues impacts directly humans and contributes to our development and wellbeing.
5. The realization of Oval-Mate showed me how important teamwork was. As the hardware engineer in this project, I had to communicate and get feedback everytime from the other members of the team because I had to meet their expectations and the client requirement. I was constantly showing them boards that I had done and waiting for them to let me know if they wanted me to make any changes. Additionally, working on every other aspect of the project as a team was making everything easier and faster. Assigning each member of the team to a specific task and giving a time frame to get it done was challenging but brought us together and gave us confidence to achieve the project.
6. While realizing this project, we ran into problems on both hardware and software. As the hardware engineer, I had to find out what was going wrong or was not working properly on the hardware. For instance, one of the stepper motor boards was not working as expected and I had to use my knowledge to find out what was the issue. I used the voltmeter to check the continuity within pins and discover that it was a soldering issue. After removing bridges between pins, the solder paste was unintentionally removed from the pins to the surface of the board.
7. As we were working on this project, I learned a lot about how stepper motors work, how to design a power management board, and how to manipulate variables efficiently in C. On the hardware side, I learned how important having headers accessible to every pin of the microcontroller is helpful and can save time. The use of LEDs as indicators to check if any data was being transferred gave us an idea of what was going on with the hardware.

F4) Nick Guida

1. The biggest take away I've gotten from my Capstone course is the ability to formulate and identify a problem, research it, and come up with feasible solutions. Throughout the project the skills that I have learned in the EE curriculum have been beneficial in terms of designing electrical components such as the power management board and IR sensor circuits, as well as testing the components through the use of an arduino and breadboard. My engineering degree has taught me that engineering design is a team effort and that the process can go through many iterations before reaching a final product or solution.
2. During the progress of the semester it was made clear that engineering is more than using math and physics to formulate a design. Engineers are involved with everything that society uses on a daily basis and it is our duty to make ethical and safe decisions when designing our products. We took this into account when designing Oval-Mate as our sponsors were an Election Software company. We needed to make sure that our product would be in safe hands and only be used for the specific task we were sponsored to make it for. We also took safety and environmental factors into account and created a safe product which can be disposed of and recycled properly when applicable.
3. Public Speaking has always been a strength of mine as I never really have nerves when talking to a group. However, I am grateful for the opportunity to speak to a group from a technical standpoint as I have never done that before. Talking about our project and getting constructive feedback from other engineering students is invaluable in what type of lessons that it can provide.
4. It is important that engineers adhere to a code of ethics. We are the forefront of society and it evolves with the things that we design and create. With this responsibility it is important to remain ethical and have the well being of everyone in mind when designing a product. Though many companies out there only care about making products no matter who they hurt I believe it is important to lead by example and find a way to make money while also helping others,
5. I personally could not be more happy about the team that I was assigned for my project. I have learned so much from this group of guys that I will remember them forever. Because we didn't know each other when we started the project we had to go through each level of team building. I appreciated this because this is more than likely what it will be like in the real world. Meeting strangers then developing a common goal and respect for one anothers skills and abilities. Eventually, becoming friends will develop trust for these people and can count on them to help you learn and grow. And they can count on you.
6. During the production of Oval-Mate I took the lead on two major tests that needed to be done to ensure we were on the right track. The first was the IR sensor. We wanted to use the IR sensor to identify landmarks on the ballot and use it for navigation. Early on we conducted tests with the sensor and ran it across the ballot at different focal lengths to see what type of readings we were getting. To do this we connected it through an arduino and created a real time graph with the data. We found that we had a sufficient amount of

distinction between black and white space so we carried on with the design. Another test we did was with the stepper motors. Since we were working with coordinates on the ballot we had to translate the amount of steps from the motor to a physical length. We ran the motor with a pen mounted numerous times before we got a consistent value.

7. If my engineering degree has taught me anything it is that I have the ability to learn anything. The challenges that I have faced in my time in college have not only raised my confidence, but given me the motivation to learn as much as I can to grow in my career and as an individual. I've learned that people are my greatest resource as well. Being able to work on a team and collaborate with different minds open you up to new sources of information that can be translated into skills. An example; Before this class I knew nothing about PCB design. My teammates all got together and taught me what I needed to know so that I could help make the power management board.

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