Smart Eraser

Final Project Report

Project Manager: Heather Libecki
Team Members: Chris Quesada, Juan Colin
Technical Advisors: Dr. Hovannes Kulhandjian, Prof. Roger Moore

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REVISION HISTORY

Version #	Date Finalized	Name of Editor	Changes Made
1	10/25/18	Heather Libecki Chris Quesada Juan Colin	The initial rough draft of the Project Charter was created, included proper sections and figures specified by Dr. Stillmaker.
2	12/9/18	Heather Libecki Chris Quesada	Revisions were made regarding system components: Ethernet and most of the planned wired connections were removed and replaced with wireless solutions. References were included in necessary figures and statements. Strengths and Weaknesses section was moved to a more appropriate location. Figures and tables were added and updated; Figure 2: not skipped anymore Figure 3: updated Figure 4: referenced correctly Figure 5: removed Figure 7: removed Figure 8: removed New figures were added. Updated GANTT chart to more clearly show dependencies. More research and background references were used. Test plan was added. Added links to items in budget and hyperlinks throughout document in LaTeX.
3	4/12/19	Heather Libecki Chris Quesada Juan Colin	Updated Final Budget Revisions were made regarding system components: Camera and main microcontroller were replaced with better options. Removed Raspberry Pi from design considerations. Removed wireless dongle from design considerations. Added Arduino Uno 3 microcontrollers to control stepper motor units Added sections pertaining to SPI and I^2C communications, updated information on image processing implementation.

Version #	Date Finalized	Name of Editor	Changes Made
			Modified components used to build prototype stand. stay in scope of final product.
4	4/12/19	Heather Libecki Chris Quesada	Changed the Arduino Uno 3 microcontrollers and the Kuman nRF24 wireless transceivers to 3 HUZZAH32 Feather Board microcontrollers for the wireless communications.
5	4/21/19	Heather Libecki Chris Quesada	Updated Milestone Schedule, GANTT Charts, and Test Plan.
6	4/21/19	Heather Libecki Chris Quesada Juan Colin	Put finishing touches on each section in *Analysis and Design* section of report. Added ultrasonic proximity sensor functionality.

ABSTRACT

The Smart Eraser is an apparatus that scans, detects, and intelligently erases markings on a whiteboard. A camera at a fixed location facing the board records an image and sends it wirelessly to a microcontroller where image-processing is performed in order to locate the markings on the whiteboard. Another programmed algorithm then determines a path to erase all markings on the board, and creates instructions that are sent wirelessly to the x-y axis stepper motors. These motors are attached to the pulleys that move the linear tracking system, which allows the eraser to move across the whiteboard to the marking locations. The eraser then returns to its standby position. An ultrasonic sensor is also attached to face the front of the whiteboard which detects if an object is too close to the mechanical system. This sensor flashes a warning light when an object is detected to be too close to the board while it is in motion.

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I. Introduction

The idea of the Smart Eraser originated from the need to maximize the class time utilized for learning. It aims to assist teachers who write lengthy, involved examples on a whiteboard while lecturing by erasing the board in between examples so the teacher can continue to lecture. This would allow students to learn in an environment with less interruptions and distractions from the material being taught, resulting in improved overall time efficiency of the amount of material being taught.

The Smart Eraser is an automatic whiteboard eraser. The main deliverable of this project is an eraser which can move left-to-right on a track, and up-and-down on another motion system attached to the track. This system is able to detect where markings are on a whiteboard through the use of a camera and an image-processing program. In the final rendition of the project, a smart phone took the place of the camera; the smart phone takes an image of the whiteboard, and the image taken is fed into a 3rd party program to resize and change the format of the image to what is required for the image processing program. The camera would have ideally been mounted across from the whiteboard, and it would have sent the image of the whiteboard to the microcontroller. The microcontroller processes the image, detects where the markings are, and traverses a path to erase all of the markings via two separate algorithms: one that finds the outer edges of the text, and one that creates a serpentine-like path that will traverse the entire area. Once the path is created, its locations are converted to a coordinate system that the mechanical aspects of the eraser are able to read. This coordinate system converts the locations of the markings into rotations of the stepper motors attached to the tracks, allowing the eraser to move. Finally, the eraser is sent to its stand-by position once all of the markings have been erased.

Due to memory constraints in place on the microcontroller used to do all of the image processing, the final rendition of the project needed the instructions for the stepper motors to be split into 3 parts: the top 1/3 of the board, the middle 1/3, and the bottom 1/3. Therefore, the program tells the eraser to move to the markings in the top 1/3, then the middle, then the bottom. In between each step, the eraser moves back to its stand by position to get ready for the next set of instructions.

The following figure is a simple pictorial representation of the final product.

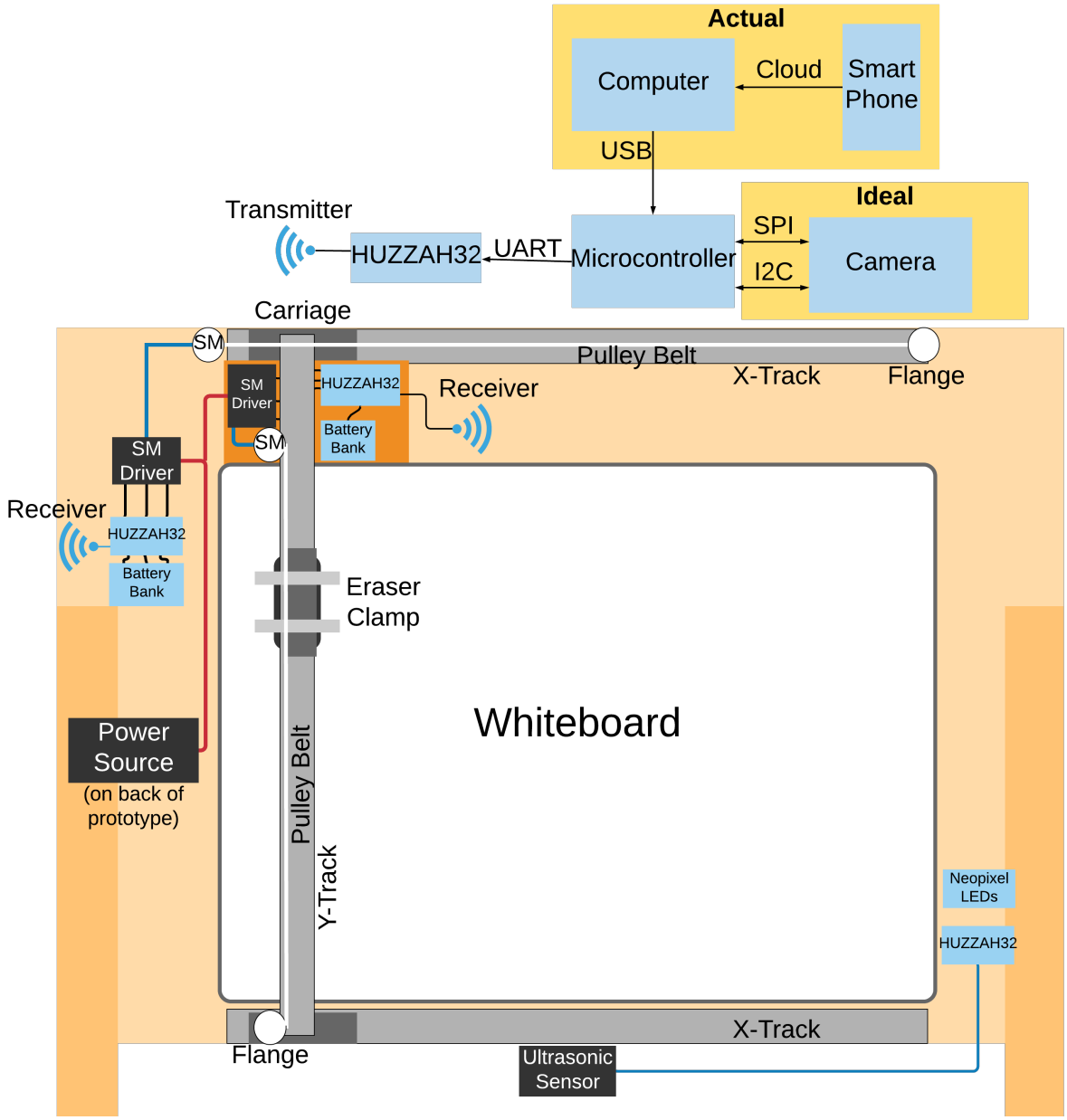


Fig. 1: Design overview of the final product

Figure 1 shows an overview of the final deliverable's mechanical and electrical components assembled with names of each item. These components and a small description of their role are listed next. For a more detailed description of each component and its role, see the *Project Description and Boundaries* section of this report.

- *Camera*: the Arducam ideally would have captured an image of a predefined (fixed) area on the whiteboard.
- *SPI*: Serial Peripheral Interface is one of two communication protocols that would have been used to communicate with the camera through the microcontroller and trigger a capture of an image.
- *I^2C*: Inter-Integrated Circuit is the other of two communication protocols that would have been used to initialize the resolution and compression type of the image that is being captured by the camera.
- *Smart Phone*: the device that takes an image of the whiteboard for the image processing program.

- *Cloud*: the method of transferring the image taken by the smart phone to the computer that changes its format.
- *Computer*: the system that changes the dimensions and format of the image in order to prepare it to be processed by the microcontroller.
- *USB*: the method of transferring the newly cropped and formatted image to the microcontroller.
- *Microcontroller*: the PSoC 6 microcontroller receives the image of the markings on the whiteboard and performs image processing to turn the image to grayscale, then uses sobel edge detection to convert where there are markings on the whiteboard to an array of 0s and Fs (with 0s representing black, blank space and Fs representing white, marked space). It then traverses the array of edges that have been detected and finds the top-most, left-most, bottom-most, and right-most locations of the markings. These four values are put into an array that is sent to the HUZZAH32 board.
- *UART*: serial communication protocol that transfers instruction data between the microcontroller and the HUZZAH32, which sends the instructions to the stepper motors.
- *HUZZAH32*: acts as an intermediary device for the microcontroller and the stepper motors, and acts as the wireless transceivers that allow wireless communication of information between the PSoC 6 board and the stepper motors.
- *Transmitter*: also known as the server, reads in the stepper motor instruction array of top-most, left-most, bottom-most, and right-most values from the microcontroller and sends them sequentially to the stepper motors via a wireless connection.
- *Receiver*: also known as the client, receives the instructions sent by the transmitter and uses an algorithm to create a serpentine-like path from the instructions that the stepper motors will understand and follow. The receiver also controls the stepper motor movement itself.
- *Battery Pack*: mobile battery unit that is used to power the HUZZAH32s on the receiving end.
- *SM*: stepper motors that allow the eraser to move in the X and Y axis directions. The stepper motors are connected to flanges on the opposite side of their axes with a pulley belt to allow movement.
- *SM Driver*: regulates the voltage, current, and rotation instructions for the stepper motors, allowing them to move the way they should with little to no risk of burnout.
- *Flange*: connects to the stepper motors via a pulley belt in order to allow movement.
- *Pulley Belt*: the belt that wraps around the flange on the stepper motor and the other flange attached opposite to the stepper motor that moves the system.
- *Carriage*: component within the track that actually moves back and forth. The carriage connects to the pulley belt that runs between the stepper motors and the flanges via washers and nuts. This connects the devices that need to move to the parts that do the movement.
- *X-Track*: the two tracks that allow the eraser to move in the X-axis direction.
- *Y-Track*: the track that allows the eraser to move in the Y-axis direction.
- *Eraser Clamp*: metal braces and brackets that clamp to the eraser and connect it to the Y-axis carriage in order to move it.
- *Whiteboard*: surface that is written on and erased.
- *Power Source*: an extra power source, besides the battery packs, which is attached to the back of the finished system. It is used to power the stepper motor drivers, and in turn, also powers the stepper motors themselves.
- *Ultrasonic Sensor*: sensor that detects changes in proximity to it. It is used as a safety precaution to those who may be standing too close to the board while it is moving.
- *Neopixel LEDs*: LEDs connected to the ultrasonic sensor that flash green when no one is close to the board, and red when someone is standing too close to it.

A. Work Distribution

Heather Libecki was responsible for being the project manager of the Smart Eraser project. She was in charge of the stepper motors and all of their various components, including their drivers, and connection

between the motors and the microcontroller, as well as the code that was written to move them. She also created the wireless connections between the receiver stepper motor HUZZAH32 boards and the transmitter HUZZA32 board. She also had Chris' assistance with writing the code for the wireless communication, as he was more experienced with Micropython. Finally, she was in charge of the algorithms used to find the outer-most edges of the markings on the board based on the array Chris got after processing the image, and using these to create instructions for the stepper motors so it would move the eraser to the markings found on the whiteboard, and erase them in a serpentine-like pattern before moving back to its standby position. Therefore, she was in charge of the setup of the stepper motors, the movement of the Smart Eraser, and the wireless communication between the receiver HUZZAH32 attached to the stepper motors and transmitter HUZZAH32, which got the instructions to where they needed to go.

Chris Quesada was in charge of the research into and understanding of the PSoC 6 microcontroller, including its comprehensive Integrated Development Environment (IDE). He was then responsible for developing a working SPI and I^2C communication between the PSoC 6 and the camera that was ideally going to be used. The I^2C communication was used to configure the image sensor to output RGB565 with a 320x240 resolution, and the reading of the image data was done with SPI. After an image was received, he developed an image processing program which takes in an image, converts it to grayscale, then uses a sobel edge detection algorithm to detect edges of objects in the image. To know if this algorithm worked correctly, he had to set up the PSoC 6 to display images on the included TFT display. He headed the creation of the UART communication between the HUZZAH32 and the PSoC 6 with assistance from Juan. To allow for easier program management, he was in charge of adding virtual memory to the PSoC 6 to allow for an entire image to be processed, rather than parts of the image. Therefore, he was in charge of the image processing brain behind the Smart Eraser, configuration of the PSoC 6 hardware, graphical display of image, addition of virtual memory, and any wired communications to and from the PSoC 6.

Juan Colin was in charge of the initial conception, design, and execution of the physical mechanical system and its interconnections. He was also in charge of drafting and making the wooden prototype stand and mounting all of the components together so as to ensure spacial efficiency and visual impact. He also assisted in setting up the Arducam via an Arduino platform to analyze the SPI and I^2C signals being sent from the camera. He also created a program on one of the HUZZAH32 boards that would connect to an ultrasonic sensor in order to detect if people were standing to close to the whiteboard while it is moving. Therefore, he was in charge of the entire physical prototype construction of the Smart Eraser, as well as the safety precautions advertised by the board to those around it.

During the project's life cycle, there were a number of deliverables that needed to be submitted to Dr. Stillmaker which were worked on by all three members to ensure a consistent flow of information throughout all written documentation, including the Project Charter and this report.

II. Project Objectives and Success Criteria

This section describes the objectives of the Smart Eraser. A more detailed description of the project can be found in the *Project Description and Boundaries* section of this report.

A. Main Objectives

The main objectives the Smart Eraser have are listed next.

- Create a functioning mechanical system that allows the eraser to move in the x and y plane in order to erase the entire whiteboard.
- Create a functioning Smart Eraser that erases detected markings in a timely manner.
- Create an image processing program to detect said markings on the whiteboard.
- Create a coordinate system based on the processed image to move the eraser to specific markings.
- Create an algorithm to determine a path for the stepper motors to take in order to eraser all markings.
- Create a motion-detection program to check for people too close to the whiteboard while the system is in motion.

B. Simple success criteria

The specific criteria that need to be met in order to consider this project a success are listed next. These criteria help to measure the success of the final product. Simple success criteria are first listed which describe the tangible goals for the project to be considered a success. Then more ambitious success criteria that describe a more ideal version of the project are listed, which include additional features that would have been added if there was more time after the completion of the simple success criteria.

1) Completed:

- The tracking system moves the eraser to all parts of the whiteboard.
- Eraser erases the entire whiteboard with no smart processing.
- Location of markings in an image are found through an edge-detection image processing program.
- Image captured can be processed to find markings on board.
- Array with locations of markings can be converted to stepper motor rotations to move eraser to proper destination.
- Image processing program on microcontroller works with the image taken to find the markings on the whiteboard.

- Motion detection is utilized for safety precautions to warn those standing too close to the whiteboard.

2) Not Completed:

- Shortest path determined through Dijkstra's analysis of the array with the marking locations.
  - This was unable to be completed within the allotted time. An alternative algorithm that erases the markings within a boundary in a serpentine-like pattern was used instead.
- Camera connects wirelessly to the microcontroller then stores it to its SDRAM.
  - It was determined that the hardwired camera prototype needed to be abandoned; because of the outputted format of the camera to the microcontroller being JPEG rather than RGB565, the connection between the two wound up being more complicated than originally anticipated. The "camera" wound up being a smart phone image which was cropped, converted to RGB565 format, then sent into the image processing program.

C. Ambitious success criteria

Ambitious success criteria detail functionalities that would have been completed if there was more time to work on the project.

1) Completed:

- Unfortunately, because not all of the simple success criteria were completed, none of the ambitious success criteria were able to be started.

2) Not Completed:

- Phone or tablet application that shows a live feed of the whiteboard from the camera
  - Application can send specific coordinates to the whiteboard to "pick and choose" what section of the board to erase.
- Attachable spray system applies whiteboard cleaning liquid solution to perform "full clean" of whiteboard.
  - Timer tells eraser to perform a "full clean" during the night when no one is using the classroom.
- Eraser can be raised off of whiteboard surface and subsequently re-pressed onto the board as needed.
- Store images each time the board gets erased to provide the teacher with the class notes for the day.
- Add remote control capabilities to control eraser at-will.
- Smart Eraser patent.

III. High-Level Requirements

The high-level requirements associated with the completion of this project are outlined in the following list.

The project should:

- Be completed within the outlined budget.
- Be implementable within 2 semesters.
- Be complex enough to warrant the title “senior design project”.
- Produce a complete Project Charter outlining the various project information, figures, and tables of the Smart Eraser.
- Have significant, roughly equal portions of the project be completed by each team member.
- Utilize material learned in core and technical elective classes throughout college careers.
- Produce a Final Project Report outlining all information needed to be met for the project, as well as all analysis, design, and result information received during the completion of the project.
- Produce a deliverable that can be presented in the Senior Project Presentation Day event held in the Satellite Student Union building.

IV. Assumptions, Constraints, and Standards

This section outlines the various assumptions that were made for the requirements of this project based on previously learned course information, the constraints the project had during its conception, and the standards that were used and followed throughout the completion of this project.

A. Assumptions

The Smart Eraser was the first large-scale project that the students involved had worked on. Therefore, there were many assumptions made about the components that would be used to complete it, the skill-set and course information needed to complete it, and the amount of time it would take to actually complete the project. Some of the major assumptions made that wound up not being followed included the budget outlined, using the DE1_SoC microcontroller for the main brain behind the Smart Eraser, using the Raspberry Pi microcontroller with wireless transceivers for the wireless communications, and the amount of time it would take to put together the wireless communication system. Because the first attempt at creating the wireless system ended in failure, a new system had to be conceptualized and created from scratch with 3 weeks left before the due date of the final working product.

B. Constraints

A few of the constraints foreseen at the beginning of the project were the additional power supplies needed to make the stepper motors and their drivers operate without having to constantly change batteries, and how the power is supplied to the system, especially the moving components. These were solved with an additional power supply and a long cord going to the stepper motor drivers and a battery pack for the moving HUZZAH32 board.

C. Relevant Information Learned from Past Courses

The following list outlines the relevant courses and the material they contain that were used throughout the project’s lifecycle.

- ECE 70 - Engineering Computations
  - C programming
- ECE 85 - Digital Logic Design
  - Developing PCB for stepper motor connections
  - Any state diagrams needed for logic between processes

- ECE 90 - Principles of Electrical Circuits
  - Developing the power scheme and parameters for the stepper motors, stepper motor drivers and track system
- ECE 106 - Switching Theory and Logical Design
  - Developing flow charts and block diagrams of the overall system
- ECE 118 - Microprocessor Architecture and Programming
  - Recursion programming and algorithms developed for shortest path
  - Determining how to store memory in a microcontroller
  - Working with GPIO connectors on a microcontroller
  - Using stepper motors, their drivers, and an additional power supply to operate the motors with a microcontroller
  - Programming push-buttons on a microcontroller
- ECE 122L - Micropython Lab
  - Setting up the wireless communication on the specific HUZZAH32 microcontroller board chosen to be the wireless transceivers for the stepper motors.
  - The Python language that is used to program the HUZZAH32 microcontroller board.
- ECE 146 - Computer Networks
  - Wireless connection between systems and how data is transferred over this connection
- ECE 174 - Computer Architecture and Organization
  - Knowing how memory is set up and the different methods of accessing it for the storage and access of the image taken from the camera.
- ECE 178 - Embedded Systems
  - Development of algorithms
  - Basic foundation of and general layout of hardware in microcontrollers, as well as the IDE that is specific to it
  - Interfacing with peripherals on the microcontroller
  - UART, SPI and I^2C communication

Based on the courses provided in the previous list, the following information was extracted from the knowledge gained while taking these classes over the last 3-4 years. Because the following information is from notes taken during these courses, there are no sources provided for where it was learned. More in depth research obtained from external sources and their references are located in the *Project Description and Boundaries* section of this report.

1) Data Storage: The images taken from the camera need to be saved to the microcontroller in order to allow the image processing program to access them. Due to knowledge gained from the *Computer Architecture and Organization* class, attempts at adding memory were made in order to account for the minimal memory provided by the 1 MB of flash. However, after ample time was spent trying to get it to work, this was abandoned in order to focus on delivering a working prototype that met our simple success criteria. Because virtual memory was not able to be added, only the flash memory was used to run our entire system which led to design changes in our algorithms. For example, only 80 rows of pixels could be stored in an array during a given processing cycle. This means that one-third of the image is processed at a time and then overwritten by the next one-third instead of being able to process all image data at once.

2) Translate Detected Markings into Coordinate System (Stepper Motor Rotations): Through team collaboration, it was decided that each stepper motor rotation would represent one pixel length. This is how a coordinate system can be developed. For example, if the image processing algorithm picks up a mark that is 56 pixels from the left of the image, and 178 pixels from the top of the image, this would result in 56 partial rotations to the right on the x-axis motor and 178 partial rotations down on the y-axis

motor. Further testing determined the partial angle of rotation needed to represent one pixel length, and is discussed further in the *Stepper Motor Movement* sub-subsection of *The Current Wireless Communication System* subsection of the *Analysis and Design* section of this report. In order to line up the physical layout of the board with a 320x240 image window, indicators are placed on the board in order to know where the image area actually is.

3) Stepper Motor System Design: The stepper motors themselves have 6.35mm teeth bore flanges. These "teeth" are used to grip the pulleys that drive the movement of the linear motion system. In order to rotate the stepper motors. Specific stepper motor drivers (DM542T) are used in order to drive them. This stepper motor "system" is designed on a PCB in order to minimize odd connections and loose wires in the final product. Also attached to these stepper motor system's PCBs are an Adafruit HUZZAH32 Feather Board microcontroller that receives the instructions needed to make the stepper motors rotate the desired distance.

4) Microcontroller Involvement: The process of learning the hardware and IDE of a microcontroller, which was gained from the Embedded Systems course, was implemented with the PSoC 6 microcontroller. Their IDE, Modus Toolbox, is an all-in-one hardware configurator, debugger, and program downloader that is based off Eclipse. The hardware configuration is very straightforward when compared to other programs like Quartus and makes developing and implementing a system much easier with everything in one place. The programs are written in C and any hardware designs that are generated create structures that can be used with provided API's(functions and macros) in order to interact with said hardware. Development of the C programs used in the system took experience gained from the Engineering computations class to employ modular programming and a more optimized flow.

5) Shortest Path Algorithm: The original plan to create a shortest path algorithm came from the knowledge of Dijkstra's algorithm gained from the *Computer Networks* course. This idea was abandoned, however, due to the time constraints on the project. An algorithm that finds the outer-most edges of the markings on the whiteboard, then erases the markings in a serpentine-like pattern was chosen instead.

6) Image Processing: One of the main components of the Smart Eraser is its image processing capabilities. The PSoC 6 is fed an image through a wired SPI and I^2C communication with the camera and store that image in memory. Once the image has completed its processing and the array of the image data needs to be sent to the HUZZAH32, it does so through a UART serial connection to the board. All of these methods of communication were learned in the *Embedded Systems* course. The rest of the image processing algorithm and other information pertaining to it had to be researched outside of the course information learned.

7) Wireless Connectivity: The instructions for the stepper motors need to be received wirelessly from the PSoC 6. The chat room program that was assigned in the *Computer Networks* course was used as a template for the wireless transmission of these instructions between the transmitter HUZZAH32 and the two receiving HUZZAH32s. This program was made with the MicroPython programming language, and was also used as an assignment in the *Micropython Lab* course.

8) Ultrasonic Sensor Proximity Detection: One of the original goals for this project was to have a motion detection system to detect if a person was moving in front of the whiteboard. Rather than detecting motion, however, the ultrasonic sensor that is used in the project detects a change in proximity of an object to the sensor. Therefore, if it detects an object to be a specified distance away, it will warn the object that it is getting too close to the system. The Micropython and mechanics behind the sensor were learned about and used in the *Micropython Lab* course.

Additional research pertaining to these topics and how they were implemented in the project are in the *Project Description and Boundaries* section of this report.

D. Standards

Based on the components and parts that were used in this project, the following standards were found to apply, and were followed during the creation and implementation of the Smart Eraser.

- IEEE 802.15.3e-2017 - IEEE Standard for High Data Rate Wireless Multi-Media Networks–Amendment 1: High-Rate Close Proximity Point-to-Point Communications
  - Applies to the wireless communication and data transfer between components in the system [26]
- IEEE Editorial Style Manual
  - Standards to follow when writing this Project Charter and any other reports that were written for this project [27]
- NEMA Standards Publication ICS 16 Motion/Position Control Motors, Controls, and Feedback Devices
  - Applies to the stepper motors being used and their operation [28]
- SPI Communications
  - Defacto standard
- I^2C Communications
  - Defacto standard
- ITU-R Recommendation BT.709
  - Applies to the coefficients used in the grayscale algorithm conversion [29]
- RS232 Serial Communications standard
  - Applies to the UART communication between the PSoC 6 and HUZZAH32 [30]

V. Project Description and Boundaries

This section contains a list of the major and minor components that are used in this project, as well as a quick overview of each of these components and how they play a role in the Smart Eraser project, and some boundaries that were overcome in order to ensure the success of this project. For a more detailed description of the procedure followed and the actual implementation of each part, see the *Analysis and Design* section of this report.

The following lists contain the major and minor components used in this project. More details about each major component's specifications and model numbers can be found in the *Equipment and Budget* section of this report.

A. Major Components

- PSoC 6 Development Kit
- Arducam
- Stepper motors
- Stepper motor drivers
- HUZZAH32 boards
- PCBs
- Rechargeable 9V batteries
- Linear motion tracks (X & Y direction)
- Linear motion carriages (X & Y direction)
- Timing belt
- Timing belt pulley flange

- Eraser
- Whiteboard
- Logic analyzer
- Ultrasonic sensor

B. Minor Components

- Wire jumpers
- Stepper motor mounting brackets
- Various screws, nuts, and bolts
- Wooden plywood board (for mobile prototype)
- Wooden frame (for mobile prototype)
- Wheels (for mobile prototype)

C. Software Components

1) SPI Communication: SPI communication is used in order to talk to the SPI interface of the Arducam-5MP- mini- plus. The PSoC 6 acts as the master and the Arducam acts as the slave. In order for successful communication between the the two, the PSoC 6 needs to send a command byte where the MSB is either a 1 for 'write' or 0 for 'read' and the other 6 bits represent an address in the Arducam. If the command bytes sent is a write command, the byte sent directly after is the data to be written to the register address. If the command byte sent is a read command, the byte sent directly after does not matter, often referred to as a dummy byte. The purpose of the SPI communication is to initiate captures from the image sensor and to then poll register 0x41 for a capture complete signal of 0x08. Once a capture complete signal has been read, transferring of the image data can ensue. These processes are shown in the following figures.

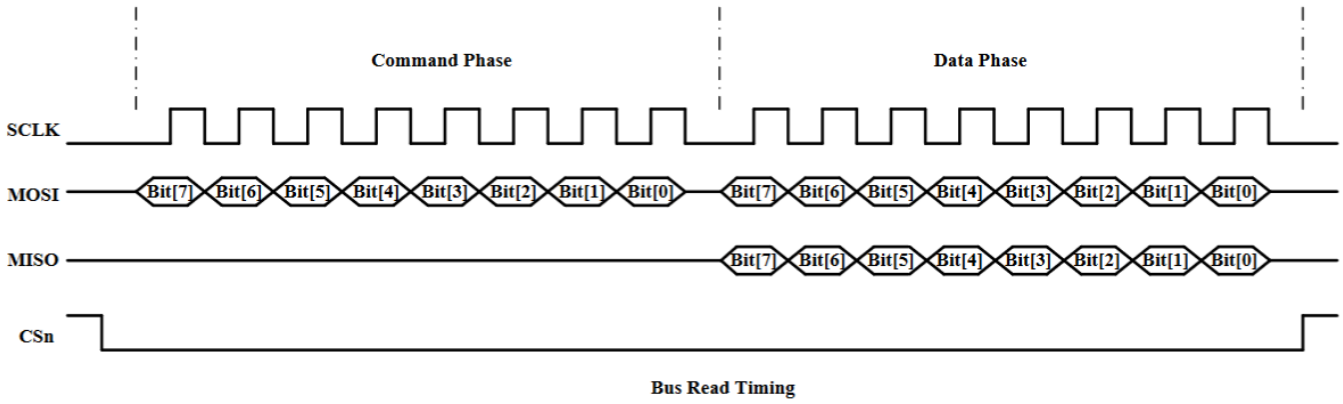


Fig. 2: Bits corresponding to a system SPI read [1]

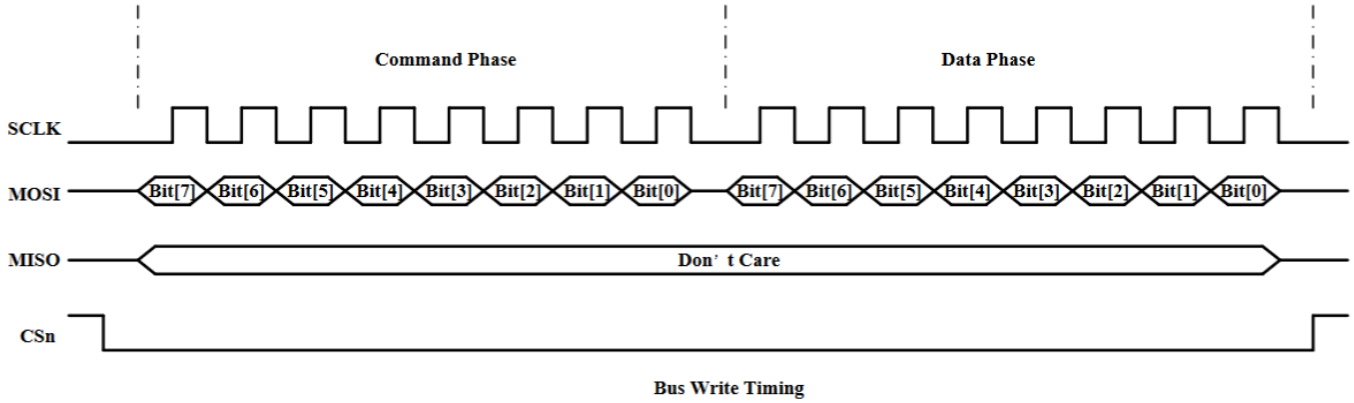


Fig. 3: Bits corresponding to a system SPI write [1]

2) I²C Communication: The purpose of including I²C communication is both to initialize and configure the image sensor of the Arducam-5MP-mini-plus. The figure below provides and example I²C exchange between a master and slave where the master is the PSoC 6 and the slave is the Arducam. The information provided from Arducam is slightly incorrect, as most developers incorrectly provide an 8-bit slave address when it should be a 7-bit. The correct address is 0x3C where a read/write bit is added on by the microcontroller. So, if its a write operation the slave address would be 0x3C plus a write-bit(0), making the slave address 0x78 (0x3C with a zero bit added onto the front of the LSB equals 0x78) and the same applies to a read operation which adds a read-bit(1). This means that there is only one slave address and not separate addresses for read and write operations.

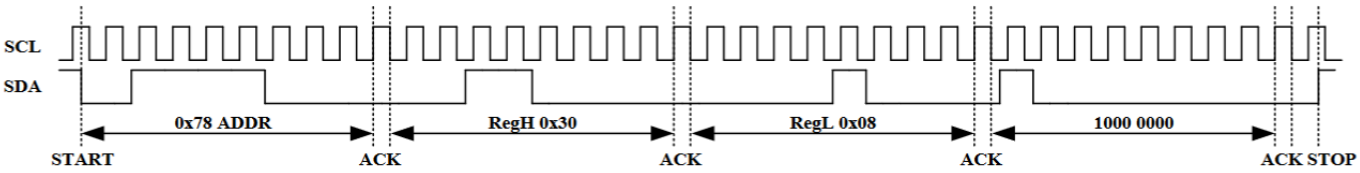


Fig. 4: Bits corresponding to a system I²C write [1]

3) UART Communication: The communication of choice between two micro controllers is often UART as it allows for the simplest method to communicate. Since there is no master and no slave packet transmission is done through a 1 receiver and a 1 transmitter.

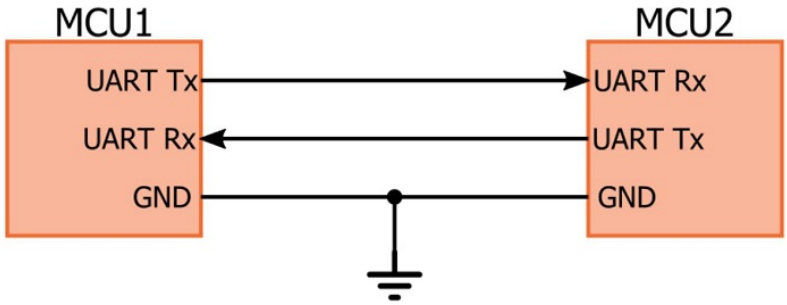


Fig. 5: UART Communication [2]

4) Grayscale Conversion from RGB565: In order to detect objects in an image, the image needs to be converted from RGB to grayscale. This is because the result of the sobel detection algorithm compares

light intensity changes against a threshold value. Using RGB pixel information does not provide a way for the intensities to be correctly compared because the R, G, & B values are used to depict color and not to represent light intensity. By converting to grayscale you are creating an intensity value from the pixel information on a scale from 0-255. This can be done by using the grayscale luminance conversion algorithm which assigns weights to each value (R, G, & B) using coefficients from CITE BT.709 :

$$Gray = (Red \times 0.2126 + Green \times 0.7152 + Blue \times 0.0722)$$

However, before this algorithm can be used, the red, green, and blue intensities need to be separated from the 16-bit value and shifted to an 8-bit scale, hence the name RGB565. Bits[15:11] represent red intensity, bits[10:5] represent green intensity, and bits[4:0] represent blue intensity.

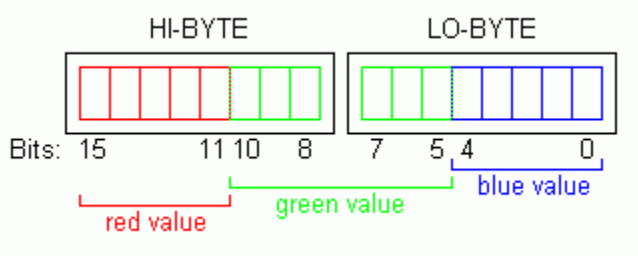


Fig. 6: How an RGB565 pixel value is stored in memory [3]

5) Sobel Edge Detection: After grayscale pixels have been generated, a sobel edge detection algorithm is used in order to detect edges in an image. This is done by convolving sobel kernels, one vertical one horizontal, through the array of gray pixels. This is shown in the following figure. By doing this, you can find the gradients in both the X and Y direction which is eventually be used in the Pythagorean Theorem to determine the magnitude of the gradient at that pixel location. The magnitude value is then compared against a threshold value (this threshold value can be altered to fit one's needs).

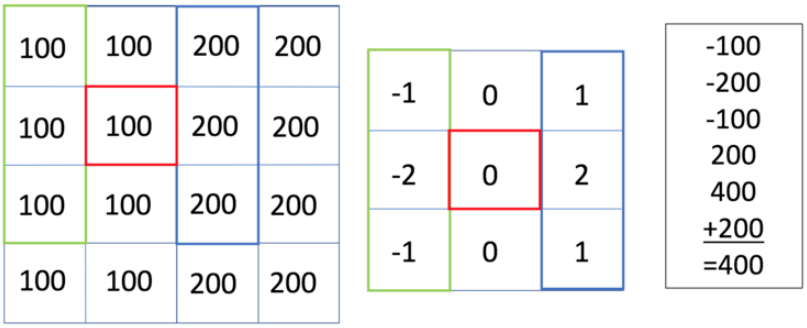


Fig. 7: Kernel convolution used in sobel edge detection [4]

6) Socket Programming for Wireless Communication: Due to malfunctioning hardware concerning the Arduinos and the Kuman wireless transceivers, the original idea for the wireless communication system had to be abandoned. The new concept is to use the HUZZAH32 Feather boards as the wireless transceivers that send and receive instructions for the stepper motors to execute. These boards can be programmed with either Micropython or Arduino programming languages, but in this project, they use Micropython to perform their tasks. One HUZZAH32 board is initialized as a transmitter (server) that connect to the PSoC 6 via an UART connection and receive the stepper motor instructions, then send these instructions to the stepper motors. Two other HUZZAH32 boards act as receivers (clients); one is attached to each stepper motor, and they receive the instructions for the stepper motors. They then give them the directions to move according to the instructions received.

The following figure shows an example of a client-server interaction using socket programming. First a socket connection is created between the client and server. This establishes a connection between the two entities so they are able to communicate with one another. On the server side, the socket must be bound to the server's IP address, and then issued a command to listen for incoming connections. Once the client sends a request to connect, the server accepts the command if the proper authorization is followed. In this project's case, a password and server name was created to ensure no other connections could be made to the system when it was being presented on Projects Day. After the two systems have connected, they enter a client/server session where they can communicate and send data between each other. However, once a "close" signal is sent to the server, or when a file has completed transmission (this depends on how the cease to connect condition is set), the server finishes reading the data sent, sees the "close" command, then closes the connection between the two entities. To learn more about the actual implementation of this type of programming and how it was used in the project, see the *The Current Wireless Communication System* subsection of the *Analysis and Design* section of this report.

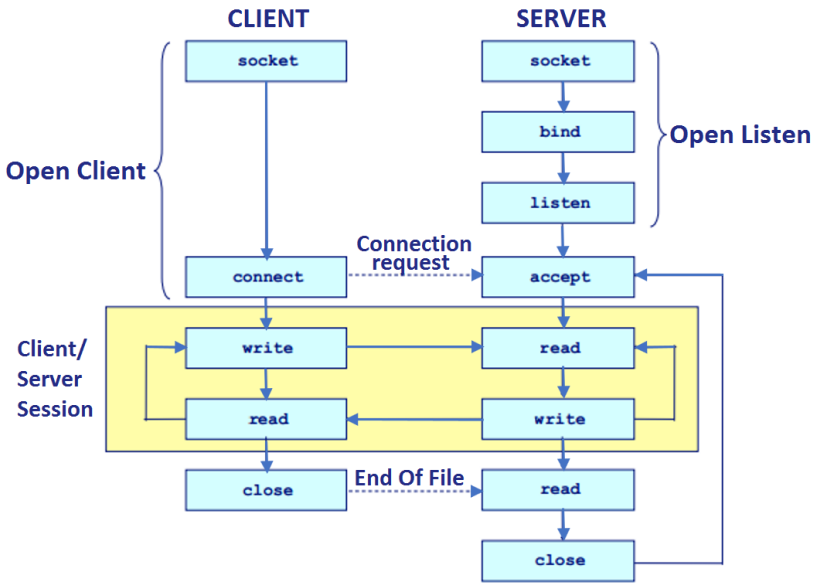


Fig. 8: Socket communication protocol between server and client [5]

7) Stepper Motor Operations: In order for the stepper motors to move, they must be programmed to receive the correct signals at the correct time to move the magnetic coils within the motor properly. They were programmed in Micropython and connected to the HUZZAH32 boards, which provides the necessary signals to allow the motors to move. Figure 9 shows the different steps and signals that need to be sent along the 4 leads connected to the internal magnetic coils in order to rotate them CW (clockwise) and CCW (counter-clockwise).

FULL STEP 2 PHASE-Ex. ,
WHEN FACING MOUNTING END (X)

STEP	A	B	A\	B\		CCW
1	+	+	-	-	↓	↑
2	-	+	+	-		
3	-	-	+	+		
4	+	-	-	+	CW	

Fig. 9: Rotation instructions for the stepper motor [6]

The motor moves when these steps are sent to their corresponding lead connections to the stepper motor drivers in a sequential order. The factor that determines how quickly the motors turn in the code that was written is how quickly the steps are traversed through when they are sent to the drivers. I.E., the faster they are traversed, the faster the motor will spin, and visa versa.

8) Moving the Eraser to the Markings: In order to move the stepper motors to the markings on the whiteboard, there are two algorithms: one detects the outermost edges of the markings, which essentially creates a "square" surrounding the markings, and the other creates a serpentine-like path within the square in order to eraser the markings. Figure 10 shows the concept behind these two algorithms, if the whiteboard was divided into an 8x8 matrix. Figure 11 shows the flowchart of the *square_detection.c* program that detects the square around the markings, and Figure 12 shows the flowchart of the *serpentine.c* program that moves the eraser to erase the markings.

In order to create the correct rotation sequence for each motor, the serpentine code had to be split into two separate files for each motor and modified accordingly. For more information on this implementation, see the *The Current Wireless Communication System* subsection of the *Analysis and Design* section of this report.

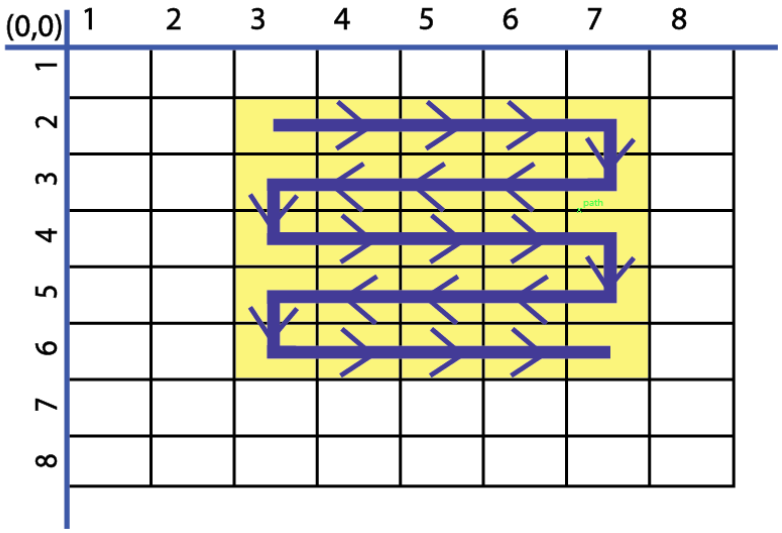


Fig. 10: Concept behind the two algorithms that move the eraser to the markings

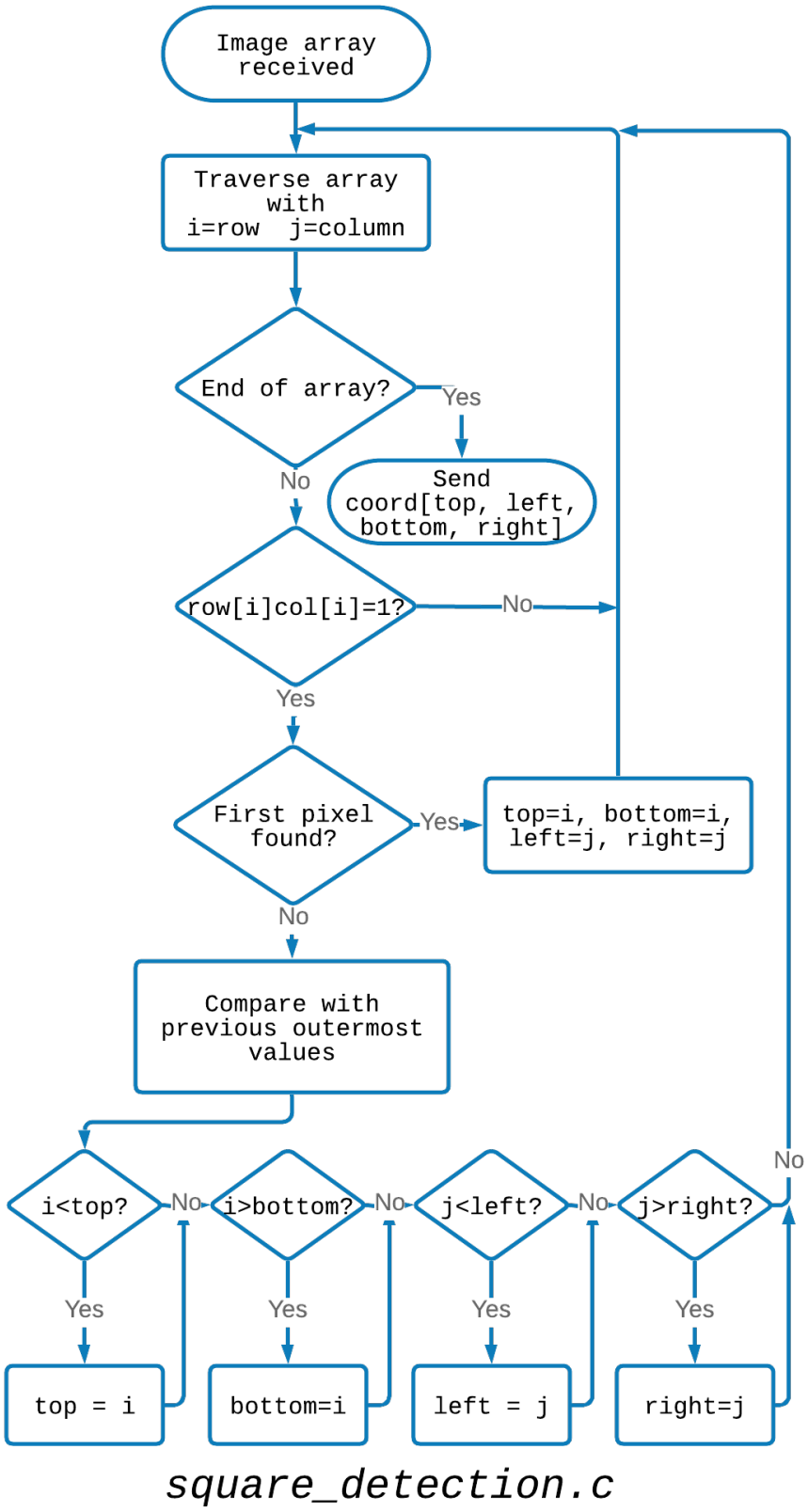


Fig. 11: Flowchart of the logic behind the *square_detection.c* program

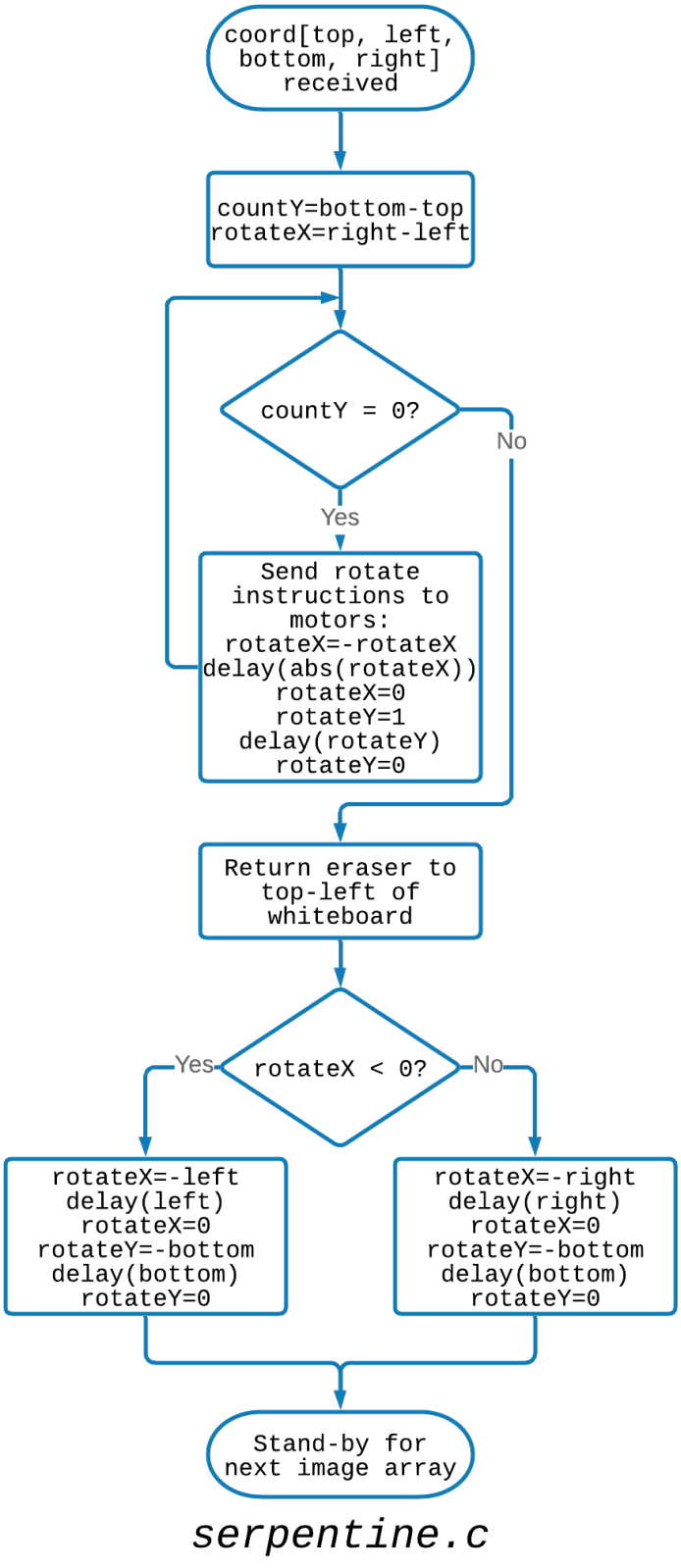


Fig. 12: Flowchart of the logic behind the *serpentine.c* program

9) Proximity Sensing Using the Ultrasonic Sensor: The Ultrasonic Sensor is able to detect changes in distance up to 4 meters. The original thought was to use these changes in distance to interrupt the eraser

during its serpentine function. This was to be a safety feature but currently it only displays red if a user is too close to the board while it is erasing.

Fig. 13: Ultrasonic sensor [7]

D. Physical Technological Components

1) Arducam: The camera is the input that drives the functionality of the rest of the system. It provides high enough quality for future improvement, but for the purposes of this project, only a 320x240 resolution is needed. The current design has the camera directly connected to the PSoC 6 microcontroller through SPI and I^2C communication to both configure the image sensor (I^2C) and initiate data transfer (SPI). Although it is referred to as a camera it is more accurately defined as a module which has an I^2C interface to configure the image sensor and a SPI interface to handle data transfer.

Fig. 14: The Arducam Mini Module 5MP OV5642 Camera [6]

2) PSoC 6 Microcontroller: Due to the processing capabilities that the Smart Eraser needs to be able to accommodate, and due to the peripheral devices that need to be attached, the PSoC 6 was found to be the ideal microcontroller to use for the computations fo the mechanism. The PSoC 6 not only allows for the straightforward programming of peripheral devices attached to it, but it also has a dual -core processor built into it which can handle the programming that needs to be done for the Smart Eraser to work as intended. Within the PSoC 6 are Serial Control Blocks(SCB) which can be configured to suite the projects needs, whether it be I^2C, SPI, or UART. The SCB is the gateway to both the Arducam and HUZZAH32. There is also a TFT display attached to the microcontroller that allows for viewing of any image captured and any image processing results. Finally, SW2 is used to initiate the process from capture to erasing.

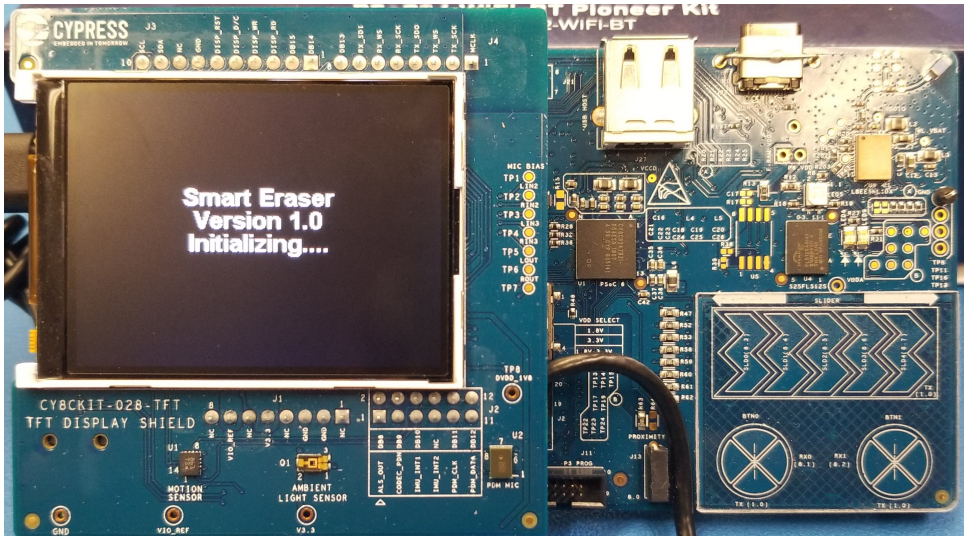


Fig. 15: The PSoC 6 microcontroller by Cypress

3) Stepper Motors: The stepper motors allow the eraser to move along the track and linear motion systems that are mounted to the wall above and below the whiteboard. Because of the weight of the components chosen to move along the track, a stepper motor with enough power and torque to move said components is needed. With this in mind, the NEMA 23 CNC Stepper Motor (with 1.26Nm holding torque, 1.8 degree step angle, 2.8A rated current per phase, 0.9âĎę resistance, and 24-48V driving voltage) was chosen for the Smart Eraser. It is connected via jumper wires to the stepper motor drivers that allow their movement. These require additional power, and this power is supplied via three 9V rechargeable lithium batteries, which is connected through the PCB that was created for the stepper motor connections.

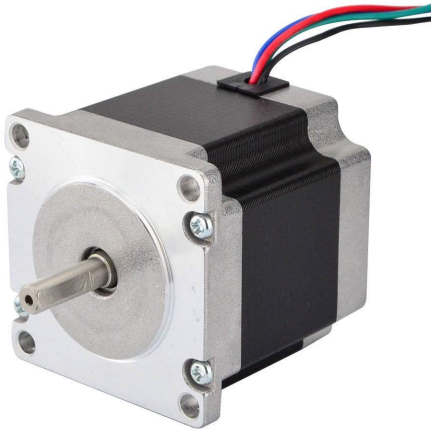


Fig. 16: 4-lead bipolar NEMA23 stepper motor [8]

4) Stepper Motor Drivers: The stepper motor drivers are an intermediary device between the stepper motors and the PCB. The drivers need to specifically work with the stepper motors that were chosen. Therefore, the stepper drivers that are used for the NEMA 23 stepper motors is the Full Digital Stepper Driver, model number DM542T. This model was not only chosen due to its compatibility with the NEMA 23 model stepper motors, but also because of its capabilities to drive the motors at lower noise, with lower heating, and with smoother movement. Like the stepper motors, the drivers need additional power, and they receive it through the PCB via three 9V rechargeable lithium batteries.

The table in Figure 17 shows the correct parameters for the drivers that need to be kept in mind when the additional power is connected to them via the PCB, and the table in Figure 9 shows the specific ports

that need to be driven by a high voltage value in order to allow the motor to actually rotate clockwise or counterclockwise.

Parameters	DM542T			
	Min	Typical	Max	Unit
Output Peak Current	1.0	-	4.2 (3.0 RMS)	A
Input Voltage Logic	+20	+36	+50	VDC
Signal Current Pulse	7	10	16	mA
input frequency Pulse	0	-	200	kHz
Width	2.5	-	-	uS
Isolation resistance	500			MΩ

Fig. 17: Limited parameters of the DM542T stepper motor drivers [9]

5) HUZZAH32 for Stepper Motor Wireless Communication: The HUZZAH32 by Adafruit is the main communication hardware for the stepper motors. The transmitter board is physically connected to the PSoC 6, and it contain the code to send the instructions received from the PSoC 6 to the receivers. The receivers contain the necessary code to receive the instructions wirelessly, and they also act as the controller for the stepper motors to move once they have their instructions.

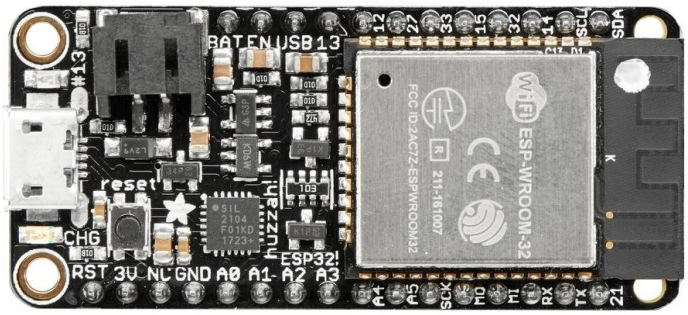


Fig. 18: Adafruit's HUZZAH32 Feather Board with ESP32 chip [10]

6) PCBs: The PCB (Printed Circuit Board) is an intermediary device between the stepper motor drivers and the Feather board, as well as the additional power that is needed to power the motors and their drivers. This PCB was created by the PCB design software DipTrace, and contains connecting pins to ensure spatial efficiency, as well as to make sure all components are connected properly. Due to the wireless system needing to be changed last minute, the PCB will not be used. However, because it is work that was put into the project, it will still be talked about in the *Analysis and Design* section of this report.

7) Additional Power: The chosen stepper motor drivers can handle a voltage input ranging from 20 - 50 V, and the stepper motors themselves can handle a voltage input from 24 - 48V. Therefore, the power source needs to be able to drive enough current to generate that range for the stepper motors. With this in mind, the 9V rechargeable lithium batteries were chosen for the additional power source when the Arduino and transceivers were being used for the wireless communication. Three of these batteries were connected in series on the PCB to provide the additional power needed to driver the motors and their drivers. The batteries can be recharged when they are depleted, which would allow them to be reused many times for the prototype as well.

Fig. 19: 9V lithium rechargeable batteries [11]

However, because the PCBs could no longer be used, additional power was gained from the TDK Lambda power supply. This supplied the stepper motors with the correct voltage.

Fig. 20: TDK Power Supply used to power the stepper motor drivers [12]

In order to power the HUZZAH32 boards, another type of power supply was used. A 5V battery bank was used to supply a reliable, long-lasting power supply. This was chosen with the length of Projects Day presentations in mind.

Fig. 21: Battery pack used to power HUZZAH32s reliably [13]

E. Physical Mechanical Components

1) Linear Motion Track System: The model 115RC linear motion track system allows the eraser to move in the x-axis direction of the whiteboard. There are two tracks mounted above and below the whiteboard, and attached to the cassettes with washers and nuts is a third track that allows the eraser to move in the y-axis direction of the whiteboard. The y-axis of the tracking system was pre-drilled at both

ends with a 7/32 inch drill bit in order to be placed on the m5 screw of the x-axis carriages. The y-axis was also pre-drilled with a 11/32 inch drill bit in order to attach the housing unit of the stepper motor system. The dimensions of the track systems and the carriages in them are shown in the following figure.

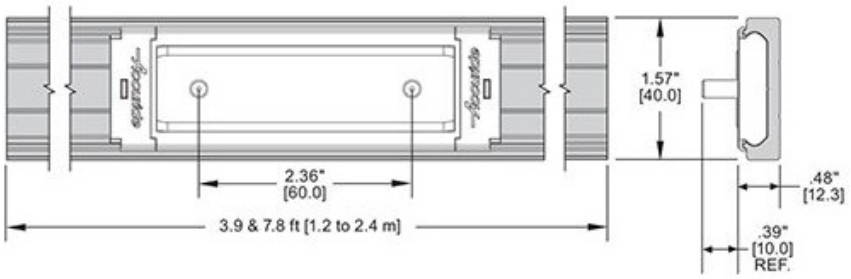


Fig. 22: Linear track system specifications [14]

2) Stepper Motor Mounts: The stepper motor steel mounting brackets are used to actually mount the stepper motors onto the track system, as well as to lift the motors off of the wood backing enough so they are above the track. This allows the pulley system to be attached correctly.

Fig. 23: Mounting brackets for the stepper motors [15]

3) Pulley System: The pulley system consists of two components: a GT2 40-teeth 6.35 mm bore timing belt pulley flange synchronous wheel, and a 5 meter long, 6mm wide GT2 timing belt. Two pulley flanges connect to either side of the track on the x and y axes, and the timing belt wraps around them. One of the flanges on each of the axes connects to the stepper motors in order to allow the belt to actually move. The belt in Figure 25 is black in order to show the details of the teeth, but the actual belt that was used is white.

Fig. 24: Pulley flange [16]

Fig. 25: Pulley belt [17]

F. Prototype Mounting Components

The following figure shows a rough view of what the final prototype will look like when it is mounted on the mobile station. The specifics components for this prototype and how it was built are explained after it.

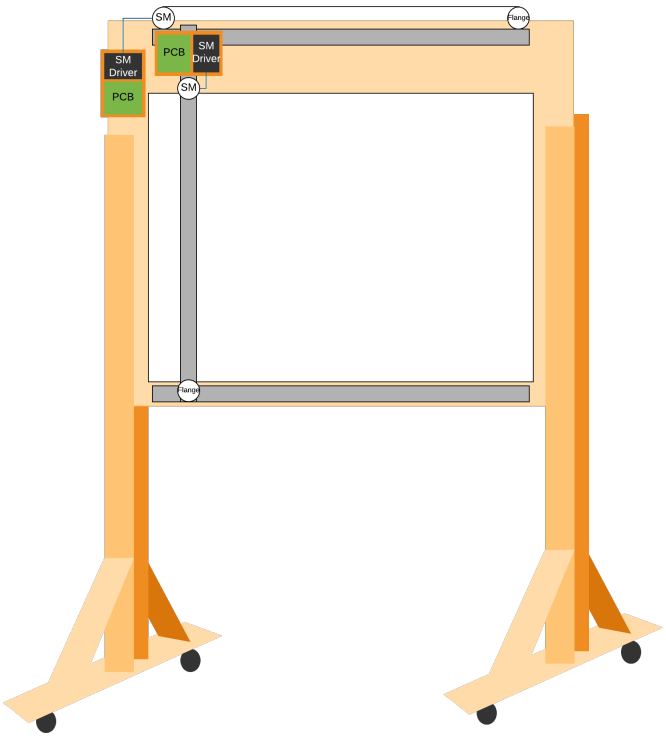


Fig. 26: Rough image of the original concept for the prototype stand

The main screws used were 3 inch T-25 star-headed screws. These were used to attach the horizontal tracks to the 2”x3” posts, which were then attached to the plywood backing of the whiteboard. These screws were also used to mount the whiteboard to the wood backing. Two 2”x3” posts were placed behind the tracks in order to give them more stability, as well as lift them off of the board enough to allow the tracks to travel in front of the whiteboard. Three more 2”x3” posts were mounted on the back of the wooden backing as well so the plywood that the whiteboard is attached to would not bow or warp due to any changes in the environment. In order to stand the board, two 2”x4” pieces of wood were placed at the bottom of the posts holding the stand up. Wheels were then attached to the bottom of this post to make the prototype stand mobile for Projects Day.

Washers and nuts were used to connect the pulley belt to the carriages on the x and y axes, which allow the eraser to move when the stepper motors rotate. Nuts and bolts were then used to connect the stepper motor system to the y axis. A metal L brace was used to mount the other flange to the opposite side of each axis from the stepper motors. Finally, braces were used to clamp the eraser to the carriage that moves across the Y axis.

The dimensions of the whiteboard prototype are shown in the next two figures. More information and details about how the system was created, built, and complete can be found in the *Project Prototype* section of this report.

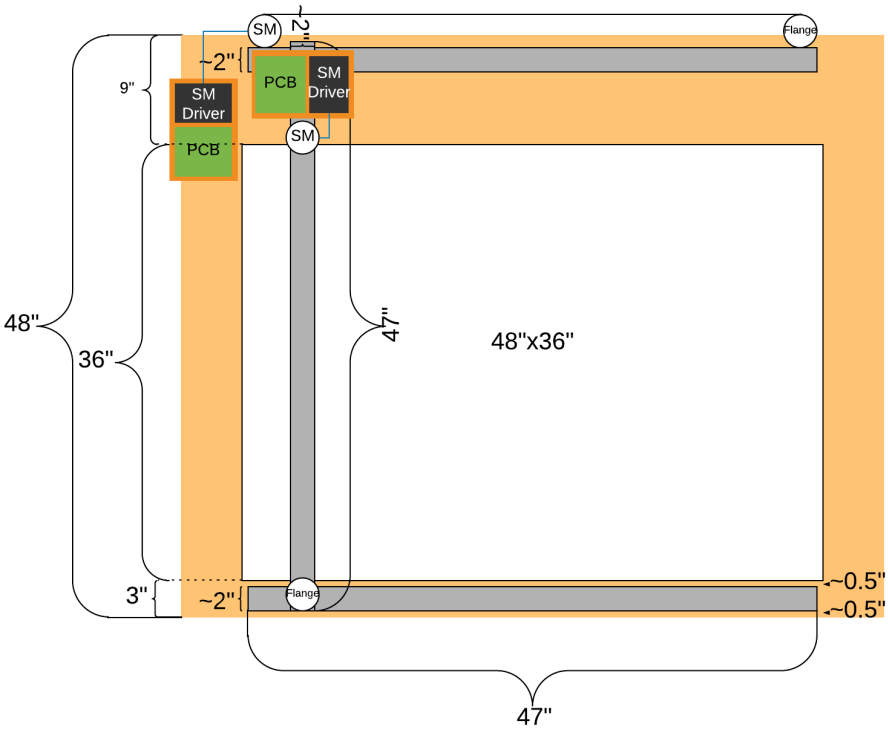


Fig. 27: Front view of the Smart Eraser system with dimensions

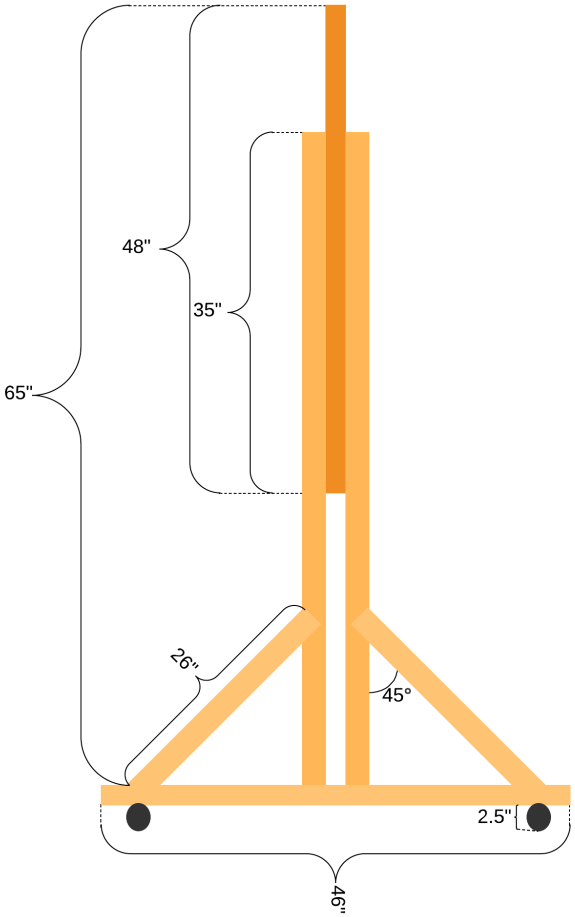


Fig. 28: Side view of the Smart Eraser system with dimensions

G. Boundaries

Because of the problems encountered with the wireless communication via the Arduino and the Kuman wireless transceivers, the wireless communication system had to be completely redesigned using the HUZZAH32 Feather boards. This is a boundary, as this part had to be completely redone with Micropython, and the PCBs that were designed for the other system were not usable, and were abandonded in favor of mounting the systems separately on the whiteboard.

Unfortunately, configuration of the camera sensor proved to be a major obstacle. It involved writing a driver from scratch that needs to configure hundreds of different registers on the Arducam-5MP-Mini-Plus to output an RGB565 image. In order to show the system working, it was possible to take a picture with a phone and run it through software to convert it to the desired resolution and output format, and pre-load it onto the PSoC 6. It should be stated that the camera does work, and based off examples from the Arducam company, JPEG image data can be received from the camera. However, due to the complexity of JPEG image data and the fact that the image processing program written is for RGB565, there is nothing that can be done with this data in the scope of this project.

H. Technical Advisor Backgrounds

Dr. Hovannes Kulhandjian, who specializes in wireless communications and networking as well as digital signal processing. He has contributed advice and information pertaining to the wireless connectivity of the camera to the image processing microcontroller. Dr. Kulhandjian was the original mind behind the idea of this project as well. Because of this, he also contributed more specifications and features to implement in the project as its completion progressed.

Roger Moore has many specialties, ranging from tesla coil winding and electrical engineering to microcontroller usage, all stemming from his various research interests. He has contributed input on components that would likely lead to the most success in this project, as well as advice on how to perform the image processing.

VI. High-Level Risks

The following list details the high-level risks of this project and what was done as a precaution against these risks in order to keep the development of the Smart Eraser safe.

- Power system malfunction causing shorts:
  - Ensure a secure connection of the power to the components from the batteries
  - Have all wired connections complete before the power is applied
  - If connections cannot be completed before power is applied, ensure that the pin will be going into the right port.
- Moving parts attached to whiteboard:
  - Always stand away from whiteboard when in motion
  - Always notify those around when it is about to start moving
  - Identify the failsafe wire to unplug in order to emergency shutdown the moving parts
  - Have a proximity-sensor system that will detect and warn someone who is approaching the whiteboard at too close of a distance
- Use of power tools to create prototype:
  - Have an experienced advisor watching over the construction of the prototype stand
  - Wear safety glasses and gloves when needed
  - Work in a well ventilated area with plenty of room

VII. Milestone Schedule

The following tables show the milestone schedule for the Smart Eraser project over the next two semesters.

Member Assign.	Start-End Date	Description
All	10/12-10/19/18	Complete Smart Eraser Project Proposal to be submitted to DPS Telecom for review.
All	10/12-10/19/18	Finalize the specifics of the budget.
All	10/15-10/19/18	Create the Project Charter rough draft to be turned in.
All	10/16-10/26/18	Draft a more detailed blueprint of the physical Smart Eraser deliverable.
All	10/16-10/26/18	Revise the Project Description; complete for future reference.
All	10/16-10/26/18	Draft the flowchart to show the logical relationships between all connected devices within the project.
All	10/18-10/19/18	Complete bi-monthly update presentation for Senior Design class.
Juan C.	10/26-11/10/18	Complete a block diagram detailing the specific connections between the devices within the project.
Heather L.	10/26-11/15/18	Research wireless communication and protocols to be used.
Heather L.	10/26-11/15/18	Research the camera and how it will send data over WiFi connection.
All	11/1-11/2/18	Complete bi-monthly update presentation for Senior Design class.
Heather L. & Chris Q.	11/1-11/21/18	Research the microcontroller to be used (DE1_SoC).
Chris Q.	11/1-11/21/18	Research the image processing program and what programming language to use.
Juan C.	11/1-12/1/18	Research the mechanical system and the power connection it requires.
All	11/15-11/16/18	Complete bi-monthly update presentation for Senior Design class.
Chris Q.	11/15-11/25/18	Test initial information found on image processing program.
Heather L.	11/15-11/25/18	Test the microcontroller after researching the ports needed for the project.
Heather L.	11/20-12/1/18	Research the coordinate system; converts pixels to stepper motor rotations in the mechanical system.
All	11/29-11/30/18	Complete bi-monthly update presentation for Senior Design class.
All	12/1-12/17/18	Complete the final draft of the Project Charter.
All	12/13-12/14/18	Present Project Charter to Senior Design class, professor, and academic advisor.

TABLE I: Senior Design Semester 1 - Research Phase

Assignee	Start-End Date	Description
All	1/5/19 - 1/6/19	Finalize parts needed and decide what order to buy them for the project.
All	1/6/19 - 1/9/19	Complete budget increase justification and send to Dr. Stillmaker.
Juan C.	1/6/19-1/16/19	Assist in research of how to get Linux onto DE1_SoC Board; research the micro SD card needed and the how to implement the QSYS system to run with Linux.
Heather L.	1/15/19 - 1/20/19	Figure out how stepper motors programmed with Arduino.
Chris Q.	1/15/19 - 1/30/19	Research and implement Linux onto the DE1_SoC.
Juan C.	1/16/19 - 1/31/19	Create schematic for wooden frame of prototype stand.
Heather L.	1/20/19 - 2/5/19	Figure out wireless communication with Arduino and wireless transceivers.
Chris Q.	1/20/19 - 1/30/19	Develop system in QSYS that allows the HPS (Linux) to communicate with its peripherals (FPGA components).
Chris Q.	1/31/19	Decided to change microcontroller from DE1_SoC to PSoC 6 under advisement from Roger Moore.
Juan C.	1/31/19 - 2/19/19	Develop more in-depth blueprint of wooden stand measurements and dimensions.
Chris Q.	2/2/19 - 2/7/19	Research PSoC 6 IDE Modus Toolbox.
Heather L.	2/5/19 - 2/18/19	Combine stepper motor code with wireless communication for wireless stepper motor system.
Chris Q.	2/5/19 - 2/15/19	Create system within Modus Toolbox for PSoC 6 to connect to needed peripherals.
Juan C.	2/14/19 - 2/19/19	Determine all different types of screws, nuts, and bolts needed for each individual part of the stand.
Chris Q.	2/15/19 - 2/18/19	Research camera modules suitable for connection with the PSoC 6.
Heather L.	2/18/19 - 3/11/19	Create and assemble PCBs with stepper motors, drivers, the Arduino, and the power needed for all.
Chris Q.	2/18/19 - 3/15/19	Develop SPI communication between the Arducam camera and the PSoC 6 microcontroller.
Juan C.	2/20/19 - 3/15/19	Design mechanical system involving pulleys and linear motion system.
Chris Q.	2/25/19 - 3/2/19	Research image processing program in C with raw data.
Chris Q.	3/2/19 - 3/9/19	Create program that translates a colored RGB565 image to grayscale.
Heather L.	3/4/19 - 3/13/19	Create algorithm to find outermost edges of markings on whiteboard with Chris's processed image data.
All	3/4/19 - 3/14/19	Prepare for Midterm Project Presentations.
Chris Q.	3/9/19 - 3/16/19	Create program that detects edges in the converted grayscale image using sobel edge detection.
All	3/14/19 - 4/12/19	Write rough draft of final project report.
Juan C.	3/15/19 - 3/31/19	Assemble entire wooden prototype stand.
Chris Q.	3/16/19 - 4/14/19	Continue trying to configure Arducam camera with PSoC 6.
Juan C.	3/31/19 - 4/12/19	Mount all mechanical parts including tracks, pulley system, and stepper motors to wooden stand.
Heather L.	4/1/19 - 4/3/19	Wireless communication with Arduinos stopped working - come up with alternative.

TABLE II: Senior Design Semester 2 - Implementation Phase - Part 1

Assignee	Start-End Date	Description
Juan C.	4/12/19 - 4/15/19	Design power system to connect to stepper motors, their drivers, and the HUZZAH32 boards on the system.
Heather L.	4/14/19 - 4/16/19	Learn basics of Micropython for new microcontrollers.
Chris Q.	4/14/19 - 4/17/19	Help Heather with learning Python language.
Heather L.	4/14/19 - 4/17/19	Figure out code for stepper motors on new HUZZAH32 microcontrollers.
Heather L.	4/14/19 - 4/21/19	Create algorithm to move stepper motors in a serpentine-like way to erase the markings using the outermost edges found in the previously made algorithm.
Heather L.	4/14/19 - 4/17/19	Create simple messaging program between two HUZZAH32s to test wireless communication.
All	4/17/19	Create and finalize Projects Day poster.
Juan C.	4/15/19 - 4/21/19	Create UART connection between HUZZAH32 and PSoC 6 to send instructions for stepper motors.
Heather L.	4/17/19 - 4/20/19	Combine wireless communication with stepper motor instructions to create wireless stepper motor system.
Chris Q.	4/17/19 - 4/28/19	Help Heather integrate stepper motor movement algorithms and image processing program.
Juan C.	4/17/19 - 4/26/19	Research motion detection system with ultrasonic sensor and HUZZAH32 board.
Juan C.	4/20/19 - 4/22/19	Test power system on breadboard and order necessary parts.
Heather L.	4/20/19 - 4/22/19	Figure out angle of stepper motor rotations needed to move one “pixel” length of the image taken of the whiteboard for coordinates.
Juan C.	4/22/19	Mount power system to wooden stand with HUZZAH32 boards and stepper motor drivers.
Heather L.	4/22/19 - 4/28/19	Combine standalone algorithms, written in C with a dummy matrix, with the actual image data that will be processed in order to give correct instructions to stepper motors for whiteboard.
All	4/22/19 - 4/30/19	Think of Projects Day, what to talk about, and how to present to the audience.
Juan C.	4/25/19 - 4/27/19	Decide how to connect to system as a failsafe for someone standing too close to moving parts.
Juan C.	4/28/19	Mount ultrasonic sensor to prototype with indicator LEDs.
All	5/2/19 - 5/9/19	Create Final Project report presentation and practice.
All	4/30/19 - 5/9/19	Write final draft of Final Project report.
All	5/7/19	Projects Day.
All	5/9/19	Final Project report due.
All	5/9/19	Final Project Presentation day.

TABLE III: Senior Design Semester 2 - Implementation Phase - Part 2

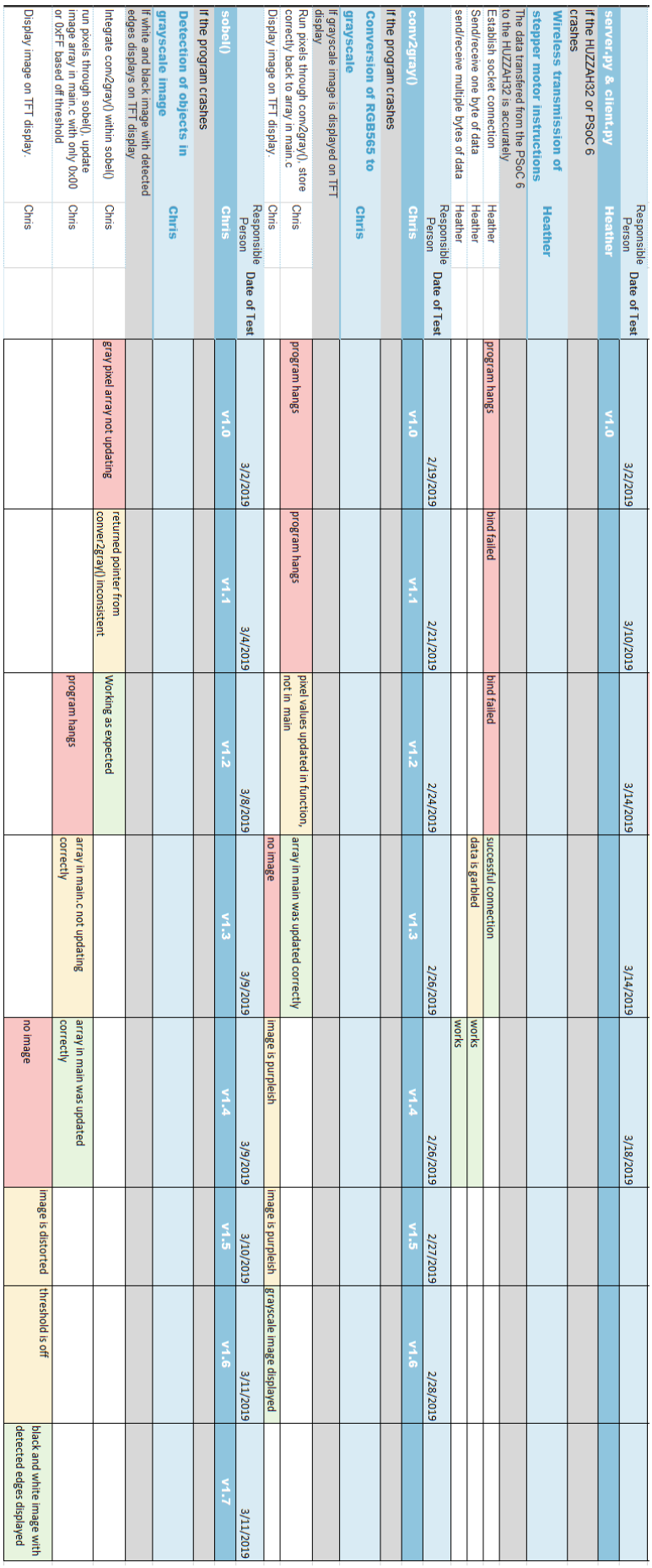
VIII. Test Plan

The following Test Plan was made to test the features of the Smart Eraser as they are completed. The test plan includes what feature is being tested, who is in charge of creating that feature, and who is in charge of testing that feature. It then lists the success criteria, which is what determines if the test was a success, and the stopping criteria, which is what determines if a test needs to be stopped.

Smart Eraser
Test Plan

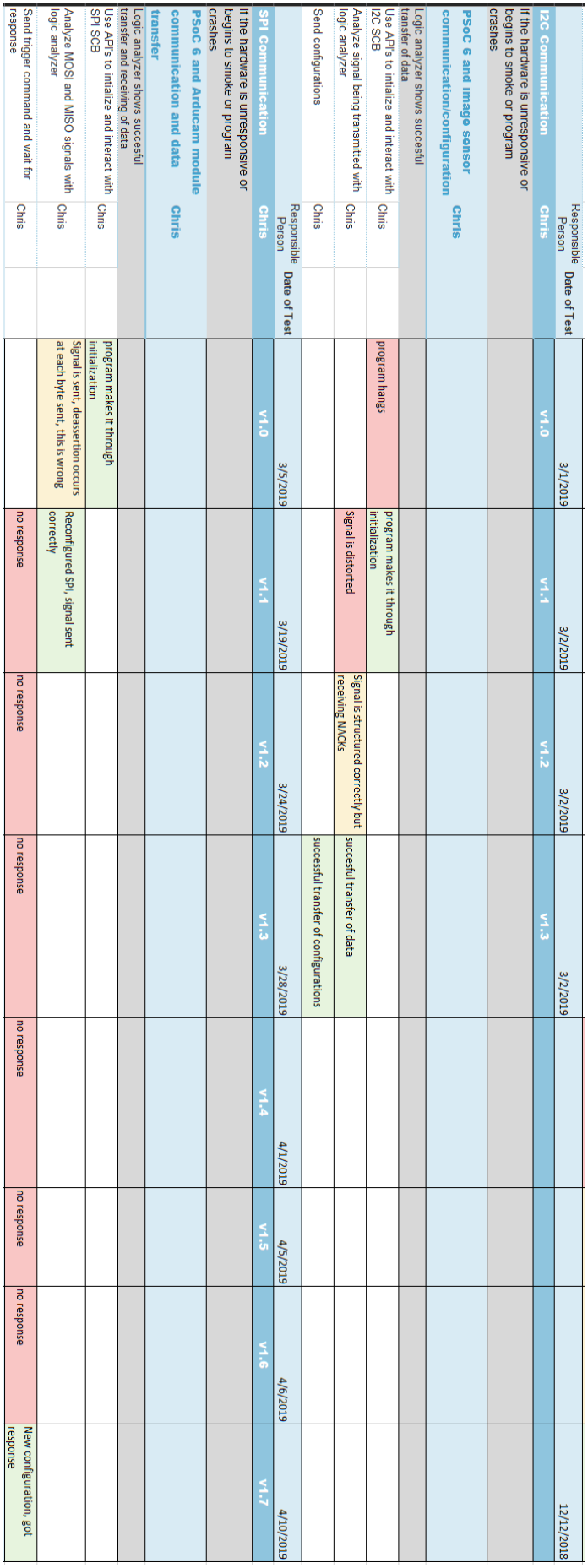
		Responsible Person	Date of Test	v1.0	2/1/2019	v1.2	2/1/2019	3/5/2019					
PSoC 6 Hardware development		**Chris**											
If the hardware is unresponsive or begins to smoke													
Configuration of GUI interface		**Chris**											
The TFT display shows what is expected from the program													
Image is correctly displayed on TFT display		Chris		Image was correctly display									
screen is responsive to commands made in program (adding text, changing image, etc.)		Chris		Program hung		Stepping through program resulted in changes on TFT display							
Configuration of SPI, UART, and I2C Serical Control Blocks (SCB)		**Chris**											
Building of application results in no errors													
I2C: clock rate, TX/RX length, mode, pin configs		Chris		No configuration errors									
SPI: clock rate, TX/RX length, mode, pin configs		Chris		clock speed/data transfer rate incompatible		No configuration errors		changes RX/TX length, no erros in new config					
UART: baud rate, parity, stop bits, pin configs		Chris		baud rate and clock rate mismatch		No configuration errors							
SM.py		**Heather**		**v1.0**	2/8/2019		3/1/2019	3/24/2019	3/28/2019	4/3/2019			
If the stepper motors fail to rotate													
Stepper motor operation		**Heather**											
rotate motors		Heather		success									
Configured to step 320 times horizontally		Heather		too short		too far		success					
Configured to step 240 times vertically		Heather						success					
run motors with prototype fully assembled		Heather						y moves, x doesn't	x moves but struggles	success			

Fig. 29: Test Plan for the Smart Eraser - Part 1



	Responsible Person	Date of Test								
server.py & client.py	**Heather**	**v1.0**	3/2/2019	3/10/2019	3/14/2019	3/14/2019	3/18/2019			
If the HUZZAH32 or PSoC 6 crashes										
Wireless transmission of stepper motor instructions	**Heather**									
The data transfered from the PSoC 6 to the HUZZAH32 is accurately										
Establish socket connection	Heather		program hangs	bind failed	bind failed	successful connection				
Send/receive one byte of data	Heather					data is garbled	works			
send/receive multiple bytes of data	Heather						works			
	Responsible Person	Date of Test								
conv2gray()	**Chris**	**v1.0**	2/19/2019	**v1.1**	2/21/2019	**v1.2**	2/24/2019	**v1.3**	2/26/2019	**v1.4**	2/26/2019	**v1.5**	2/27/2019	**v1.6**	2/28/2019	
If the program crashes																
Conversion of RGB565 to grayscale	**Chris**															
If grayscale image is displayed on TFT display																
Run pixels through conv2gray(). store correctly back to array in main.c	Chris		program hangs	program hangs	pixel values updated in function, not in main	array in main was updated correctly										
Display image on TFT display.	Chris					no image	Image is purpleish		image is purpleish		grayscale image displayed		
	Responsible Person	Date of Test														
sobel()	**Chris**	**v1.0**	3/2/2019	**v1.1**	3/4/2019	**v1.2**	3/8/2019	**v1.3**	3/9/2019	**v1.4**	3/9/2019	**v1.5**	3/10/2019	**v1.6**	3/11/2019	**v1.7**	3/11/2019
If the program crashes																	
Detection of objects in grayscale image	**Chris**																
If white and black image with detected edges displays on TFT display																	
Integrate conv2gray() within sobel()	Chris		gray pixel array not updating	returned pointer from conver2gray() inconsistent	Working as expected												
run pixels through sobel(). update image array in main.c with only 0x00 or 0xFF based off threshold	Chris				program hangs	array in main.c not updating correctly	array in main was updated correctly		image is distorted	threshold is off	black and white image with detected edges displayed
Display image on TFT display.	Chris						no image										

Fig. 30: Test Plan for the Smart Eraser - Part 2



	Responsible Person	Date of Test								
I2C Communication	**Chris**		**v1.0**	**v1.1**	**v1.2**	**v1.3**				**12/12/2018**
If the hardware is unresponsive or begins to smoke or program crashes										
PSoC 6 and image sensor communication/configuration	**Chris**									
Logic analyzer shows succesful transfer of data										
Use API's to intialize and interact with I2C SCB	Chris		program hangs	program makes it through initialization						
Analyze signal being transmitted with logic analyzer	Chris			Signal is distorted	Signal is structured correctly but receiving NACKs	succesful transfer of data				
Send configurations	Chris					successful transfer of configurations				
	Responsible Person	Date of Test								
SPI Communication	**Chris**		**v1.0**	**v1.1**	**v1.2**	**v1.3**	**v1.4**	**v1.5**	**v1.6**	**v1.7**
If the hardware is unresponsive or begins to smoke or program crashes		3/5/2019	program makes it through initialization							
PSoC 6 and Arducam module communication and data transfer	**Chris**	3/19/2019	Signal is sent, deassertion occurs at each byte sent, this is wrong	Reconfigured SPI, signal sent correctly						
Logic analyzer shows succesful transfer and receiving of data		3/24/2019								
Use API's to intialize and interact with SPI SCB	Chris	3/28/2019								
Analyze MOSI and MISO signals with logic analyzer	Chris	4/1/2019								
Send trigger command and wait for response	Chris	4/5/2019								
		4/6/2019	no response	no response	no response	no response	no response	no response	no response	New configuration, got response

Fig. 31: Test Plan for the Smart Eraser - Part 3

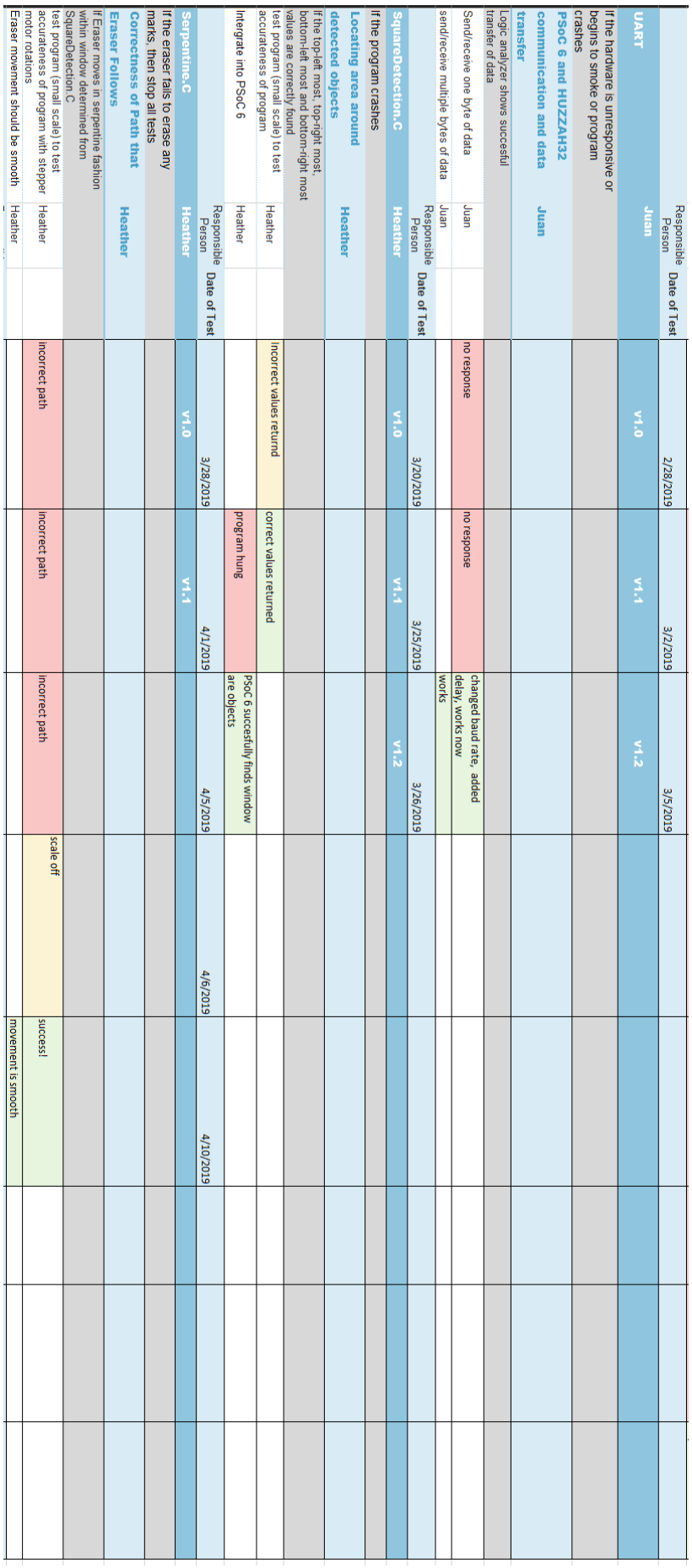
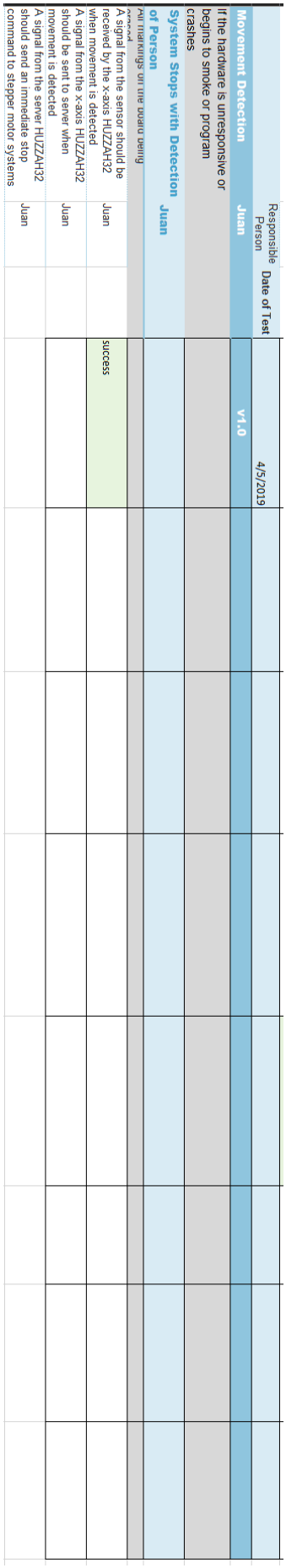


Fig. 32: Test Plan for the Smart Eraser - Part 4



	Responsible Person	Date of Test									
Movement Detection	**Juan**										
If the hardware is unresponsive or begins to smoke or program crashes			**v1.0**								
System Stops with Detection of Person	**Juan**	4/5/2019									
A signal from the sensor should be received by the x-axis HUZZAH32 when movement is detected	Juan		success								
A signal from the x-axis HUZZAH32 should be sent to server when movement is detected	Juan										
A signal from the server HUZZAH32 should send an immediate stop command to stepper motor systems	Juan										

Fig. 33: Test Plan for the Smart Eraser - Part 5

IX. Gantt Charts

The following figures show the GANTT chart schedules over the next two semesters. These list the tasks to be completed, who is in charge of what task, and the time duration the task is expected to take.

Project Start Date: 10/12/2018 (Friday) | Display Week
Project Lead: Heather Libecki

WBS	TASK	LEAD	START	END	DAYS	WORK DAYS
1	**Project Preperation/Design**			-		-
1.1	Complete Smart Eraser project proposal to be submitted to DPS Telecom for review.	ALL	Fri 10/12/18	Fri 10/19/18	7	6
1.1.1	Revise the project description; Complete for future use.	ALL	Mon 11/12/18	Sun 11/25/18	13	10
1.2	Rough draft of the project charter	ALL	Mon 10/22/18	Fri 10/26/18	4	5
1.2.1	Final draft of the project charter	ALL	Sat 10/27/18	Fri 11/16/18	20	15
1.2.2	Final Presentation	ALL	Sat 12/01/18	Fri 12/14/18	13	10
1.3	Draft detailed blueprint of the Smart Eraser deliverable	ALL	Mon 10/22/18	Wed 10/24/18	2	3
1.3.1	Draft flowchart of system overview	ALL	Mon 10/22/18	Fri 10/26/18	4	5
1.3.2	Draft block diagram detailing interconnections of system components	ALL	Wed 10/24/18	Fri 10/26/18	2	3
2	**Research**			-		-
2.1	Research De1-SoC structure and relevant components	Chris	Fri 10/26/18	Fri 11/02/18	7	6
2.1.1	Research the wireless communication and interface standards for De1-SoC	Heather	Fri 11/02/18	Fri 11/09/18	7	6
2.1.2	Research the SDRAM interface standards for De1-SoC	Juan	Fri 11/02/18	Fri 11/09/18	7	6
2.1.3	Research the wireless communication and interface standards for 1080p POE sv3c camera	Heather	Mon 11/05/18	Thu 11/15/18	10	9
2.1.4	Research GPIO interface standards for the De1-Soc	Heather	Fri 11/02/18	Fri 11/09/18	7	6
2.2	Research C syntax for altera monitor program	Chris	Fri 11/09/18	Fri 11/16/18	7	6
2.2.1	Research C libraries relevant to project scope	Chris	Fri 11/16/18	Tue 11/20/18	4	3
2.3	Research image processing using C	Chris	Thu 11/15/18	Thu 11/22/18	7	6
2.4	Research mechanical track system	Juan	Sat 11/10/18	Tue 11/20/18	10	7
2.4.1	Research interface standards for NEMA 23 stepper motors	Heather	Tue 11/20/18	Sun 11/25/18	5	4
2.4.2	Research interface standards and power needs for DM542S stepper motor drivers	Heather	Tue 11/20/18	Sun 11/25/18	5	4
2.4.3	Research Power requirements for system	Juan	Tue 11/20/18	Sun 11/25/18	5	4
2.5	Design and order PCB's for stepper motors and stepper motor drivers	Heather and Juan	Sun 11/25/18	Wed 12/05/18	10	8

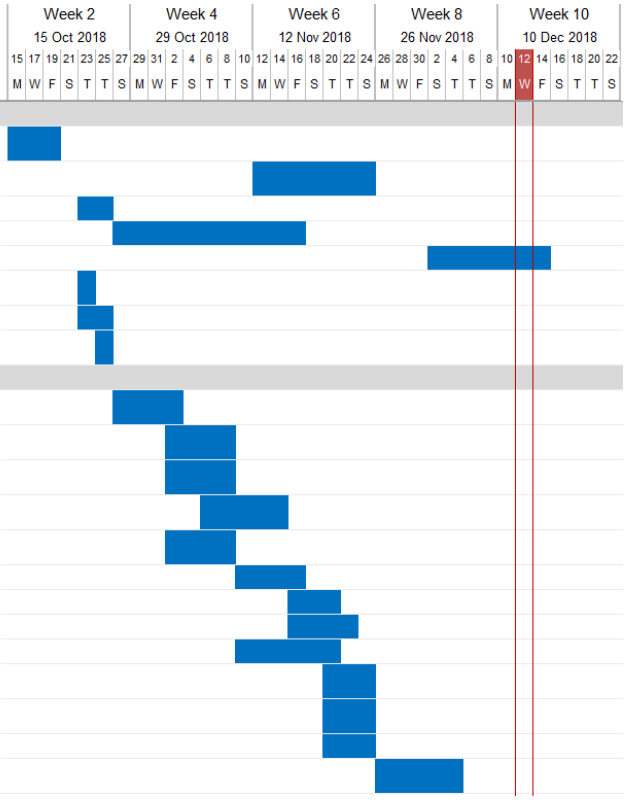


Fig. 34: GANTT chart for Senior Design Semester 1 - Research Phase

Project Start Date: 1/1/2019 (Tuesday) | Display Week: 1
Project Lead: Heather Libecki

WBS	TASK	LEAD	START	END	DAYS	WORK DAYS
1	**Development**			-		-
1.1	Develop a System in Quartus for DE1_SoC that fits the needs of the project. (Scrapped)	Chris	Tue 1/01/19	Fri 1/11/19	10	9
1.2	Develop program to operate the stepper motors	Heather	Tue 1/15/19	Sun 1/20/19	5	4
1.2.1	Send instructions to Stepper Motors using Kuman transceivers (Scrapped)	Heather	Sun 1/20/19	Tue 2/05/19	16	12
1.2.2	Develop wireless communication system for the SMART ERASER	Heather	Tue 2/05/19	Mon 4/01/19	55	40
1.3	Research Hardware of PSoC 6 microcontroller and learn Modus Toolbox	Chris	Fri 2/01/19	Fri 2/08/19	7	6
1.3.1	Develop underlying structure of the SMART ERASER system on PSoC 6 (main.c)	Chris	Fri 2/08/19	Sun 2/10/19	2	1
1.4	Research camera options	Chris	Mon 2/11/19	Tue 2/12/19	1	2
1.4.1	Set up and test chosen camera option	Chris	Wed 2/13/19	Wed 3/13/19	28	21
1.5	Draw up the schemtatic for the prototype stand	Juan	Thu 1/03/19	Tue 1/15/19	12	9
1.6	Midterm presentation	All	Thu 3/14/19	Thu 3/14/19	0	1
1.6.1	Begin development of the prototype stand	Juan	Sat 2/02/19	Fri 2/15/19	13	10
1.6.2	Assemble prototype stand	Juan	Fri 2/15/19	Mon 2/25/19	10	7
1.7	Begin development of image processing program	Chris	Wed 3/13/19	Thu 3/28/19	15	12
1.7.1	Test image processing program by viewing resulting image	Chris	Fri 3/15/19	Thu 3/28/19	13	10
1.8	Develop Communicatoin between PSoC 6 and transmitter	Juan	Mon 2/25/19	Tue 3/05/19	8	7
1.9	Add motion detecting capabilities to the SMART ERASER system	Juan	Tue 3/05/19	Fri 3/15/19	10	9
1.9.1	Test the motion-detecting program.	Juan	Sat 3/16/19	Mon 4/15/19	30	21
1.10	Develop coordinate generation for stepper motors from image processing	Heather	Tue 4/02/19	Fri 4/12/19	10	9
1.11	Develop Erasing algorithm based on given coordinates	Heather	Fri 4/12/19	Thu 4/25/19	13	10
1.12	Projects Day	All	Tue 5/07/19	Tue 5/07/19	0	1
1.13	Final Project and video due	All	Thu 5/09/19	Thu 5/09/19	0	1

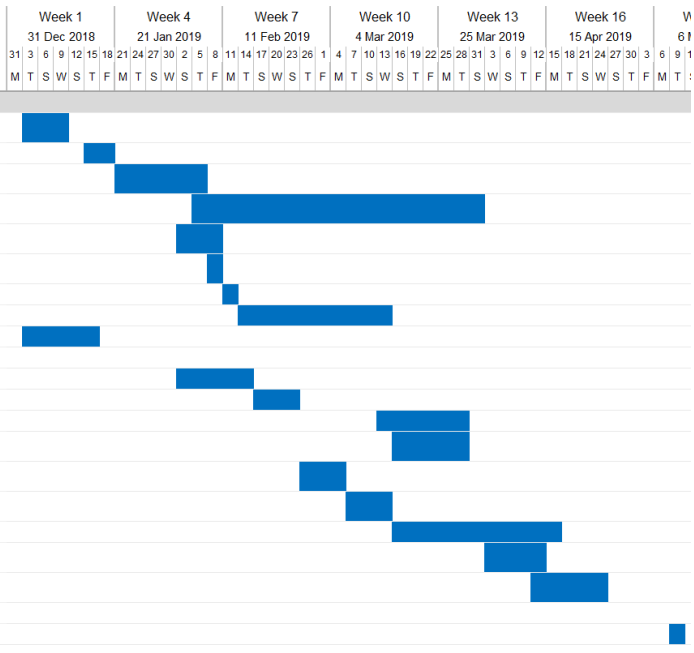


Fig. 35: GANTT chart for Senior Design Semester 2 - Implementation Phase

X. Equipment and Budget

The following table lists the components that were bought in order to complete the Smart Eraser, as well as the company that made them and their cost. The costs are listed without taxes and shipping costs taken into account, but the total of the budget at the bottom of the table includes these. The components are listed in alphanumeric order.

Component Name and Model	Production Company	Cost
Aluminum GT2 40 Teeth 6.35mm Bore Timing Belt Pulley Flange	Uxcell	$7.19 x4
Antenna Wireless Transceiver nRF24L01+PA+LNA	Kuman	$13.99
Arducam Mini Module Camera 5 Megapixel OV5647	Arducam	$39.99
Arduino MKR1000 WiFi with Headers	Arduino	$33.95
Assembled HUZZAH32-ESP32 Feather Board with Stacking Headers	Adafruit	$21.95 x3
CNC Stepper Motor Driver DM542T	STEPPERONLINE	$38.99 x2
Li-ion 9V Battery Charger Bay	EBL Official	$12.99
Magnetic Whiteboard 48”x36”	Lockways	$49.99
NEMA 23 CNC Stepper Motors	STEPPERONLINE	$19.99 x2
NEMA 23 Stepper Motor Mounting Bracket 4 pack	Jiuwu	$18.99
PSoC 6 WiFi-BT Pioneer Kit	Cypress	$99.00
Stepper Motor PCBs	PCBWay	$147.00
Various Braces and Glue	Home Depot	$27.46
Various Screws, Nuts, and Bolts	Home Depot	$24.64
Wood Plywood Backing 96”x48”	Home Depot	$39.82
Wood 2”x4”	Home Depot	$12.27 x4
10 Meter GT2 6mm Steel Core White Open Ended Timing Belt	Nineone	$15.89
115RC Cassette with Stainless Steel Bearings	Accuride	$45.00 x3
115RC 47” Aluminum Track	Accuride	$36.22 x3
2” Caster Rubber Wheels with Swivel and Brake	Home Depot	$3.98 x4
9V Battery Clips	BBTO US	$6.25
9V Battery Holders for PCBs	Mouser	$1.90 x10
9V Rechargeable Batteries 6 pack	EBL Official	$25.99 x2
TOTAL COST		**$1,202.13**
Allotted Budget		**$930.00**
Over Budget Cost		**$272.13**

TABLE IV: Cost of components for project

As shown in the table for the budget, this project has exceeded the original expected budget by almost $300. The original estimate was not taking into account the problems that were run into during the course of the project’s life cycle. For example, the Arduino and Kuman wireless transceivers had to be changed to the HUZZAH32 Feather boards for the wireless communications because of their inoperability. This and a few other unforeseen circumstances pushed the budget over the limit. Now that this experience has been had, for future projects, more research will be done on what exactly will be needed for each step of the way, and which approach will be the best before confirming the budget. This way, perhaps the budget can be more closely followed.

Along with the components listed in the budget, the following resources were also used to complete the project.

Name of Equipment	Type	Description
DipTrace	Software	Designing PCBs
Arduino IDE	Software	For programming and running the Arduinos when they were being used for the wireless communications.
Lucid Charts	Software	For all figures, flowcharts, and diagrams that were created
Modus ToolBox IDE	Software	Programming and setting up the system for the PSoC 6.
uPyCraft IDE	Software	Programming the HUZZAH32 Feather Boards.
Various connectors and jumper cables	Hardware	For connections between components
Digital Multimeter	Hardware	For testing and recording voltages, currents, and resistances across components.
Solderless Breadboard	Hardware	For testing purposes.
Logic Analyzer	Hardware	For testing purposes.

TABLE V: Equipment used besides the components bought

XI. Roles of Team Members

This section contains a more in depth look at what the specific roles of each team member were throughout this project. Included in this section is each member's areas of expertise, areas they were not experienced in, and what they had to work on the most throughout the completion of the Smart Eraser.

A. Heather Libecki

She had the responsibility of being the project manager for the Smart Eraser project. She also wanted to take charge of the stepper motors and their operations. She has had previous experience with stepper motors and how they work, so she was ready to take on this task. The technical advisor Dr. Kulhandjian wanted the project to be as wireless as possible, so wireless transceivers were decided upon to communicate with the stepper motors from a master controller that would send instructions. She decided to take on the task of creating the wireless communications as well, as she has a personal interest in wireless connections and networking programming. Although she had no experience in wireless communications, she wanted to learn this for the project. Finally, because she was in charge of the connections and movement of the stepper motors, she needed to create the algorithms that would actually allow the stepper motors to move the eraser to where they needed to go based on the image processing that Chris did. She was responsible for the algorithm that would find the outer-most edges of the markings on the whiteboard, then for the algorithm that took those coordinates and created a serpentine-like path, out of stepper motor instructions, that the eraser would need to follow. The following list details her strengths and weaknesses that would assist her for this project.

- Strengths: programming (Verilog, C programming), PCB design, mathematics, debugging, circuit implementation, problem solving, technical writing, public speaking
- Weaknesses: circuitry design, power systems, socket programming with Micropython

B. Chris Quesada

Has experience in working with embedded systems and developing code for different applications. This project will be heavy on the software side, using both *C* and *Python* to receive data, analyze it, and then send an output. He also developed the UART, SPI, and I^2C communications needed for the Smart Eraser system. A solid understanding of arrays, pointers, and how information is stored in memory was applied towards implementing the image processing techniques used to find pixels that represent markings

in the digital image. His work in ECE 70, concepts and experience gained in CSCI 41, and research into image processing allowed for the succesful completion of the Smart Eraser image processing capabilities. Researching SPI and I^2C in Embedded systems along with further research into theses communications along with UART during the Smart Eraser developement led to successful implementations of all three. He also assisted Heather with the developement of the wireless communicaions between the HUZZAH32 microcontrollers.

- Strengths: programming (C, C++, Python), programming concepts (arrays, pointers, structures, data types), embedded systems, developing algorithms, communications(SPI, UART, I^2C)
- Weaknesses: circuitry design, mathematics, public speaking, power

C. Juan Colin

Has experience in working with electrical systems and physical circuit design. He is proficient in the use of problem solving techniques to create a functioning system with given design specifications. His part of the project was dependent on learning the physical mechanical aspects of the design, and how the connected parts will be powered. Therefore, he was in charge of the main mechanical system as well as the wooden prototype stand, and how the power can be supplied to the technological components in order to allow all parts of the system to work properly and move the way they need to. He also used knowledge from previous classes to program a microcontroller to detect the presence of a person in front of the whiteboard in order to provide a safety measure because there are moving parts in this project. He needed to research Micropython from scratch and use that knowledge to accomplish this.

- Strengths: electrical systems, circuitry design, problem solving, power systems, public relations
- Weaknesses: programming (Assembly, Verilog), technical writing and spelling

XII. Analysis and Design

In this section, the implementation of the components that came together to make the Smart Eraser functional will be described.

A. I^2C Communication - PSoC 6 to Arducam

Inter-Integrated-Circuit(I^2C) is a popular method for interactions between processors and slower ICs. For optimal efficiency, short distances should be used so it is mainly for intra-board connections. The naming scheme used to define the components is referred to as a master/slave relationship where there is one master and one or more slaves. Communication between the master and slave is through messages, with the messages being structured in a specific way. A start and stop bit are used to indicate the start and end of a message. After the start bit, an address is given, usually 7-10 bits, followed by the read/write bit. As was the case with Arducam, the data sheets for slave devices often incorrectly list the slave address with the read/write bit included. Using the PSoC 6 APIs for the I^2C Serial Control Block(SCB) added a start and stop bit to the given slave address based on whether it was a read or write. So, after omitting the LSB of the slave address provided from Arducam, communications worked perfectly(0x78 - LSB = 0x3C). This is known as the address frame. There are also 2 data frames that ensue, each a byte wide. Between each frame either an ACK is received from the slave or the communication failed and the ACK bit is set to NACK. The flow of how a message is sent can be seen in Figure 36.

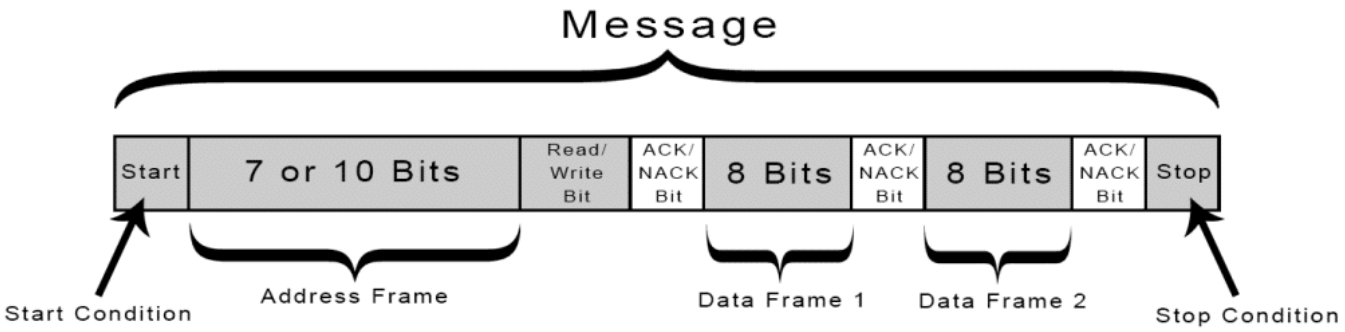


Fig. 36: Simple overview of an I2C message [18]

Some confusion may arise when it is stated that in order to communicate with the Arducam module both I^2C and SPI are needed to do so. This is because the Arducam is just that, a module, that has different components. The difference between these two types of communication is that I^2C is needed to initialize the image sensor on the module, determining what is transferred to the FIFO storage, located on the module as well. For example, with I^2C, the resolution, format, and size of the image can be configured. With SPI, the actual capture and transfer of the image data from that FIFO storage is done. Basically, the I^2C can only interact with the image sensor itself and the SPI communication is for operating the entire module. The layout of the different components is shown in Figure 37

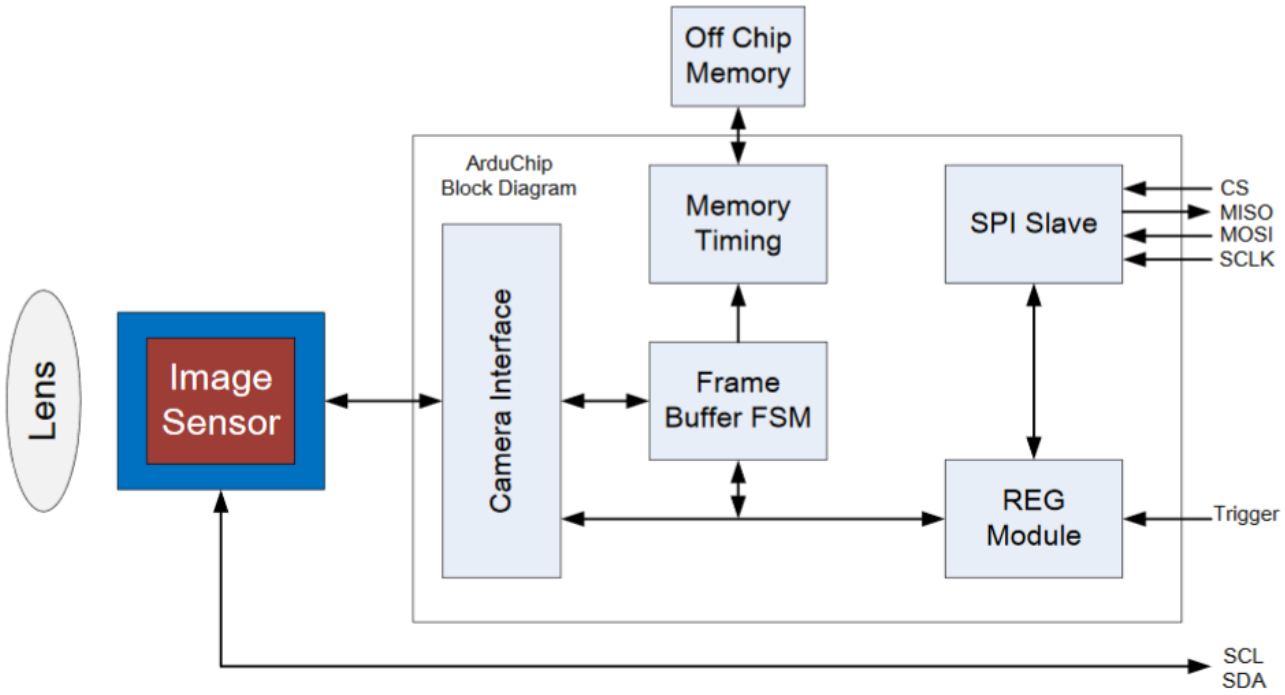


Fig. 37: Arducam module block diagram [1]

Unfortunately due to time constraints, although the I^2C communication works correctly, attempts at configuring the image sensor to output RGB565 with a resolution of 320x240 were unsuccessful. This is due to the hundreds of control registers that can be found in the sensor and not knowing which ones need to be set and what values to set in them. This can be a project all on its own. However, the analysis and design will still be explained.

In the file Arducam.C, found in XVI, MyCam_Init() uses the Write_I2C() function to send configuration signals to the image sensor of the Arducam module. These configurations are stored in structures in the

beginning of the code file. As can be seen, just in the first configuration structure alone, there are over 250 configurations that need to be sent to the image sensor to get a RAW 1280x960 image stored to the FIFO buffer of the Arducam module. This is followed by another, much smaller set of configurations that is meant to resize the image. Due to the inability to set the output to RGB565, an attempt to receive RAW data was attempted and is the reasoning for sending theses configurations. Receiving RAW data requires another component to be added to the image processing, demosaicing, and is currently still in development. The Write_I2C() function uses a combination of APIs provided by Cypress in order to interact with Serial Control Block 3 (SCB3) configured to be a I^2C master. It can be found in the section XVI.

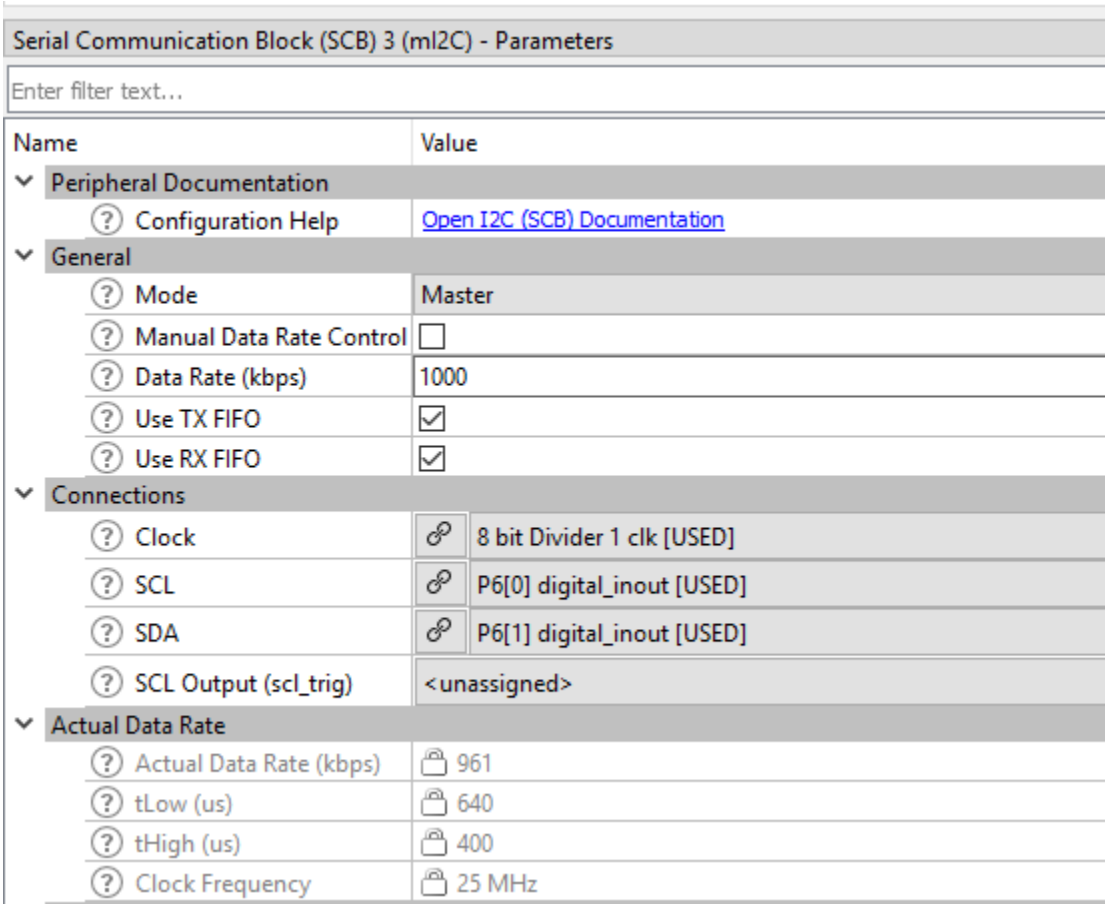


Fig. 38: Hardware Configuration of I2C

B. SPI communication - PSoC 6 to Arducam

Serial Peripheral Communication (SPI) is a common form of wired communication between different systems. The master/slave relationship used in I^2C is also used in SPI. There is no official standard for SPI however it is so widely used that it can be referred to as a De facto standard due to everyone operating along the same assumptions. These assumptions include the 4 modes SPI operate in and each mode is a different combination of the clock phase, when data is evaluated, and clock polarity, whether the clock is high or low when not in use. Once the mode has been decided, the slave clock dictates the rate of transaction between master and slave and therefore, the master must be configured accordingly. A Master-Out-Slave-In (MOSI) line feeds data, either MSB or LSB first, to the shift register in the SPI interface of the slave device. For every bit received, the slave will send a bit back to the master along the Master-In-Slave-Out (MISO) line. During a SPI exchange, every bit sent is a bit received and depending if you want to read or write data, the bits received are sometimes irrelevant (writing to slave).

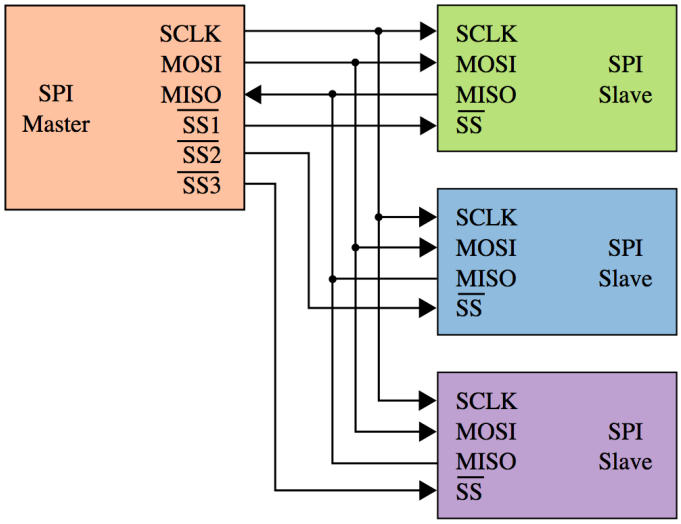


Fig. 39: Simple overview of SPI communication [19]

For the Smart Eraser system, the PSoC 6 is the master and the Arducam module is the slave. According to Arducam's data sheet, the Arducam SPI interface operates in SPI mode 0, meaning CPHA = 0 and CPOL = 0. Therefore the PSoC 6 is configured to operate in that mode as well. Also according the Arducam's data sheet the max frequency of its SPI interface is 8 MHz and therefore the PSoC 6 was configured to send a 7.142857 MHz signal to meet the requirement. Both the RX and TX of the PSoC 6 was set to be 16 bits wide in order to properly communicate with the Arducam SPI interface. An example of what the Arducam needs in order for proper communication can be found in figures 2 and 3. The command byte, sent first, is structured so that the MSB is designated as the read/write byte, leaving the other 6 bits to represent an address in the Arducam SPI interface. The following byte is the data byte which contains specific data if the action is a write. If it is a read SPI transaction then this byte is known as a dummy byte because its just sent to push what needs to be read to master. The reason the TX and RX were set to 16 bits instead of 8 is because when this command and data byte is sent to the Arducam, the CS line needs to be asserted while both bytes are sent. When the PSoC 6 was configured with an 8-bit TX and RX, it would de-assert the CS line between each byte. This caused improper communication between the devices because from the point of view of the Arducam, it was only receiving command bytes.

This can be observed in the Arducam.C file, in any of the functions that use the Write_SPI() function. A packet of 2 bytes is built and then placed into the TX of the PSoC 6 for transfer, which is handled by Write_SPI(). These functions are:

- MyCam_Test(): Tests whether or not the SPI is working correctly
- MyCam_Trigger(): Function that initiates a capture
- MyCam_Check_Capture_Status(): Function that polls the capture ready flag in register 0x41 of the Arducam module.

Code Implementation (Packet assembling):
txBuffer = (((uint16_t)WRITE + (uint16_t)TEST_SPI) « 8) + (uint16_t)TEST_VALUE;

Code is from MyCam_Test() in Arducam.C located in section XVI

The Write_SPI() function uses a combination of the APIs provided by Cypress in order to interact with the Serial Control Block 1(SCB1) that has been configured as aa SPI master. It is located in the I2Cmaster.C file found in XVI.

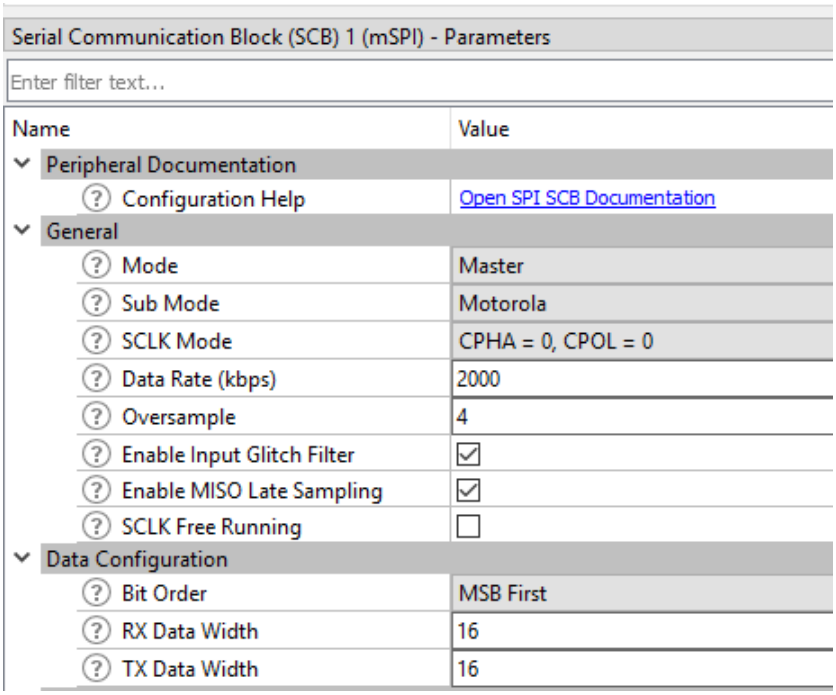


Fig. 40: Hardware configuration of SPI (1)

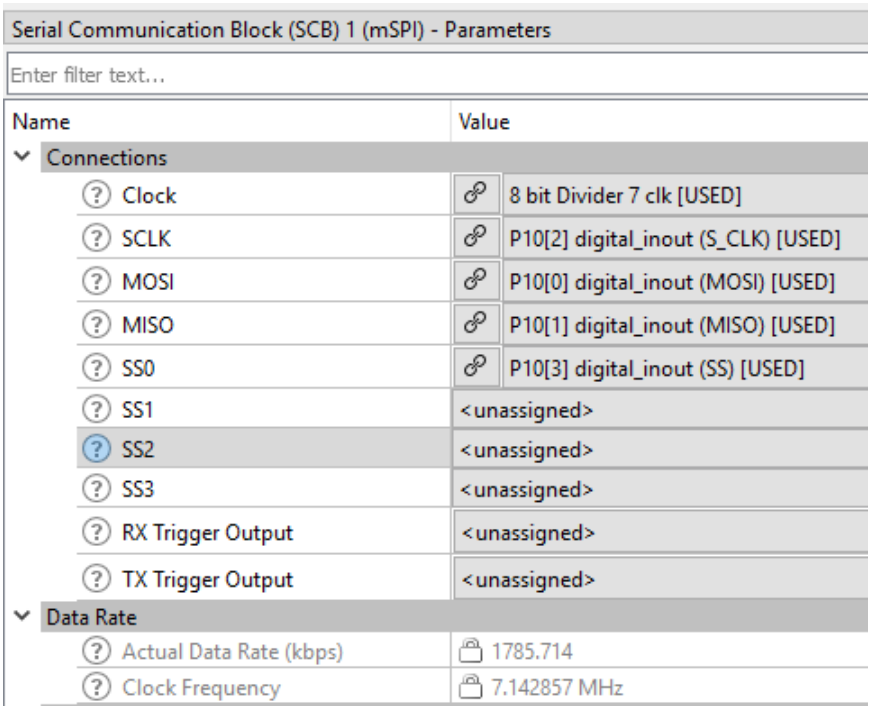


Fig. 41: Hardware configuration of SPI (2)

C. Image Processing

1) Resolution: The original idea was to use a high-definition image to process because it would be able to capture more information, and therefore more accurately detect objects in a picture. This was assumed without taking into account the capabilities of the microcontroller. As it has been stated, attempts to add more physical memory to the system proved to more difficult than expected, leaving the program to only operate with a limited amount of memory. Due to this limitation, as well as matching the resolution of the TFT screen, a resolution of 320x240 was chosen to implement the image processing aspects of the system. It should be stated that the program was structured in a way that allows for easy changing of resolutions. Another impact of memory limitation is that only 80 rows of the image can be evaluated at a time. The resolution parameters are set in ImProc.H which can be found in section XVI.

2) Output Format: There are a multitude of image formats than can be used and each one has its own specific way to read pixel information. JPEG was immediately decided against due to its lossy nature and high level of complexity to read pixel data. That left RGB, raw RGB, and YUV formats. Going a level down, each of the three formats have different arrangements and sizes in which they can be formed. For example, RGB can be either 888, 565, 555, 444, and even still further the ordering of the R,G, and B can vary.

Cypress provides an example project that interacts with the TFT display and uses an example image with a format of RGB565 and resolution of 320x240. Since the Arducam can, if configured correctly (a whole project in itself), output this format with that resolution, pre loaded images with this formatting were used to test and develop the image processing aspects of the system. Without being able to see the results on the TFT display of what was being applied to the pixel data, the image processing program would have never worked correctly.

For the Smart Eraser system, as mentioned above, a format of RGB565 was chosen. Not only would images captured be able to be displayed on the TFT display, but the way in which the image data would be received from SPI communication would be relatively straightforward. Pixel information is broken up between 2 consecutive bytes, a high and low byte. Knowing how RGB565 is arranged, every two bytes of information received over SPI would be used to constructed one pixel of information and due to the nature of the SPI hardware configuration of the PSoC 6, each SPI transfer is 2 bytes. Therefore each SPI transfer consists of one complete pixel.

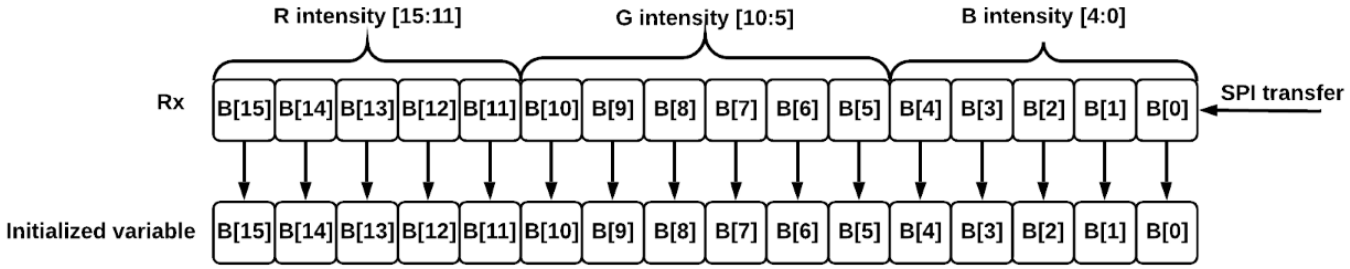


Fig. 42: Pixel Information being received through SPI from Arducam

3) Resolution: There are many different ways to do grayscale conversion from RGB. All are capable of achieving what was needed for Smart Eraser System, and the only difference between the methods are how true to gray the image looks and whether it has a darker or lighter tone to it. Because it is more accurate to the human eye, the Luminance method was chosen for the Smart Eraser system to convert to grayscale, mainly for the fact that the images would be viewed and not just processed behind the scenes.

Here is quick description of some different methods, including Luminance:

- Averaging Method

  - $Gray = (Red + Green + Blue)$ [31]
- Luminance Method
  - $Gray = (Red \times 0.2126 + Green \times 0.7152 + Blue \times 0.0722)$ [31]
- Desaturation
  - $Gray = (Max(Red, Green, Blue) + Min(Red, Green, Blue))/2$ [31]
- Decomposition (Max or Min)
  - $Gray = Max(Red, Green, Blue)$ [31]
  - $Gray = Max(Red, Green, Blue)$ [31]
- Single Color Channel
  - $Gray = Red$ [31]
  - $Gray = Green$ [31]
  - $Gray = Blue$ [31]

Once again, which method that is used is not important, it is separating the intensities from each other and then comparing them on an equivalent scale. An output format of RGB565 uses 16 bits to represent a single pixel, as shown in (figure with rgb565 output in previous section). In order to separate these intensities, the variable that contains the pixel information (type uint16_t) is masked accordingly to pull out the R,G, and B intensities, storing them into new variables (type uint8). Masking is the process of performing a logical AND operation on a variable to isolate bit values contained in that variable. As demonstrated in figure 43 if the pixel data variable is ANDed with the Red Mask variable, only bits[15:11] will be retained.

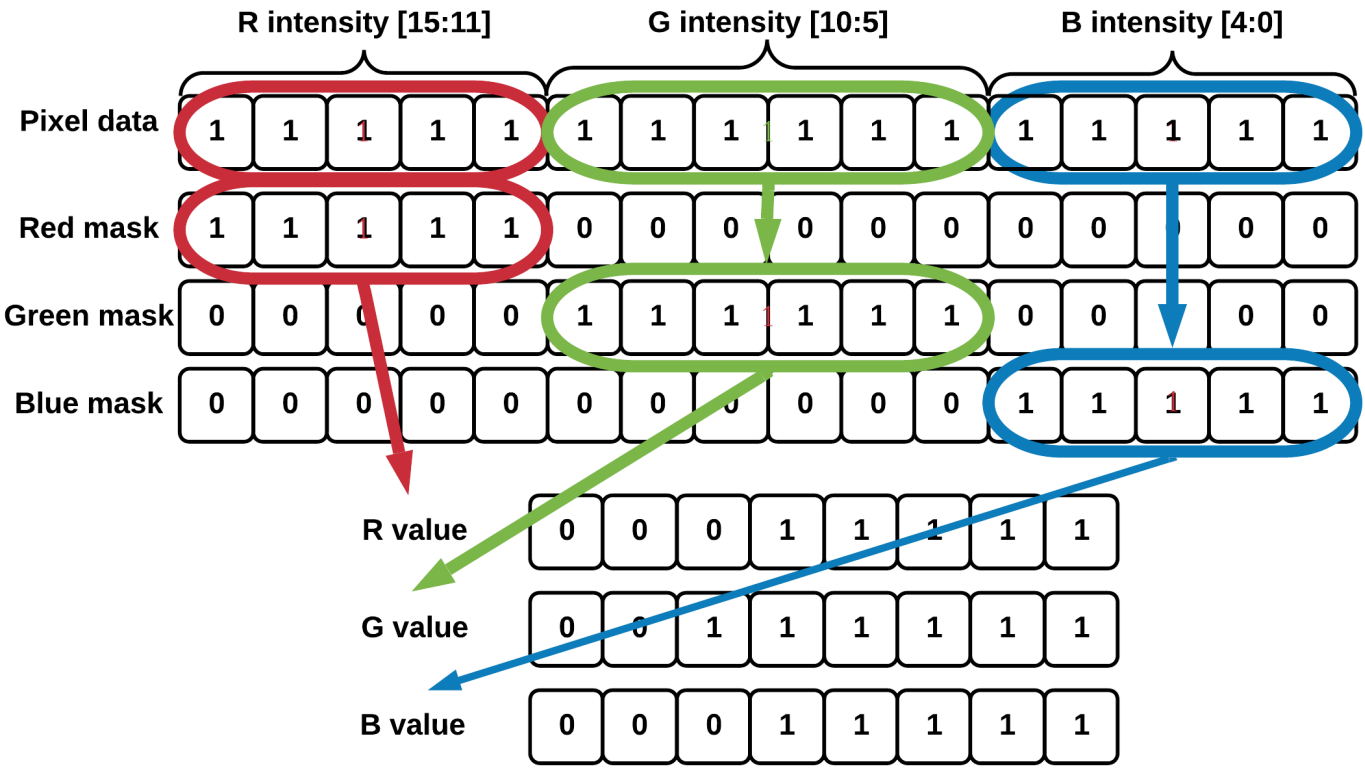


Fig. 43: How red, green, and blue intensities are seperated from one another

With the newly separated values as is, R and B represent shades of gray on a scale of 0 to 32 whereas G represents shades of gray on a scale of 0 to 64. If these values were to be used in one of the grayscale conversion algorithms, an image in shades of purple would be generated. This is known because it isnâĂŹt

clearly stated anywhere that when using these conversion formulas, the intensities have to be represented by the same number of bits and therefore initial trials did not take this into account. Therefore some simple shifting is required before the formulas can be used. All intensities were upscaled to 8 bits so that values are compared on the complete range of grays (0 - 255) rather than descaling the green intensity down to 5 bits so that values are compared on a smaller, incomplete range of grays (0 - 32).

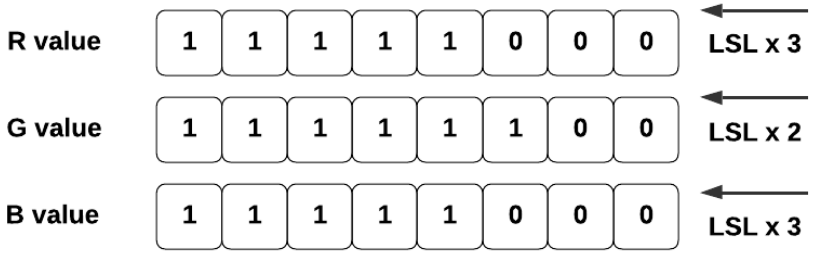


Fig. 44: Scaling seperated red green and blue intensities up to 8 bit numbers

Code Implementation (Separation and scaling):

```
R  = ((pixel \& 0b1111100000000000) >> 11 << 3);
G = ((pixel \& 0b0000011111100000) >> 5 << 2);
B = (pixel \& 0b0000000000011111) << 3;
```

Code is from conv2gray() in ImProc.C located in section XVI

At this point the RGB values are ready to be run through the conversion formula to generate a gray pixel value, in 8 bits. This gray value will then be used as the new R, G and B intensities of the original pixel, creating a shade of gray in the RGB565 format. To build this new RGB565 pixel, the process up until now is done in reverse. New variables are created to hold âĂIJprocessedâĂİ values of RGB that are of type uint16_t, to match the original pixel data length.

Gray = (Red * 0.2126 + Green * 0.7152 + Blue * 0.0722)

Fig. 45: Luminance method for converting RGB to grayscale

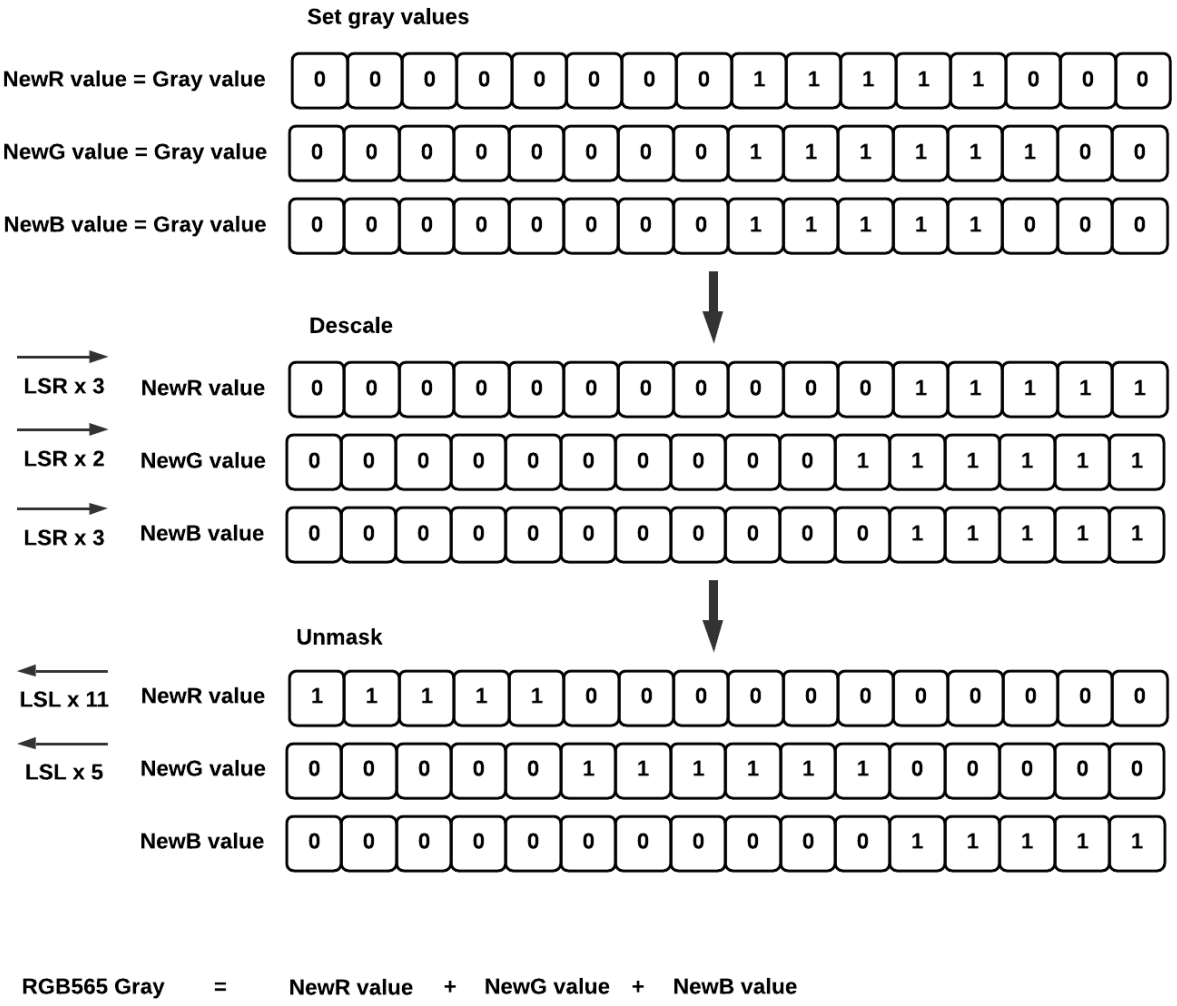


Fig. 46: Process in reverse: In order to create gray RGB pixel

Code Implementation (conversion, descaling, reassigning):

```
Gray\_pixel = (R * 0.2126) + (G * 0.7152) + (B * 0.0722);
R\_processed = ((uint16\_t)Gray\_pixel)>> 3 << 11;
G\_processed = ((uint16\_t)Gray\_pixel)>> 2 << 5;
B\_processed = (uint16\_t)Gray\_pixel >> 3;
pixel = (uint16\_t)(R\_processed + G\_processed + B\_processed);
```

Code is from conv2gray() in ImProc.C located in section XVI

4) Grayscale Results:

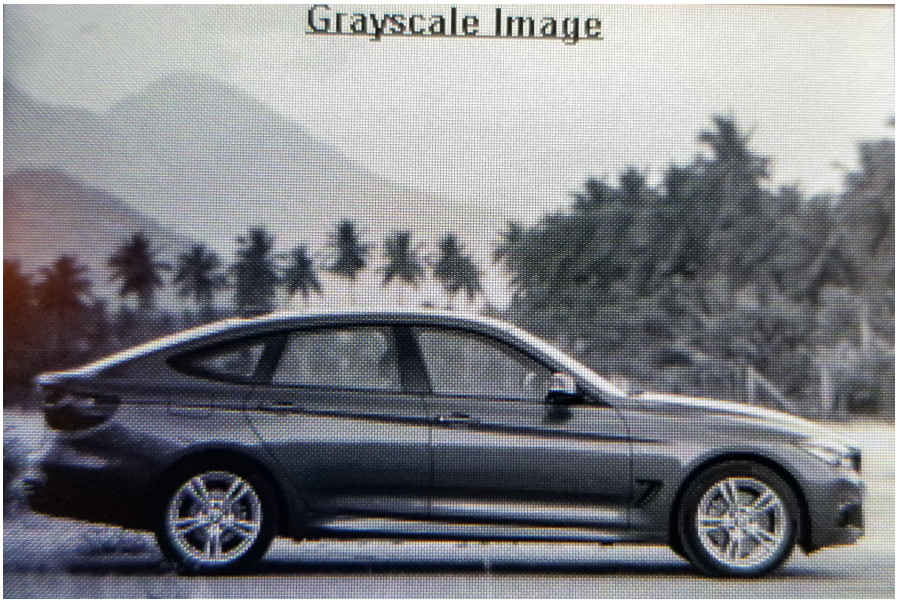


Fig. 47: Reuslts of grayscale algorithm from PSoC 6 (1)

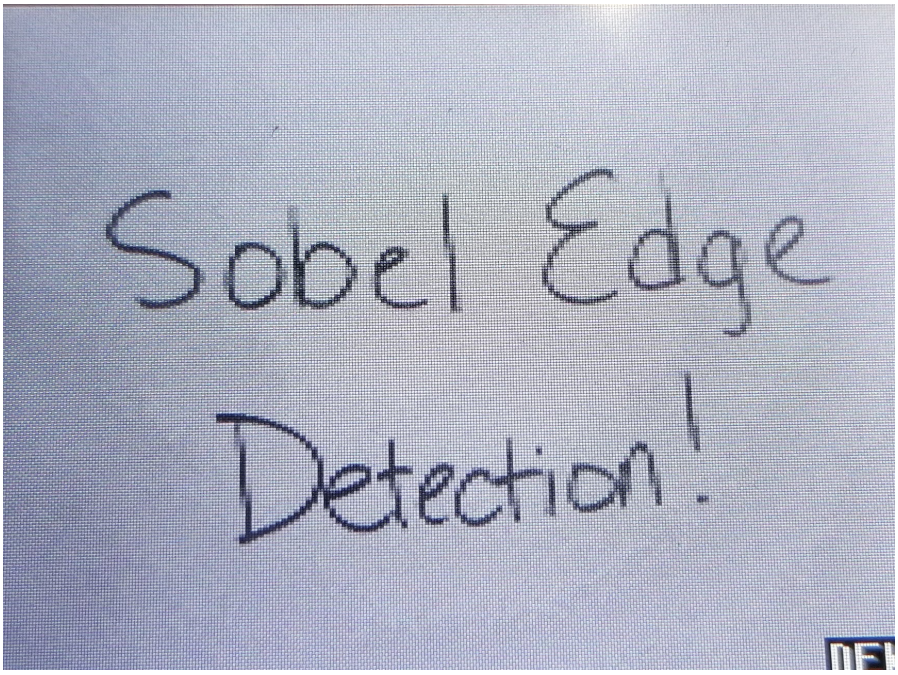


Fig. 48: Reuslts of grayscale algorithm from PSoC 6 (2)

5) Sobel Edge Detection: Sobel edge detection is an edge detection algorithm that uses a sobel kernel to detect differences in intensities at each pixel location. This is done by convolving a sobel kernel through each pixel in an image array. The pixel information must be grayscale in order for changes in intensity to be seen. A sobel kernel is a 3x3 array containing specific values to determine changes in values (gradients) from one edge to another. This has to be done for both vertical and horizontal edges, so there will be a kernel for each. The values inside the kernel are what make it a Sobel kernel. Using different values would classify it as a different type such as, SobelâĂŞFeldman or Scharr.

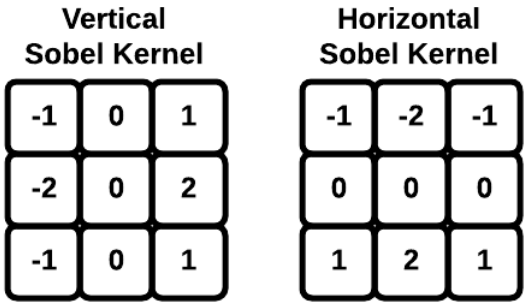


Fig. 49: Sobel Kernels

When moving through the image array, the center of the 3x3 kernel must never reach a border pixel otherwise a segmentation fault will prompt. This is because the pixel being evaluated (at the center of the kernel) relies on information from the surrounding pixels. If you were to attempt to pass the kernel through any part of the border, there will be some portion of the kernel that is out of bounds of the defined memory region. This is shown in figure 50.

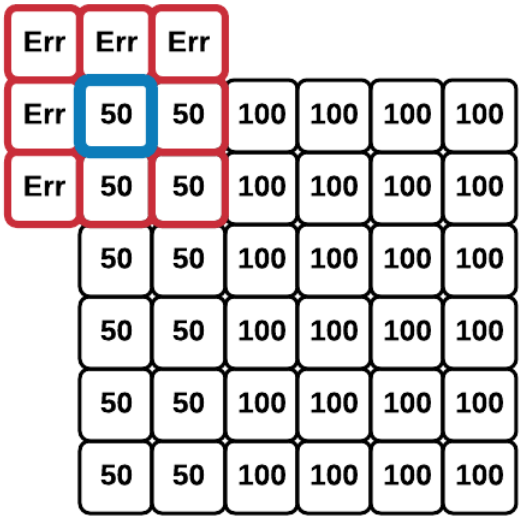


Fig. 50: Visual of what happens if the the sobel kernel is convolved along a boundary

Code Implementation (boundary detection):

```
for (k = Length + 1; k < bound - Length; k++){
     if ((k + 1) \% Length == 0) {
     ptr\_GD = ptr\_GD + 2;
     ptr\_PD = ptr\_PD + 2;
     k = k + 2;
}
```

Code is from sobel() in ImProc.C located in section XVI

Once boundaries are accounted for in the program, the kernel can be convolved through the image array.

At each pixel location (inside of boundary pixels) the operation shown in figure (right below) is carried out, both for the X and Y gradient.

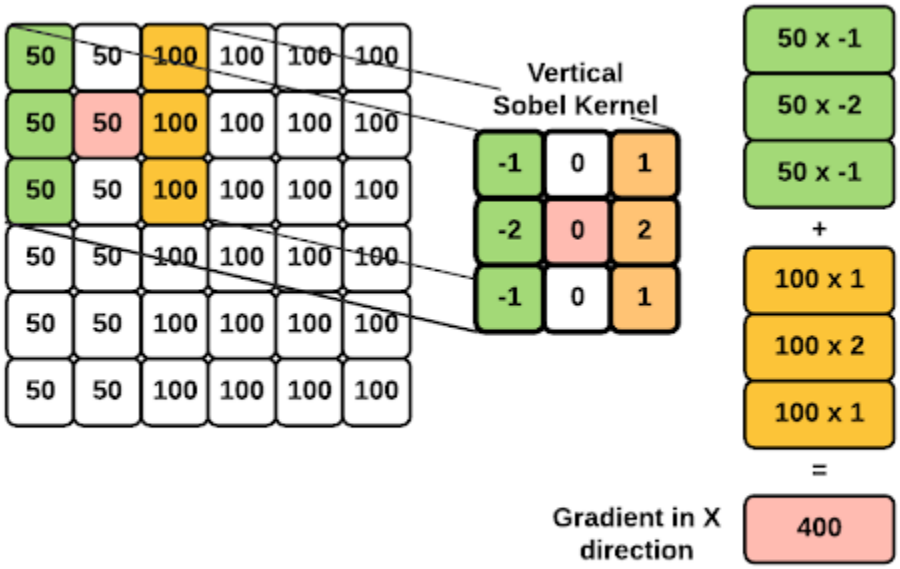


Fig. 51: Operation of the vertical kernel

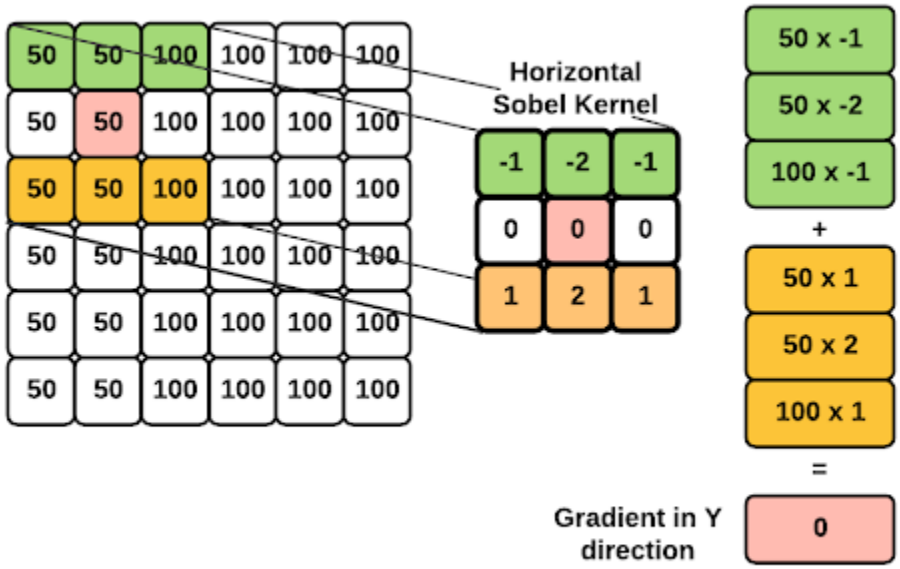


Fig. 52: Operation of the Horizontal kernel

Finding the gradient in both the X and Y direction at any given pixel location (aside from boundary pixels) allows the total magnitude to be found at that location. This is done by taking the Gx and Gy values and using the Pythagorean Theorem.

$$G = \sqrt{(Gx^2 + Gy^2)}$$

Fig. 53: Using Pythagorean theorem to determine the magnitude of the gradient

Code Implementation (kernel convolution):

```
Gx =(sobel_kernel[0])*(*(ptr_GD - Length + 1)) + (sobel_kernel[1])*(*(ptr_GD + 1))
    +
   (sobel_kernel[2])*(*(ptr_GD + Length + 1)) - (sobel_kernel[0])*(*(ptr_GD - Length
      - 1)) -
   (sobel_kernel[1])*(*(ptr_GD - 1))    - (sobel_kernel[2])*(*(ptr_GD + Length - 1));

Gy =(sobel_kernel[0])*(*(ptr_GD - Length + 1)) + (sobel_kernel[1])*(*(ptr_GD -
    Length))    +
   (sobel_kernel[2])*(*(ptr_GD - Length - 1)) - (sobel_kernel[0])*(*(ptr_GD + Length
      + 1)) -
   (sobel_kernel[1])*(*(ptr_GD + Length)) - (sobel_kernel[2])*(*(ptr_GD + Length -
      1));

G = (sqrt(pow(Gx,2) + pow(Gy,2)));
```

Code is from sobel() in ImProc.C located in section XVI

The total magnitude G is now compared against a threshold value, which can be manipulated to adjust the strength of edge detection. If only sharp changes in intensity are desired, to be recognized as an edge then you would set the threshold value very high and if any change of intensity is desired then the threshold will be set very low. It is a trial and error to see if the image turns out correctly or not and is easily adjustable. Conditional statements are used to then compare against this threshold to set a pixel value to either white (detected edge, G is above threshold) or black (nothing detected, G is below threshold).

6) Results of Sobel Edge Detection:

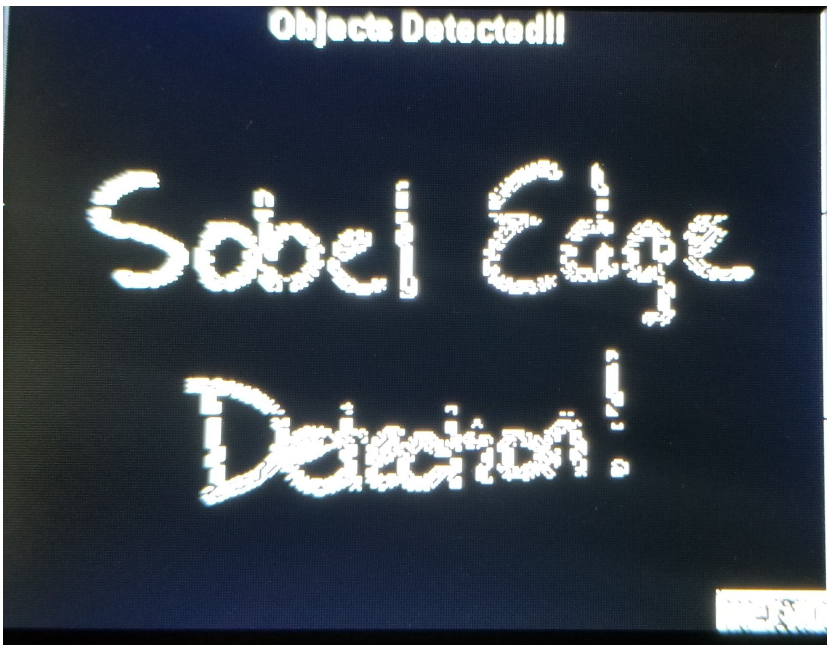


Fig. 54: Results of Sobel edge detection

D. Square_detection.c Algorithm

In order to begin the process of the eraser moving to the correct locations on the whiteboard, a rough detection of where the markings are located on the board needs to be found first. Using the array that the sobel edge detection algorithm produced, an algorithm was created to detect essentially the "square" in which the data was located. That is, it detects the top-most, left-most, bottom-most, and right-most locations of the white pixels in the finished array in order to create a virtual "square" around the data. The flowchart for the logic of the algorithm is shown in 11 in the *Project Description and Boundaries* section of this report. See the following figure for a visual representation, with an example of the board being divided into an 8x8 grid. In this example, the "square" coordinates for the top, left, bottom, and right-most markings is 2, 3, 6, 7 respectively, with the origin of the x and y axis being at the top-left corner of the board. This is how the system will know where to erase the data. The blue-arrowed path in the next figure represents the serpentine.c program, which is explained in the *Serpentine.c* Algorithm section of this report.

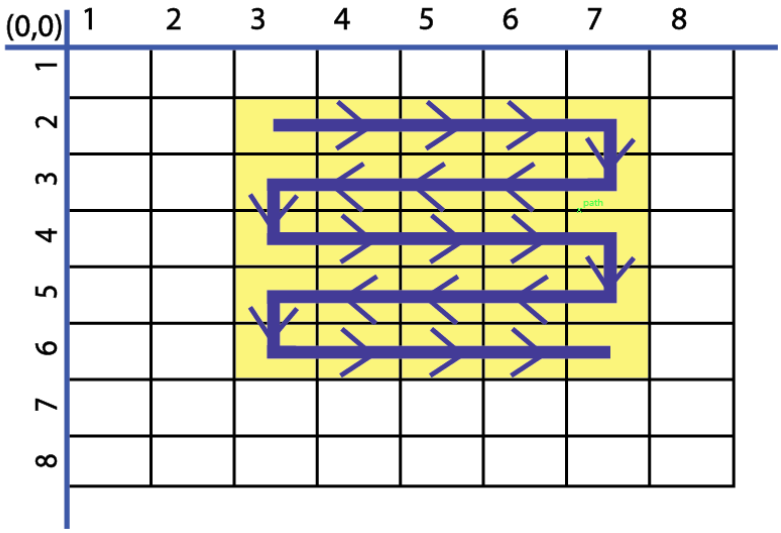


Fig. 55: Visualization of *square_detection.c* and *serpentine.c* working together to eraser markings on the whiteboard

The actual code for this algorithm has been completed using a "dummy" matrix with random values of 0s and 1s representing blank space and markings. The code for this is in *Appendix 3* of this report. The result with this dummy matrix is shown in the following figure. This program is then combined with the *serpentine.c* algorithm explained in the *Serpentine.c Algorithm* section of this report.

```
Here is your matrix:
0  0  0  0  0  0  0  0  0  0  << row 0
0  0  0  0  0  0  0  0  0  0  << row 1
0  0  0  0  1  1  1  1  0  0  << row 2
0  0  0  0  0  1  1  1  0  0  << row 3
0  0  0  0  0  1  1  1  0  0  << row 4
0  0  0  0  0  1  1  0  0  0  << row 5
0  0  0  0  1  1  1  0  0  0  << row 6
0  0  0  0  1  1  1  1  0  0  << row 7
0  0  0  0  0  1  1  1  0  0  << row 8
0  0  0  0  0  0  0  0  0  0  << row 9

These are the values that were found:
top-most = 2
left-most = 4
bottom-most = 8
right-most = 7

Therefore, the coordinates to be sent to the stepper motors are:
Coord = [2  4  8  7  ].

I hope your values are what they were supposed to be!

Press any key to continue . . .
```

Fig. 56: Result of *square_detection.c* program with the dummy matrix introduced within it for testing

E. UART Communication - PSoC 6 to HUZZAH32 (server)

Universal Asynchronous Receiver/Transmitter (UART) was chosen as the communication protocol between the main microcontroller (PSoC 6) and server microcontroller (HUZZAH32). This is the simplest of the three communication protocols used in the Smart Eraser. As the name suggests, communication is asynchronous, meaning there is no clock regulating the transfer of data between devices. Instead a baud rate is used, which is defined as the rate information can be transferred along a communication channel. Unlike SPI and I^2C, there is no master/slave relationship and thus communication relies on a few, simple parameters. Each device must be set to the same parameters in order to properly communicate. These parameters include; baud rate, parity, stop bit(s). The Smart Eraser system operates with a 115200 baud rate, parity enabled and set to even, with 1 stop bit and aheres to the RS232 standard of serial communication [30].

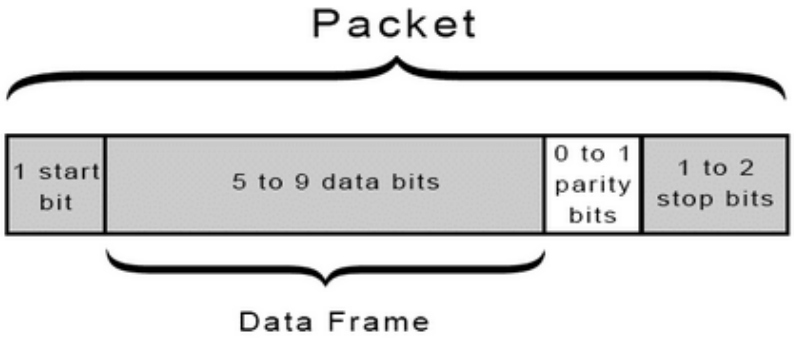


Fig. 57: UART packet contents [20]

The original plan was to communicate with I^2C because the PSoC 6 already had a configured SCB for master I^2C transferring capabilities. However, due to limitations with the HUZZAH32 (currently only configurable as master (both SPI and I^2C)) UART was chosen instead. While researching UART it was found that this is often the chosen method of communication between MCUs so it worked out being the best option anyways. The code implementation of sending packets to the server (written in C) and how

the server receives the packets (written in Python) is shown below:

Code Implementation (UART TX):

```
Cy_SCB_UART_PutArray(KIT_UART_HW, ptr_PD, 25);
Cy_SysLib_Delay(1);
Cy_SCB_UART_ClearTxFifoStatus(KIT_UART_HW, CY_SCB_UART_TX_DONE);
```

Code is from Process_Image() in main.C located in section XVI

Code Implementation (UART RX):

```
def UARTread():
  uart.init(9600, bits = 8, parity = 0, stop = 1, rx = 16, tx = 17)
  buff = bytearray(8)
  while not uart.any():
    pass
  uart.readinto(buff)
  uart.init(baudrate = 9600)
  return buff
```

Code is from UARTread() in UART.py located in section XVI

F. The Original Plan for Wireless Communication

When this project was originally started, the idea was to use wires to connect all of the components. This meant that a long wire would need to be used to connect the components on the Y-axis of the whiteboard in order to allow it to move. This idea was abandoned when everyone involved realized that not only would wireless communication allow for a more âĂIJpleasing to the eyeâĂİ design, but would also add a layer of complexity to the projectâĂŹs difficulty.

The original plan for the wireless communication was to use Raspberry Pi boards that would connect to the DE1_SoC wirelessly via a wireless dongle that would plug into the DE1_SoC. However, the transceivers that were found that would allow the Raspberry Pi boards to be wireless were only compatible with Arduino boards, so the Raspberry Pi was changed to Arduino. Soon after, problems arose from using the DE1_SoC, so the microcontroller changed to the PSoC 6, and the new plan became to hardwire the transmitter Arduino to the PSoC 6.

1) Arduino Wireless Communication: Arduino microcontrollers are notoriously straightforward to use because of their open-sourced nature, meaning that there are already many libraries that are made for the board for various other external devices they can be used with, as well as applications that they can be used for. Therefore, the wireless communication between the transmitter and receiver Arduinos was straightforward, as well as the connections between the board and the transceiver.

The transmitter Arduino that would send instructions to the stepper motors was the model MKR1000, and the transceiver that could process the wireless communication and send the information needed was a Kuman nRF24L01 with an attachable antenna to extend the range that the wireless radio signal could reach. The pin layouts for the MKR1000 and the transceiver are shown in the following figures.

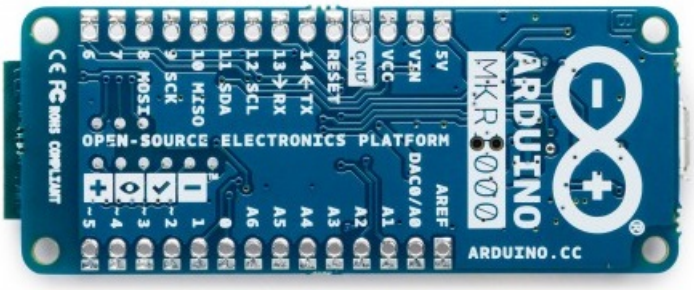


Fig. 58: Image and pin layout of the MKR1000 WiFi module by Arduino [21]

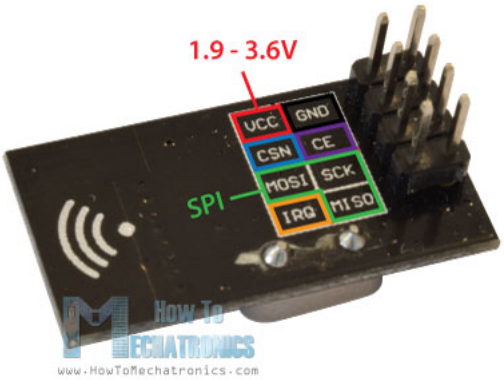


Fig. 59: Image and pin layout of the Kuman nRF24L01 transceivers[22]

A diagram showing the connections between these two chips is in the following figure.

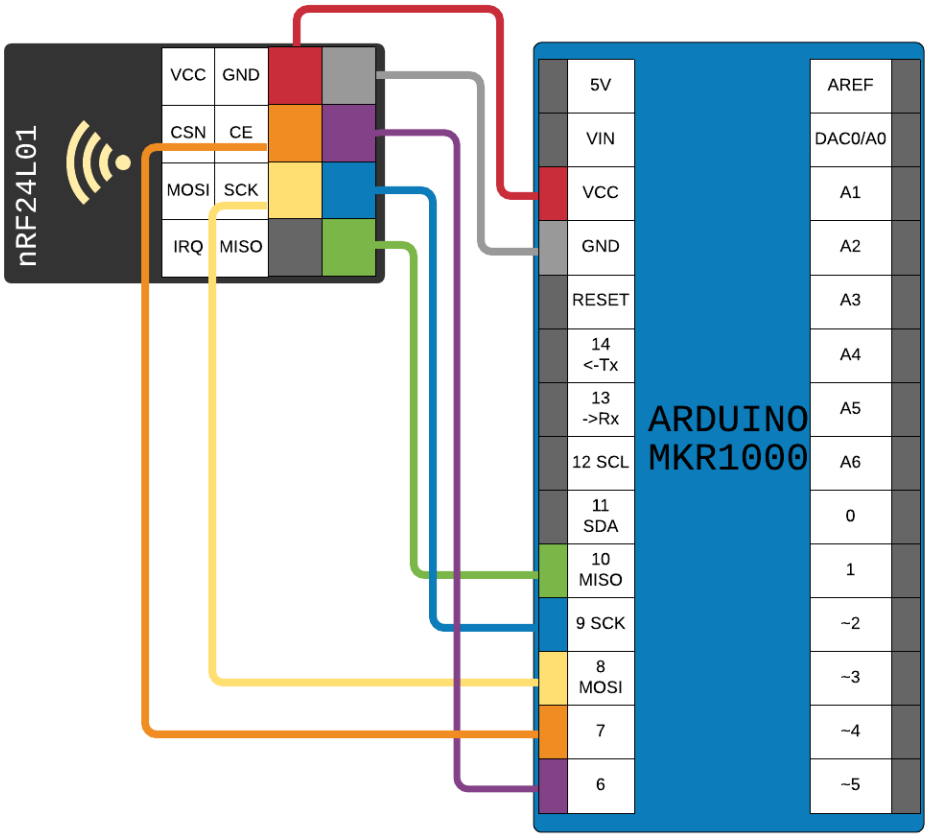


Fig. 60: Pin connections between the MKR1000 microcontroller and the wireless transceiver to create the transmitter module

For the code of the transmitter, the template code was taken from the example shown by Dejan Nedelkovski, and is shown in Appendix 1 of this report. In order to use the wireless transceiver, the specific library made for it needed to be included. The RF24 radio was then configured to use pins 6 and 7 on the Arduino as the CE and CSN pins shown in 59. In the setup of the program, the radio connection is initialized, the PA level is set to the minimum it can be, and the radio is set to be a transmitter with the stopListening() function. The addresses the transmitter will be sending data to are also outlined. The PA is the Power Amplifier factor, and the higher it is, the more unstable it can be, which would then require a bypass capacitor to be connected between the voltage power source and ground connected to the chip. Therefore, it was kept to a minimum, especially because the modules were so close together, so it was unnecessary to amplify it more.

Next, in the main loop of the program, in order to send a signal to a specific address, a writing pipe needs to be opened to that address. Only one writing pipe can be open at a time, so separate writing pipes to each receiver were opened and continuously alternated between in the loop. The number for the stepper motors to rotate a certain degree were then sent using the radio.write() function, whos parameters include a pointer to the name of the variable to send to the receiver, and the length of the data.

The receivers that were attached to each stepper motor were the Arduino UNO R3, and the transceivers were the same model used for the transmitter. The Arduino UNO R3 used is shown in the following figure.

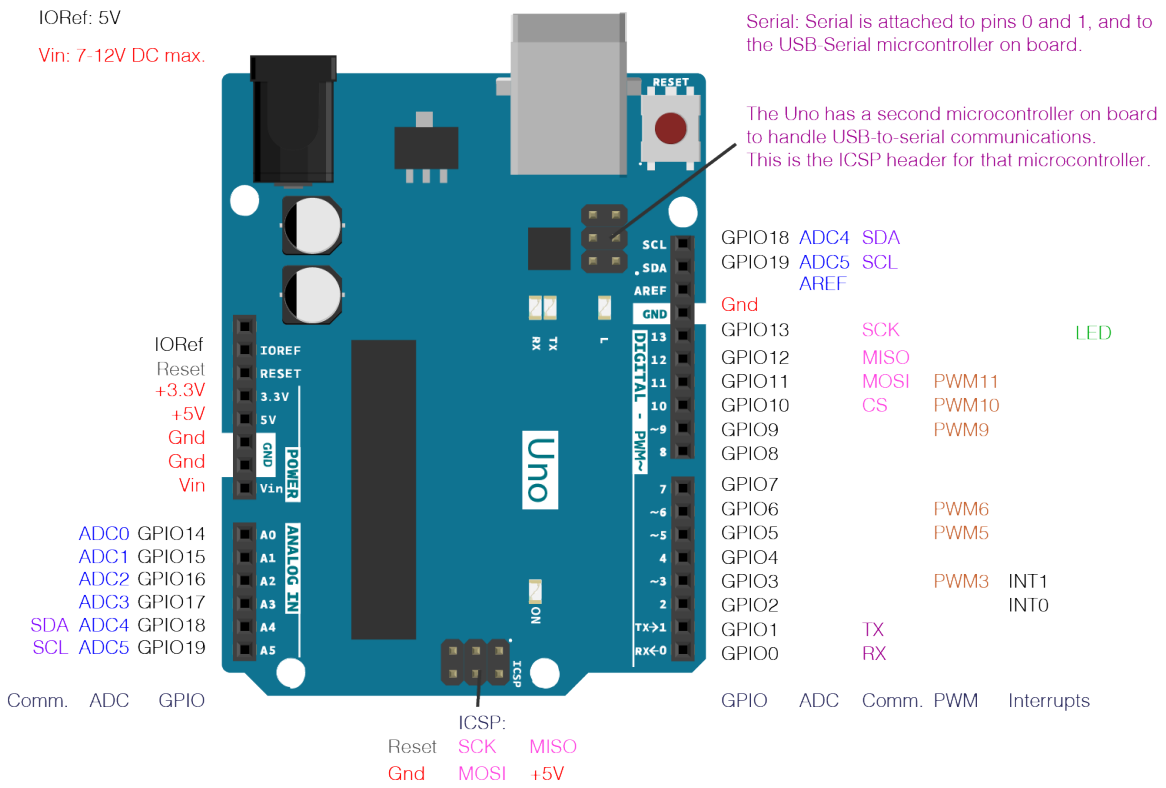


Fig. 61: Pin layout on the Arduino UNO R3 [23]

The pin connections between the UNO R3 and the wireless transceiver are shown in the following figure.

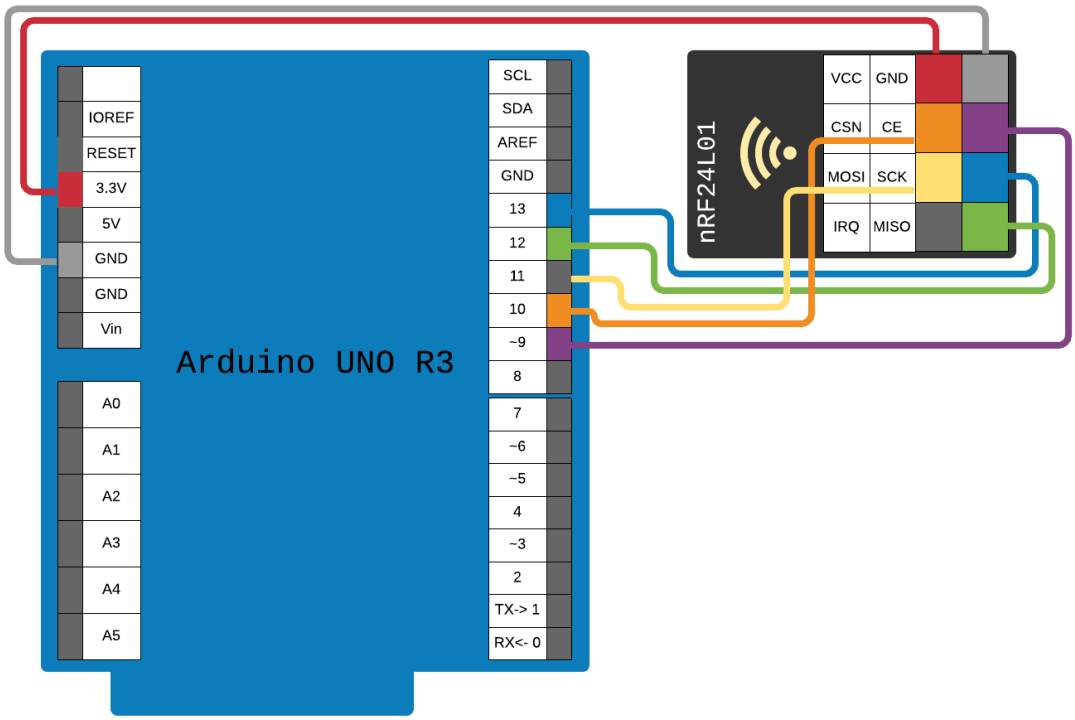


Fig. 62: Pin connections between the UNO R3 microcontroller and the wireless transceiver to create the receiver modules

For the code of the receiver, the template code was taken from the example shown by Dejan Nedelkovski, and is shown in Appendix 2 of this report. In order to use the wireless transceiver, the specific library made for it needed to be included. The RF24 radio was then configured to use pins 9 and 10 on the Arduino as the CE and CSN pins. In the setup of the program, the radio connection is initialized, the PA level is set to the minimum it can be, and the radio is set to be a receiver with the startListening() function. The address of the receiver is set, and the baud rate is also set for the Serial Monitor within the Arduino IDE so it will read in data at the specified rate. Next, in the main loop of the program, a loop is created to check if there is data available to receive. If there is, the data is read into a variable to be used for the stepper motor movement.

When both of these programs ran, they each received the instructions wirelessly and were able to move the stepper motors the right degree of rotation. However, unfortunately, due to an unknown reason the wireless communication stopped working with about 30 days left to complete the project. The most likely culprit for the malfunction may have been due to faulty transceivers; upon further inspection of the reviews left by those who have used these devices in the past, many did not work correctly upon arrival. Therefore, this method of wireless communication had to be replaced with three HUZZAH32 Feather boards by Adafruit, with one being used as a host server (a.k.a. the transmitter) and two being used as clients to the server (a.k.a. the receivers). This leads to the current wireless communication system, which is a connection between a ‘host’ or ‘server’ (which acts as the transmitter) and the ‘client’ (which acts as the receievr).

G. The Current Wireless Communication System

The decided upon wireless communication system was to use a client/server implemented on HUZZAH32s. One would act as the server, directly interacting with the PSoC 6 and the other two would be clients, attached to the stepper motor systems. Using micropython, the server uses libraries and socket programming in order to achieve this. Both clients and server will be set up as stations and a router will be used in order for the server to talk to the clients. There are few things that are necessary in order for this to work. There needs to be two separate IP addresses for the network and server as well as defining a port on the server side so that the clients know what to look for. Lastly, as this is a TCP connection, there must be acknowledgment for every packet sent. These ACKs are handled behind the scenes through the Python socket library.

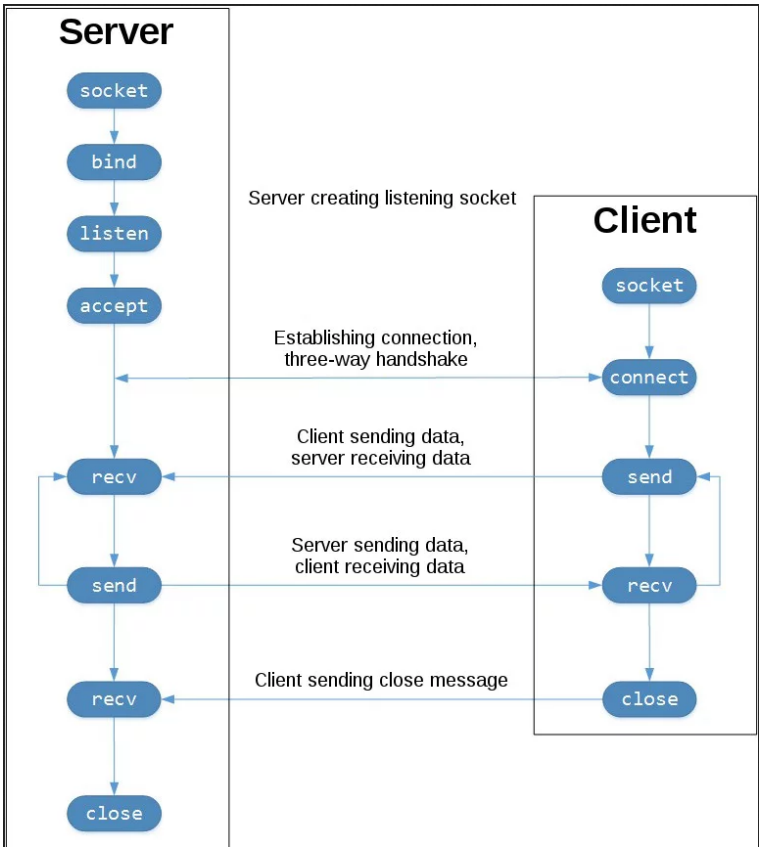


Fig. 63: Overview of client/server interaction [5]

1) Server: The HUZZAH32 used for the server is connected to the PSoC 6 through UART so that it can receive the results generated from *Square_Detection.c* that runs on the PSoC 6. After initialization is done and the socket is listening for connections, it will stay in an infinite *while loop* to wait for both clients to connect. Each client that connects creates a new client thread on the server. Since there are a maximum of two clients, there will only ever be 2 threads running alongside the main. This worked out for the Smart Eraser system as the HUZZAH32 is much better at working as a client than a server handling multiple clients due to threading limitations in the current firmware. After exactly 2 client threads have been created, the main loop then waits for information to come in over UART. A *UARTread()* function is called which waits in a passing loop until information is received. When data is detected through UART, the incoming data is stored into a byte array and returned to the main function. This process can be seen in figure 64.

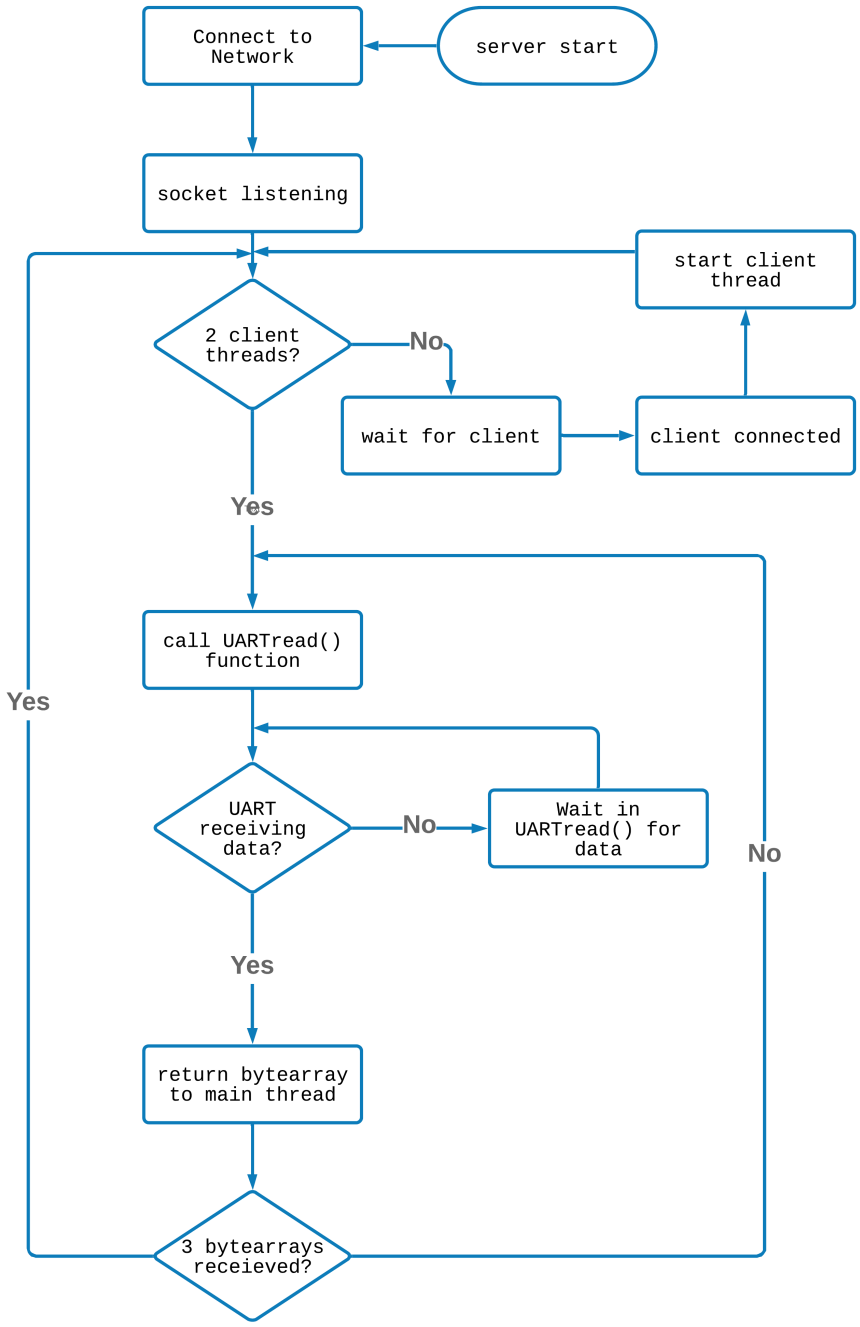


Fig. 64: Flowchart of how the Server code works

The client threads wait on this information before they can move any further. Both threads have access to the global byte array that stores the information incoming from UART. As soon as this array is not empty, the threads attempt to acquire the lock. Whichever one doesn't will have to wait until the other one is done sending its information, at which point the lock will be released. This is so that the micro controller does not become overwhelmed with too many parallel processes happening at once. This process happens for each 1/3 of the image that is processed meaning there will be three blocking calls in each thread to received all the information from each section. After the third byte array is received and both

threads send the necessary data, each thread will exit (terminate). The only process running at this point should be the main thread waiting for two more client connections, starting the process all over again.

Code Implementation Server (main thread):

```
while 1:
 k = 0
 while (k < 2):
  conn, addr = s.accept()
  print('Connected with ' + str(addr[0]) + ' : ' + str(addr[1]))
  start\_new\_thread(clientthread ,(conn, addr))
  k = k + 1
 self.List1 = []
 self.List2 = []
 self.List3 = []
 self.List1 = UARTread()
 self.List2 = UARTread()
 self.List3 = UARTread()
 time.sleep(5)
 self.List1 = []
 self.List2 = []
 self.List3 = []
 k = 0
```

Code is from SMserver.py located in section XVI

Code Implementation Server (client threads waiting for UART):

```
while self.List1 == []:
 pass
while not lock.acquire():
 pass
print(self.List1)
#Send first set of instructions
conn.sendall(self.List1)
time.sleep(2)
lock.release()
```

Code is from SMserver.py located in section XVI

2) Clients: The two other HUZZAH32's will be used to act as clients, receiving information from the server that will be used to set variables for stepper motor movement. The information being received is in the form of byte arrays, which need to be converted for mathematical operations. Although the solution is quite simple, it took some major digging to come across a solution that was straightforward and actually worked. Most solutions were not able to be implemented with micro python. Thanks to user JohanL on a stack overflow forum under the topic "Convert python byte "array" to int "array [32], we were able to convert the byte array to useful data. It turns out that the list constructor in python can translate a bye array into data that can be used with math operations. Therefore, a list was created out of the byte array information received from the server. Once the client has 3 lists of information from the server, they run the *serpentine()* function corresponding to the three different sections in the image.

Code Implementation Server (client threads waiting for UART):

```
while self.List1 == []:
 pass
```

```
while not lock.acquire():
 pass
print(self.List1)
#Send first set of instructions
conn.sendall(self.List1)
time.sleep(2)
lock.release()
```

Code is from SMclientX.py located in section XVI

3) Serpentine.c Algorithm: After finding the square in which all the data is contained on the whiteboard, another algorithm takes the edges of the square detected and creates a series of instructions for the stepper motors. The logic flowchart of this algorithm is shown in 12 These instructions are the number of rotations needed to move the stepper motors in a certain direct, and are given to each motor serially to take a similar path to the one shown in Figure 55. First, the motors are given the instructions to move to the top-left space of the data square. Then, the X-axis motor is continually given instructions to move from the far left side of the square to the far right of it, and the Y-axis motor is continually given instructions to move down one rotation in order to traverse down the square until all the material is erased. The algorithm then checks to see if the eraser stopped on the right side or the left side of the square based on how many rotations it needed to take to erase the markings. Based on this position, it gives the final instructions to the stepper motors to move the eraser back to its stand-by position at the top left of the entire whiteboard to await the next instructions sent to it. When this program is ran with dummy values, it sends the correct sequence of instructions to the x and y stepper motors in the format of the number of rotations it needs to take if it were traversing the same dummy matrix from the *square_detection.c* algorithm.

```
top space: 2. left space: 4. bottom space: 8. right space: 9.
starting x position=4
starting y position=2
rotateX=5
x =5
y =1
y =0
x =-5
x =0
y =1
y =0
x =5
x =0
y =1
y =0
x =-5
x =0
y =1
y =0
x =5
x =0
y =1
y =0
x =-5
x =0
y =1
y =0
x =5
x =0
x =-9
x =0
y =-8
y=0
Press any key to continue . . .
```

Fig. 65: Result of *serpentine.c* program with the dummy values introduced within it for testing

4) Stepper Motor Movement: The stepper motors that were chosen for this project are the NEMA 23 CNC stepper motors. Stepper motors contain magnetic coils surrounding a magnetic rotor that need to be powered in a certain sequence in order for the rotor to turn in either a clockwise (CW) or counter-clockwise (CCW) rotation. This particular stepper motor is a 2-phase bipolar motor, meaning it contains 2 groups of coils, and it uses all coils within the motor to work to turn the motor the direction needed. A layout of the inside of this motor is shown in the following figure, which shows how the coil windings are oriented in comparison with the rotor. The different color names represent the colors of the wires that need to be connected to the stepper motor driver.

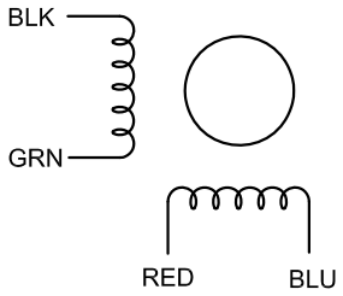


Fig. 66: Rotor and coil layout in the bipolar 2-phase NEMA 23 stepper motor

The specific combination of pulses in the order they need to be for CW and CCW motion are shown in Figure 9 in this report. The pulse configurations shown in this figure allow the code to begin to be formed in order to rotate the stepper motors in the directions needed. The colors that correspond to the A, B, A B input leads are shown in the next figure.

TYPE OF CONNECTION (EXTERN)		MOTOR	
PIN NO	BIPOLAR	LEADS	WINDING
1	A —	BLK	A
2	A\ —	GRN	A\
3	B —	RED	B
4	B\ —	BLU	B\

Fig. 67: Labeling of lead colors corresponding to winding inputs

Because of the libraries included in the Arduino library, the code for the stepper motors was as simple as initializing the stepper motor pins being used as shown in Appendix 2, setting the speed in the initialization loop, then putting the number of rotations per minute into the function defined. However, because the wireless communication unfortunately stopped working, the code for the stepper motors to move needed to be redone in Micropython in order to allow the motors to move with the new HUZZAH32 boards being used for the wireless communications.

With the HUZZAH32 microcontrollers, the stepper motor code is also straight forward, as the coding language they use is Micropython. In this language, the code is as simple as putting the correct phases in 4 steps (as shown in 9) by listing them as numbers in an array, then sending those steps to the stepper motor serially. If the motor needs to rotate in the counter clockwise direction, the array with the 4 steps can be reversed using the *.reverse()*. A check condition checks for a negative number in order to perform this operation. The code for this part is in *Appendix 15* of this report. The results of this code running

are the stepper motors rotating depending on the number put into the variable ‘x’.

5) HC-SR04 Ultrasonic Sensor: The HC-SR04 is an ultrasonic sensor that can detect objects between the range of 2 cm to 4 m. To detect objects, a pulse is sent via the trigger pin (minimum of 10 Âţs), which triggers an 8 cycle 40 kHz burst of ultrasound. The time it takes to receive the echo of that burst can be used to calculate the distance of the object. Because the frequency is relatively high, the HC-SR04 Is a shorter-range sensor (4m is approximately 13 feet). This means that to increase the range of detection, the frequency would need to be lowered. The sensor needs to be connected to a microcontroller and be provided with 5V (not 3.3V), a ground, and 2 connections to GPIO pins (for the trigger and echo signals).

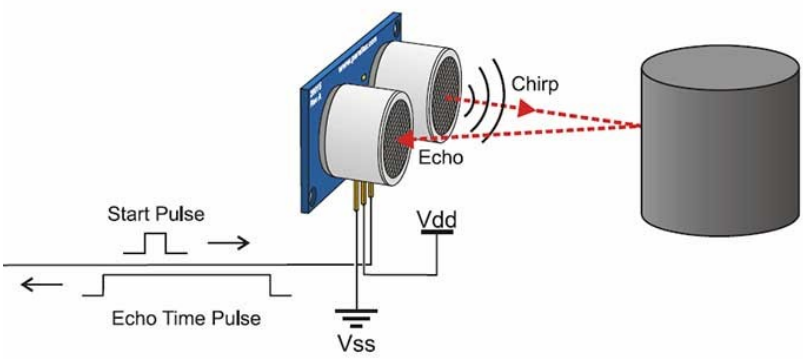


Fig. 68: How the ultra sonic sensor works [24]

Code Implementation Ultra Sonic Sensor:

```
while self.List1 == []:
pass
while not lock.acquire():
pass
print(self.List1)
#Send first set of instructions
conn.sendall(self.List1)
time.sleep(2)
lock.release()
```

Code is from SMclientX.py located in section XVI

H. Hardware

1) Using the Logic Analyzer: The logic analyzer is vital to figuring out how data is actually being transferred between interfaces. The I^2C, SPI and UART communications that were developed for the Smart Eraser system would not have been successfully implemented without using the logic analyzer. While creating the software to interact with these communications the need for APIs was needed in order to do so. Some of these APIs are not 100% descriptive of what they actually do and was only discoverable through using the analyzer. Figure 69 shows results of a finally sending and receiving information over SPI successfully.

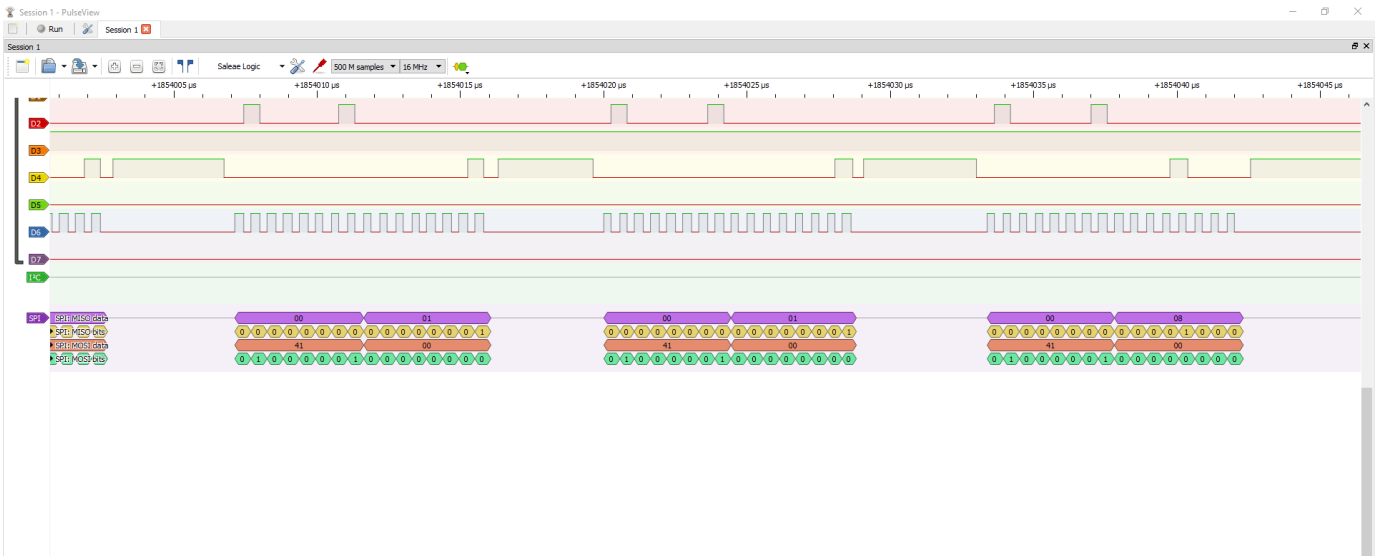


Fig. 69: SPI analysis using the logic analyzer

2) Stepper Motor and Driver Connections: In order to drive a stepper motor, an H-Bridge needs to be used in order for current to flow to the correct coils, which supply the amperage needed to rotate the internal magnetic coil. In this project, the DM542T stepper drivers act as the H-bridge needed. The four different-colored leads (black, green, red, blue) are plugged into the A+, A-, B+, B- nodes, respectively. These nodes will send out the proper pulse signals to the stepper motor, as well as the voltage and current needed to drive them, depending on the inputs given to the PUL and DIR nodes. The PUL+, PUL-, DIR+, and DIR- nodes are connected to the HUZZAH32 Feather board in order to control the stepper motors. These signals are those that need to be coded into the microcontroller in order to be the control behind the motors. The PUL nodes control the pulse signals sent to the bipolar motor coils, and the DIR nodes control the direction of the flow of current into the coils, thus allowing the motors to run both CW and CCW. The driver used is shown in the following figure.

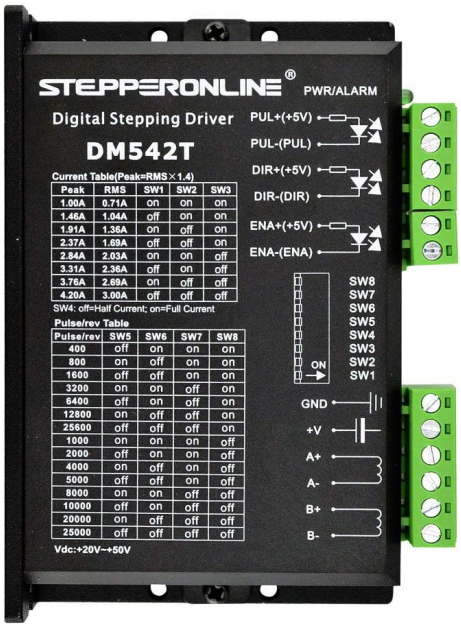


Fig. 70: Stepper motor driver for the NEMA 23 [25]

The stepper driver is able to be modified to alter the current flowing out to the stepper motors. The amperage supplied to the motors is directly proportional to the amount of torque the motors can provide. The Y-axis stepper motor driver's configuration allowed 1A to flow to the motor, and it was able to pull the weight attached to it. However, because there is a heavier load on the X-axis motor, the configuration had to be changed to allow more current to flow to get more torque to pull the extra weight without difficulty. That driver was set to the next setting up, which is 1.46A, and this allowed it to pull the extra weight fine. The max tolerance of current the motors can take is 2.8A, so if more weight was added as well, the motors would more than be able to handle it.

3) Power Parameters: The power rating for each component was important to take into account when thinking about the power supplies for the wireless components. The stepper motors are rated to have a driving voltage of anywhere from 24-48V, and the stepper drivers a driving voltage of 20-50V. Taking the mobility of the components into account, the final decision for the power sources for the different stepper motor components on the whiteboard wound up being three 9V batteries in series for one setup. Ideally, there would be 27V flowing to each stepper motor through the stepper drivers, but when measured in the lab, it wound up being about 24V flowing to each motor system. This is plenty to move the motors the way they need to, so this is the method that was chosen. For the other setup, a more stable power source will be used. This was decided for two reasons: the first being that the X motor system will not be moving, so it can have a dedicated power system that doesn't move, and can therefore be plugged into a power outlet if need be. The second reason for this decision was because the X motor needs a higher current due to the higher torque needed to move the heavier load of the Y-axis components. The following equation can be used to understand the power consumption parameters that were taken into account when making sure the batteries would provide enough current for the mobile part of the system. Figure 71 shows an image of the separate power supply.

$$PowerConsumption = E_{kWh/day} = \frac{P_{(W)} \times t_{(h/day)}}{1000_{W/kW}}$$

Fig. 71: TDK Lambda power supply [25]

4) Printed Circuit Boards (PCBs): In order to connect everything in the original configuration of the wireless communication system, PCBs were made to ensure loose wires would not detract from the overall look of the final prototype. These PCBs were made for each stepper motor in order to connect the wireless transceivers, the Arduino UNO R3 microcontrollers, a 9V battery to the Arduino board for wireless power, and to connect the 3 9V batteries in series that would have powered the stepper motor drivers. The following figure shows the layout of the PCBs.

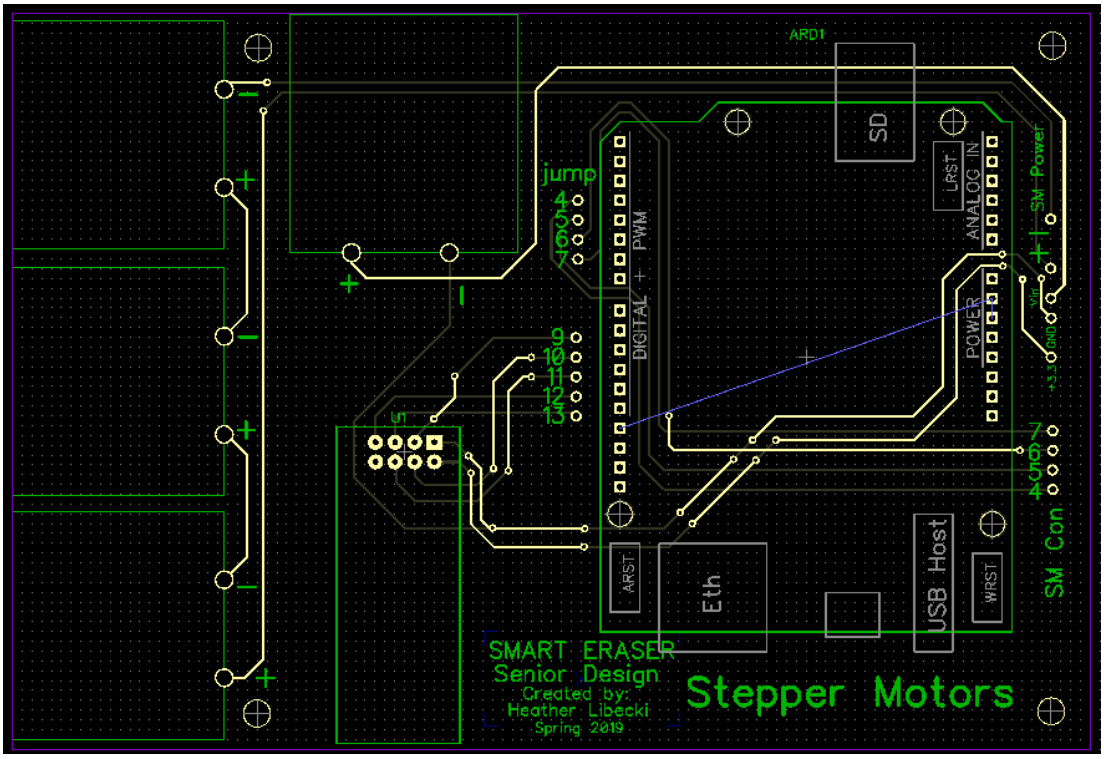


Fig. 72: Layout of PCBs

The following figures show a before and after shot of what the components looked like connected before and after using the PCBs. They are much more organized and pleasing to the eye to look at.

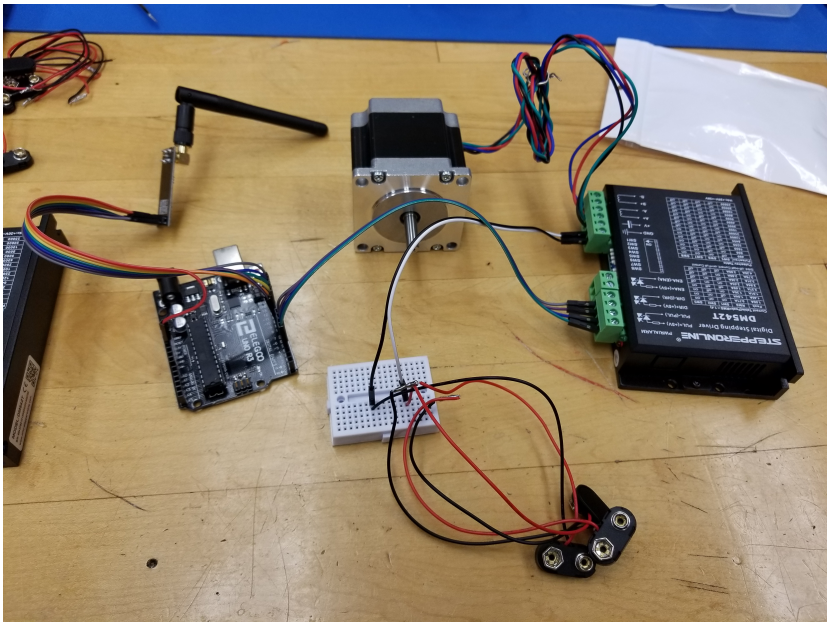


Fig. 73: Connection of stepper motor system before PCBs

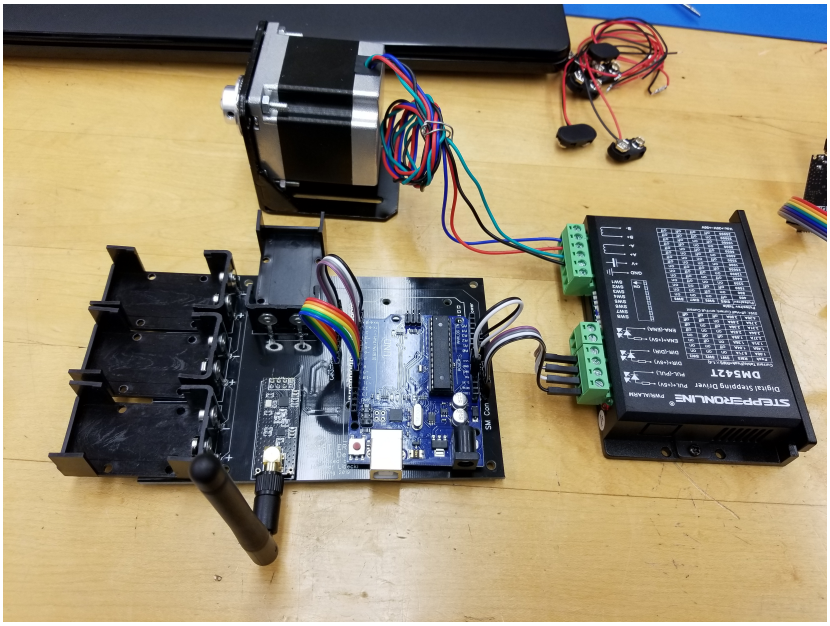


Fig. 74: Connection of stepper motor system after PCBs

Unfortunately, because the wireless transceivers stopped working three weeks before the project needed to be completed, the PCBs were not used in the final version of the product.

I. Project Prototype - Planning

This section contains all information about the conception, creation, and finalization of the prototype stand for the Smart Eraser to be mounted on.

1) Initial Prototype Design: The following images show the initial conception of the prototype stand, as well as some rough dimensions.

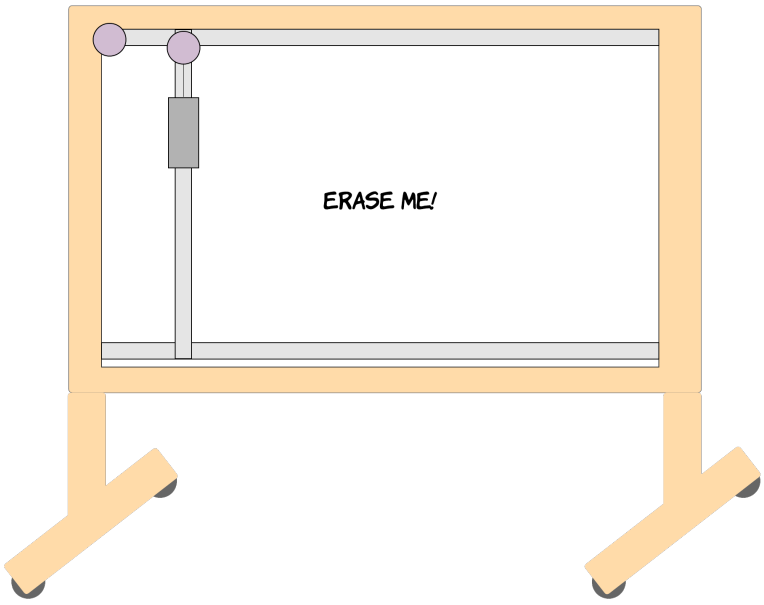


Fig. 75: A rough initial image of the prototype

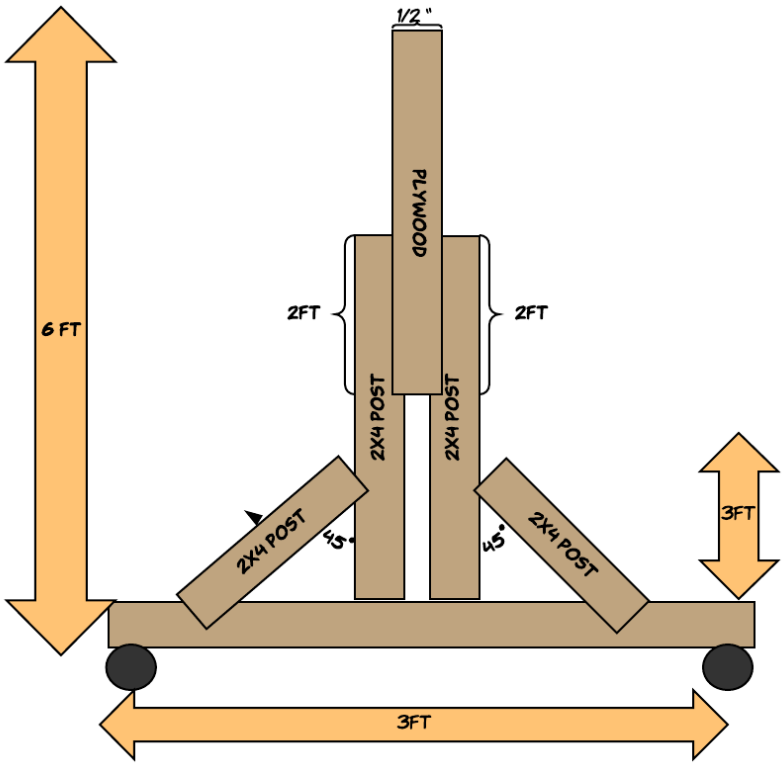


Fig. 76: A rough side view with dimensions of the prototype

These images helped to think of how large the stand should be.

2) Final Prototype Design and Dimensions: After the initial conception of the prototype stand, more definitive dimensions were found for the different components that would be connected to the board. The following figures show the more detailed dimensions, as well as a more detailed figure that shows where everything would be placed relative to each other.

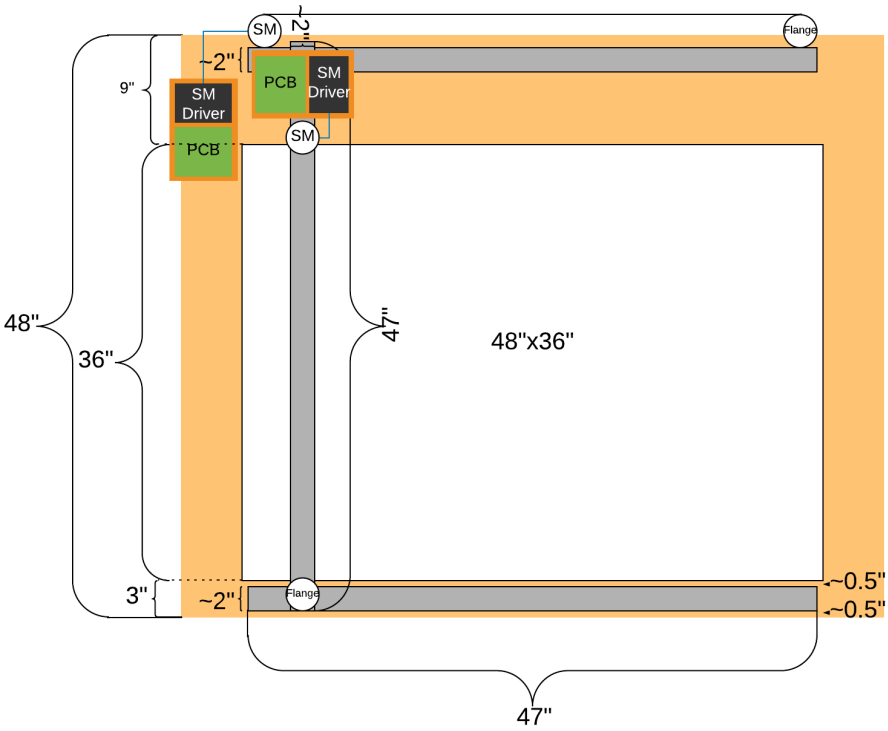


Fig. 77: The front view of the prototype stand schematic

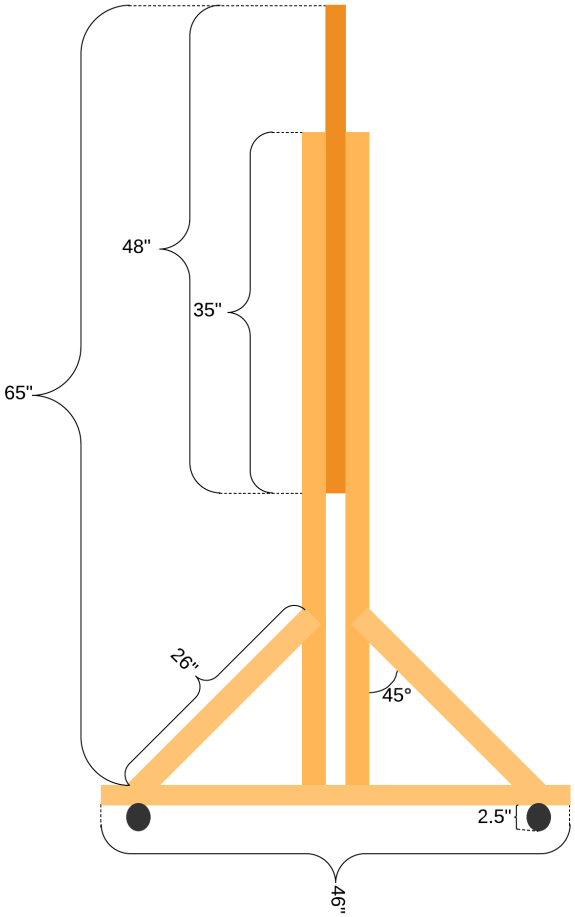


Fig. 78: The side view of the prototype stand schematic

The prototype stand stands about 7 feet tall, but the whiteboard itself is lined up so the top is level with about 6 feet off the ground. This height was chosen in order to have the whiteboard at a position in front of the user so they wouldn't need to strain to write on it. Looking at the side view image of the dimensions of the whiteboard, there are two 2"x4" posts on each side of the wooden backing to hold the board up: one attached to the front of the board, and one attached at the same place as the other, but on the back of the board. This design was chosen with the stress being placed on one post in mind; too much stress on one of the posts would result in a more unstable design, especially with the moving parts on the board. At the bottom of these posts are more 2"x4" posts that are parallel with the ground that measure a little over half of the height of the entire prototype. This length was decided upon in order to ensure there was enough room to attach two more 2"x4" posts at a 45 degree angle to the vertical 2"x4" and the horizontal 2"x4" to enable it to be more sturdy. The horizontal posts have wheels attached to the bottom of them so the prototype stand can be mobile, as it needs to be brought to the Satellite Student Union for Projects Day. Finally, the plywood that everything (the whiteboard, the tracks, the stepper motors and drivers, etc.) is attached to was limited one side only being 48", so this was decided to be the height of the device. The original width of the board was 96", but it was cut down to 66" in order to allow room for the 2"x4"s to attach to the board, as well as the stepper motors, their drivers, and the PCBs. Three separate 2"x3" pieces of wood were also cut and put on the back of the plywood to prevent the plywood, and subsequently the components being mounted to it, from warping due to instability or weather conditions when it is taken outside to go to the Satellite Student Union on Projects Day.

After finishing the conception of the prototype, building it and putting everything together came next.

J. Project Prototype - Building

Building the prototype took approximately 3 days; one day for connecting all of the wood pieces, and 2 for connecting all of the tracks, stepper motors, and making sure they would all be able to work together if motors rotated the pieces. An additional day was needed a couple weeks later to mount the smaller pieces, including the motor drivers and power systems. The following sections detail the steps that were took to put the system together, and they also contain images of the finished product.

1) Component Mounting Steps: The following list contains the steps that were followed when putting the stand together.

1) Take measurements and sketch lines to cut the wood.
2) Cut the plywood to be 48"x66" at Home Depot.
3) Cut the 2"x4" posts at all necessary lengths, widths, and angles.
4) Cut the 2"x3" posts for the stability of the unit to their appropriate lengths.
5) Drill and screw together the posts to the plywood.
6) Drill and screw together the horizontal posts to the bottom of vertical posts so the stand can actually stand.
7) Drill and screw together the 2"x3" posts to the back of the board.
8) Take measurements for the housing of the X-axis track (the board between the plywood and the track).
9) Cut the leftover posts and drill and screw them onto the plywood.
10) Drill the wheels to the bottom of the stand.
11) Drill the holes into the X and Y-axis tracks to mount onto the board, and mount onto the carriages of the X-axis.
12) Mount the stepper motors.
13) Mount the flange on the opposite side of the tracks.
14) Wrap the pulley belt around the stepper motors and the flanges.
15) Attach belt to carriages with washers and nuts so the axes will actually move when the stepper motor rotates.
16) Attach the braces to the Y-axis carriage to create a clamp to hold the eraser.
17) Attach the smaller pieces (including the stepper motor drivers, power systems, etc.) to the board.

2) Final Product: The final product in progress showing how the components were mounted to the front of the board, as well as the finished final product, are shown in the following figures.

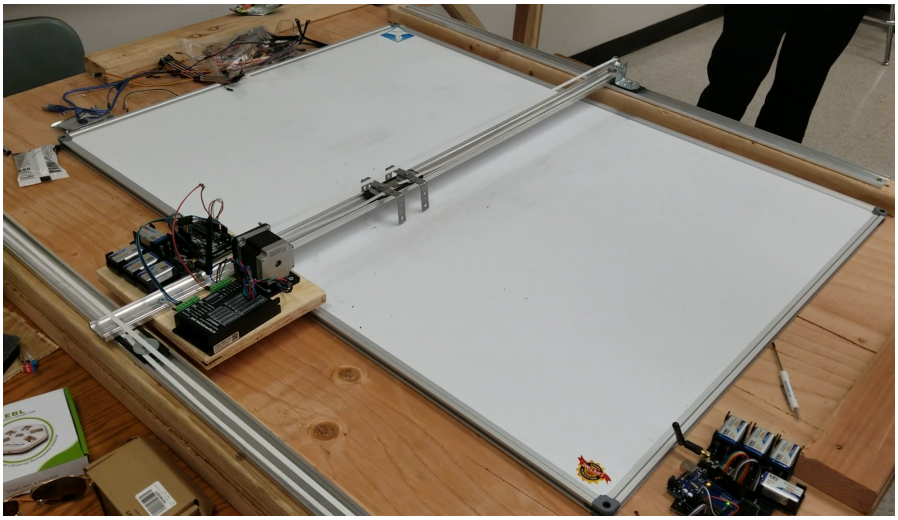


Fig. 79: The building of the prototype stand in progress

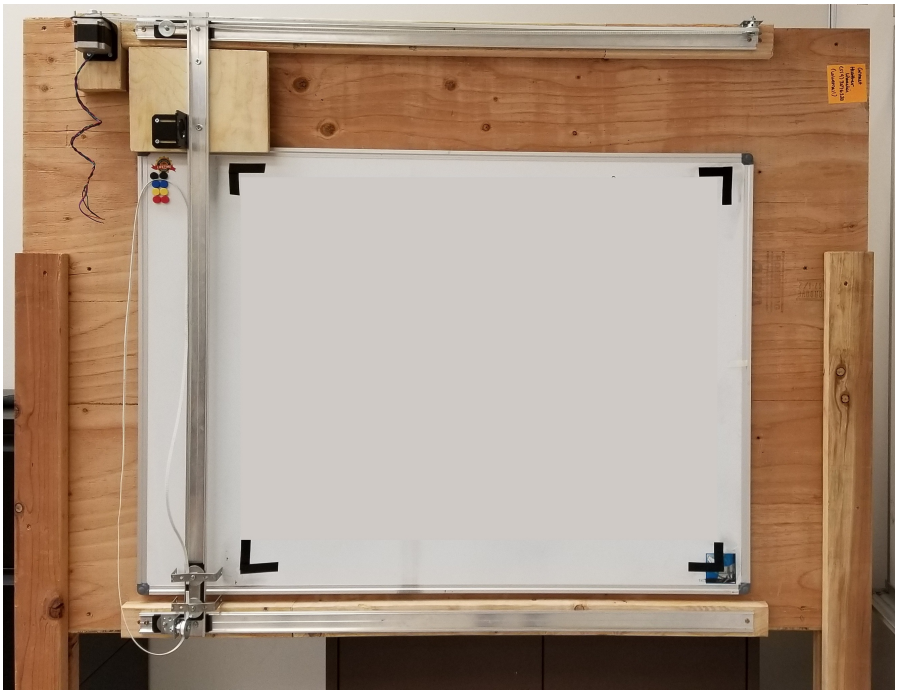


Fig. 80: The front view of the actual prototype stand

The dimensions of the product were slightly altered from those written on paper, as they didn't account for the height of the door frame to get the board out of the room. It was lowered to be able to fit under the door with 1"-2" of leeway; the standard doorway height is approximately 84 inches, so in order to comply with this standard, the plywood of the prototype was lowered about 5 inches downward. Originally, there was no forethought as to how the plywood would be kept straight across and not warp, because this factor was not considered. After realizing that this would be an issue, three 2"x3" pieces of wood were cut and put onto the back of the board to keep it from warping due to instability or environmental conditions. Finally, the original plan did not account for how tall the components would be coming off of the board.

Therefore, more 2”x3” pieces of wood were used to lift the tracks off of the plywood so the tracks would be in front of the whiteboard, rather than on top of it. Other than these changes, the original plan for the whiteboard wound up being a success.

XIII. Stakeholder List

1) Aaron Stillmaker, Ph.D.: As the professor of the Senior Design course, he wants to guide the students working on the Smart Eraser toward success through the completion of this project. Is also the manager of the project deliverable due dates.

2) Hovannes Kulhandjian, Ph.D.: As a technical advisor of this project, he wants to see the success of this idea. He also held the original concept of this project, therefore he wants to help give technical advice to the students working on the Smart Eraser, as well as see the final product of their efforts.

3) Roger Moore: As a technical advisor of this project, he wants to see the success of this idea. He has contributed his opinions on some of the technology and methods used for the image processing program, and wishes to see this project come to fruition. Although he has offered advice and his expertise, he does not wish to be apart of the Approvals signature section of this report. Therefore, in that section, his name is omitted.

4) Richard Martinez, Research and Development - DPS Telecom: Sponsor that will be contributing funds to this project. He will also be providing the expertise of those who work at his company, as well as any additional resources that may be needed for testing the product and creating any deliverables. Although his company has contributed these funds to this project, he does not wish to be a part of the Approvals signature section of this report, as he considers the fund a “donation” rather than a “contribution”. Therefore, in the Approvals section, his name is omitted.

5) Heather Libecki: Project Manager, Team Member

6) Chris Quesada: Team Member

7) Juan Colin: Team Member

XIV. Project Approval Requirements

The following list details the requirements that must be met in order for the Smart Eraser to be approved by the various stakeholders in the project.

- All requirements listed in the High-level requirements section of this project charter, which state that the project must:
  - Be completed within the outlined budget.
  - Be implementable within 2 semesters.
  - Be complex enough to warrant the title “senior design project”.
  - Produce a complete Project Charter outlining the various project information, figures, and tables of the Smart Eraser.
  - Have significant, roughly equal portions of the project be completed by each team member.
  - Utilize material learned in core and technical elective classes throughout college careers.
  - Produce a deliverable that can be presented in the Senior Project Presentation Day event held in the Satellite Student Union building.
- Additional requirements requested due to the acceptance of the sponsership from DPS Telecom:
  - Deliver a project report.

- Create and manage a project archival on GitHub (or similar).
- Implement a working prototype.
- Create a 3-4 minute video, including a business plan with some marketing information.

XV. Approvals

Signature: _____
Heather Libecki - Project Manager

Signature: _____
Chris Quesada - Team Member

Signature: _____
Juan Colin - Team Member

Signature: _____
Hovannes Kulhandjian, Ph.D. - Technical Advisor

Signature: _____
Aaron Stillmaker, Ph.D. - Course Instructor

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XVI. Appendices

Appendix 1 - transmitter_xy.ino

```
/*
* SMART ERASER SENIOR DESIGN PROJECT
* Stepper Motor Transmitter
* by Heather Libecki
*
* with help from Dejan Nedelkovski
*/

/*transmitter should be MRK1000*/
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <Stepper.h>

RF24 radio(6, 7); // CE, CSN
const byte address[][6] = {"00001", "00002"};
void setup() {
  radio.begin();
  radio.setPALevel(RF24_PA_MIN);
  radio.stopListening();
}
void loop() {
  int steps1 = 3200; //revolutions specific to stepper motor
  radio.openWritingPipe(address[0]);
  radio.write(&steps1, sizeof(steps1));
  Serial.println(steps1);
  delay(500);
  int steps2 = 3600;
  radio.openWritingPipe(address[1]);
  radio.write(&steps2, sizeof(steps2));
  Serial.println(steps2);
  delay(500);
}
```

Appendix 2 - receiver_x.ino

```
/*
* SMART ERASER SENIOR DESIGN PROJECT
* Stepper Motor Receiver for X-axis
* by Heather Libecki
*
* with help from Dejan Nedelkovski
*/

/*receiver should be UNO*/
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
#include <Stepper.h>

// initialize the stepper library on pins 7 through 4
int stepsPerRev = 1600;
Stepper myStepper(stepsPerRev, 7, 6, 5, 4);

RF24 radio(9, 10); // CE, CSN
const byte address[6] = "00001";
void setup() {
  Serial.begin(9600);
  radio.begin();
  radio.openReadingPipe(1, address);
  radio.setPALevel(RF24_PA_MIN);
  myStepper.setSpeed(120);
  radio.startListening();
}
void loop() {
  if (radio.available()) {
    int steps1;
    radio.read(&steps1, sizeof(steps1));
    myStepper.step(steps1);
//   Serial.println("clockwise");
    Serial.println(steps1);
    delay(500);
    myStepper.step(-steps1);
//   Serial.println("counterclockwise");
    Serial.println(steps1);
    delay(500);
  }
}
```

Appendix 3 - main.c

```
/*******************************************************************************
* File Name:  main.c
*
* Version:   1.0
*
* Description: Uses SPI and I2C communication to receive image form Arducam,
*        process the image to find edges, translates detected edges to
*        coordinates for stepper motors, and sends coordinate information
*        to HUZZAH32 server via UART communication.
*
*        This code was modified from a template provided by Cypress
*        Semiconductor Corporation -> TFTemWin example
*
* Author:  Chris Quesada
*******************************************************************************/
#include "cy_pdl.h"
#include "cycfg.h"
#include "GUI.h"
#include "cycfg_qspi_memslot.h"
#include "cy_smif.h"
#include <Interface.h>
#include <SPIMaster.h>
#include <I2CMaster.h>
#include <stdbool.h>
#include <time.h>
#include <ImProc.h>
#include <math.h>
#include <Arducam.h>

/*******************************************************************************
* Global constants
*******************************************************************************/

#define NUMBER_OF_PAGES    (1u)
#define BTN_PRESSED      (0u)
#define BTN_RELEASED     (1u)

/************************ Function Prototypes ******************************/
int Trigger_Capture(void);
void Process_Image(void);
void (*PageArray[NUMBER_OF_PAGES])(void) = {Process_Image, /*func1, func2,
    func3.....*/};

/*******************************************************************************/

/* Reference to bitmap test image */
extern GUI_CONST_STORAGE GUI_BITMAP bmExampleImage;


/*******************************************************************************
* Function Name: void ShowStartupScreen(void)
********************************************************************************
*
* Summary:   This function displays the startup screen. This was provided by
*          Cypress.
```

```
*
* Parameters: None
*
* Return:  None
*
*******************************************************************************/
void ShowStartupScreen(void)
{
   /* Set font size, foreground and background colors */
   GUI_SetFont(GUI_FONT_24B_1);
   GUI_SetColor(GUI_WHITE);
   GUI_SetBkColor(GUI_BLACK);

   /* Clear the screen */
   GUI_Clear();

   /* Print the text CYPRESS EMWIN GRAPHICS DEMO TFT DISPLAY */
   GUI_SetTextAlign(GUI_TA_HCENTER);
   GUI_DispStringAt("Smart Eraser", 160, 80);
   GUI_SetTextAlign(GUI_TA_HCENTER);
   GUI_DispStringAt("Version 1.0", 160, 100);
   GUI_SetTextAlign(GUI_TA_HCENTER);
   GUI_DispStringAt("Initializing....", 160, 120);
}

/*******************************************************************************
* Function Name: void ShowInstructionsScreen(void)
********************************************************************************
*
* Summary:   This function shows screen with instructions to press SW2 to
*          scroll through various display pages. This was provided by
*          Cypress.
*
* Parameters: None
*
* Return:  None
*
*******************************************************************************/
void ShowInstructionsScreen(void)
{
   /* Set font size, background color and text mode */
   GUI_SetFont(GUI_FONT_24_1);
   GUI_SetBkColor(GUI_BLACK);
   GUI_SetColor(GUI_WHITE);
   GUI_SetTextMode(GUI_TM_NORMAL);

   /* Clear the display */
   GUI_Clear();

   /* Display instructions text */
   GUI_SetTextAlign(GUI_TA_HCENTER);
   GUI_DispStringAt("PRESS SW2 ON THE KIT", 160, 90);
   GUI_SetTextAlign(GUI_TA_HCENTER);
   GUI_DispStringAt("TO CAPTURE IMAGE", 160, 110);
}

/*******************************************************************************
```

```
* Function Name: Trigger_Capture(void)
*******************************************************************************
*
* Summary:   This functions sends a trigger command to the Arducam module
*        via SPI
*
* Parameters: None
*
* Return:  int status
*
*******************************************************************************/
int Trigger_Capture(void)
{
  /* Buffer to hold command packet to be sent to the slave by the master */
  uint16_t txBuffer  = {0};

  /* Buffer to save the received data by the slave */
  uint16_t rxBuffer  = {0};

  MyCam_Test(rxBuffer, txBuffer);
  MyCam_Trigger(rxBuffer, txBuffer);

  return 0;
}

/*******************************************************************************
* Function Name: Process_Image(void)
*******************************************************************************
*
* Summary:   This function takes an image, converts it to grayscale, detects
*        edges, implements square detection on detected edges, sends
*        results to HUZZAH32 via UART
*
* Parameters: None
*
* Return:  None
*
*******************************************************************************/
void Process_Image(void)
{
  int         flag              = 0;
  int      k                 = 0;
  uint16_t   txBuffer             = {0};
  uint16_t   rxBuffer             = {0};
  uint16_t  Dummy[1]          = {0};
  uint16_t  *ptr_Dmmy           = &Dummy;
  uint16_t  Pixel_Data[Length*Height]   = {0};      // Will hold processed pixels
  uint16_t  Gray_Data[Length*Height]   = {0};      // Will hold grayscale pixels to
     be run through Sobel edge detection
  uint16_t    *ptr_PD             = &Pixel_Data;    // Pointer to processed pixels
     array
  uint16_t  *ptr_GD             = &Gray_Data;     // Pointer to grayscale pixels array
  uint16_t    *ptr_Image_PD         = bmExampleImage.pData;  // Pointer to Pre-loaded
     image for image processing testing
  //uint16_t  *ptr_Image_PD         = &Pixel_Data;    // Pointer to Pre-loaded image
     for image processing testing
  int         start               = 0;
```

```
  int      middle               = 0;
  int        middleGStart         = 1;
  int        middleBStart         = 2;
  uint8 BayerFilter[2][Length]     = {0};


  GUI_SetBkColor(GUI_BLACK);
  GUI_Clear();
  GUI_DrawBitmap(&bmExampleImage, 0, 0);

//-------------------------- STILL IN DEVELOPEMENT----------------------------//

  /* ---------------------------Initializations---------------------------- */
  /*MyCam_Init();
  Trigger_Capture();

  while (flag != CAPTURE_COMPLETE) {
  flag = MyCam_Check_Capture_Status(rxBuffer, txBuffer);
  }

  Cy_SysLib_Delay(1000);

  GUI_BITMAP Image = {
    (unsigned int)Length,     // xSize
    (unsigned int)Height,     // ySize
    640,                    // BytesPerLine
    16,                     // BitsPerPixel
    (unsigned char *)Pixel_Data,   // Pointer to picture data
    NULL,                   // Pointer to palette
    GUI_DRAW_BMPM565,         // Specifies RGB format
  };

  Cy_SysLib_Delay(1000);

  MyCam_Pixel_Read(txBuffer, ptr_PD, start, &BayerFilter);
  middle = middleGStart;

  for (k = 0; k < Height - 1; k++) {
    ptr_PD = MyCam_Pixel_Read(txBuffer, ptr_PD, middle, &BayerFilter);
    if (middle == middleGStart)
      middle = middleBStart;
    else if (middle == middleBStart)
      middle = middleGStart;
  }

  ptr_PD = &Pixel_Data;
  GUI_DrawBitmap(&Image, 0, 0);
  Cy_SysLib_Delay(750);

  for (k = 0; k < Height - 1; k++) {
    ptr_PD = MyCam_Pixel_Read(txBuffer, ptr_PD, middle, &BayerFilter);
    if (middle == middleGStart)
      middle = middleBStart;
    else if (middle == middleBStart)
      middle = middleGStart;
  }
```

```
ptr_PD = &Pixel_Data;
GUI_DrawBitmap(&Image, 0, 80);
Cy_SysLib_Delay(750);

for (k = 0; k < Height - 1; k++) {
  ptr_PD = MyCam_Pixel_Read(txBuffer, ptr_PD, middle, &BayerFilter);
  if (middle == middleGStart)
    middle = middleBStart;
  else if (middle == middleBStart)
    middle = middleGStart;
}
ptr_PD = &Pixel_Data;
GUI_DrawBitmap(&Image, 0, 160);
Cy_SysLib_Delay(750);

/* GUI_BITMAP is a structure the EMWIN graphics driver
 * uses to display an image */

GUI_BITMAP Image = {
    (unsigned int)Length,     // xSize
    (unsigned int)Height,     // ySize
    640,                    // BytesPerLine
    16,                     // BitsPerPixel
    (unsigned char *)Pixel_Data,   // Pointer to picture data
    NULL,                   // Pointer to palette
    GUI_DRAW_BMPM565,         // Specifies RGB format
  };

/*****************************************************************************
* Function Call: conv2gray()
******************************************************************************
*
* Summary:   This function takes an image and converts it to grayscale. Each
*        time the function is called, 80 rows of pixels are evaluated and
*        the pointer to the image data is returned to be the starting
*        point of the next function call. The array that holds the processed
*        pixels is what will be displayed on the screen. This is just for
*        demonstration purposes and won't be used in the final system.
*
*        first call -> 0 - 79;
*        second call -> 80 - 159;
*        third call -> 160 - 239
*****************************************************************************/

//ptr_Image_PD = conv2gray(ptr_Image_PD, ptr_PD, ptr_GD);
//GUI_DrawBitmap(&Image, 0, 0);

//ptr_Image_PD = conv2gray(ptr_Image_PD, ptr_PD, ptr_GD);
//GUI_DrawBitmap(&Image, 0, 80);

//ptr_Image_PD = conv2gray(ptr_Image_PD, ptr_PD, ptr_GD);
//GUI_DrawBitmap(&Image, 0, 160);

//ptr_Image_PD = bmExampleImage.pData;  // Reset test image pointer to beginning

/*****************************************************************************
* Function Call: sobel()
```

```
  ********************************************************************************
  *
  * Summary:   This function takes an image, uses conv2gray() to convert an image
  *        to grayscale, and the uses sobel edge detection to detect edges
  *        in the image. Each time the function is called, 80 rows of pixels
  *        are evaluated and the pointer to the image data is returned to be
  *        the starting point of the next function call.
  *
  *        first call -> 0 - 79;
  *        second call -> 80 - 159;
  *        third call -> 160 - 239
  ********************************************************************************/

  ptr_Image_PD = sobel(ptr_Image_PD, ptr_PD, ptr_GD);
  GUI_DrawBitmap(&Image, 0, 0);

  for (k = 0; k < 1024; k++){
    Cy_SCB_UART_PutArray(KIT_UART_HW, ptr_PD, 25);
    Cy_SysLib_Delay(1);
    Cy_SCB_UART_ClearTxFifoStatus(KIT_UART_HW, CY_SCB_UART_TX_DONE);
    ptr_PD = ptr_PD + 128;
}

  ptr_PD = &Pixel_Data;

  Cy_SysLib_Delay(500);

  ptr_Image_PD = sobel(ptr_Image_PD, ptr_PD, ptr_GD);
  GUI_DrawBitmap(&Image, 0, 80);

  for (k = 0; k < 1024; k++){
    Cy_SCB_UART_PutArray(KIT_UART_HW, ptr_PD, 25);
    Cy_SysLib_Delay(1);
    Cy_SCB_UART_ClearTxFifoStatus(KIT_UART_HW, CY_SCB_UART_TX_DONE);
    ptr_PD = ptr_PD + 128;
  }

  ptr_PD = &Pixel_Data;

  Cy_SysLib_Delay(500);

  ptr_Image_PD = sobel(ptr_Image_PD, ptr_PD, ptr_GD);
  GUI_DrawBitmap(&Image, 0, 160);

  for (k = 0; k < 1024; k++){
    Cy_SCB_UART_PutArray(KIT_UART_HW, ptr_PD, 25);
    Cy_SysLib_Delay(1);
    Cy_SCB_UART_ClearTxFifoStatus(KIT_UART_HW, CY_SCB_UART_TX_DONE);
    ptr_PD = ptr_PD + 128;
  }

  ptr_PD = &Pixel_Data;

  /* -------------------Set font size, font color to black-------------------- */
  GUI_SetFont(GUI_FONT_16B_1);
  GUI_SetColor(GUI_WHITE);
```

```
  /* -------Set text mode to transparent, underlined and center aligned------- */
  GUI_SetTextMode(GUI_TM_TRANS);
  GUI_SetTextAlign(GUI_TA_HCENTER);

  /* ----------------------Print the page title text------------------------- */
  GUI_DispStringAt("Objects Detected!!", 160, 0);

}

/*******************************************************************************
* Function Name: bool IsBtnClicked
********************************************************************************
*
* Summary:   This non-blocking function implements SW2 button click check.
*
* Parameters: None
*
* Return:  Status of the SW2 button:
*        true when button was pressed and then released and
*        false in other cases
*
*******************************************************************************/
bool IsBtnClicked(void)
{
   uint32 currBtnState;
   static uint32 prevBtnState = BTN_RELEASED;

   bool result = false;

   currBtnState = Cy_GPIO_Read(SW2_PORT, SW2_PIN);

   if((prevBtnState == BTN_RELEASED) && (currBtnState == BTN_PRESSED))
   {
      result = true;
   }
   prevBtnState = currBtnState;

   Cy_SysLib_Delay(5);

   return result;
}


/*******************************************************************************
* Function Name: int main(void)
********************************************************************************
*
* Summary:   This is the main for this code example. This function does the following
*          1. Initializes the EmWin display engine
*          2. Displays startup screen for 3 seconds
*          3. In an infinite loop, displays the following screens on
*            key press and release
*            a. grayscale and image detection
*
* Parameters: None
*
* Return:  None
```

```
*
*******************************************************************************/
int main(void)
{
  uint8 pageNumber = 0;
   /* ------------------------Initializations------------------------------- */
   init_cycfg_all();
   __enable_irq();
   GUI_Init();
   initSPIMaster();
   initI2CMaster();

   cy_stc_scb_uart_context_t KIT_UART_context;

   Cy_SCB_UART_Init(KIT_UART_HW, &KIT_UART_config, &KIT_UART_context);
   Cy_SCB_UART_Enable(KIT_UART_HW);

  /* --------------Display the startup screen for 2 seconds----------------- */
  ShowStartupScreen();
  Cy_SysLib_Delay(2000);

  /* ----------------------Show Instructions Screen------------------------- */
  ShowInstructionsScreen();

  /* ------------------Display various pages in a loop---------------------- */
   for(;;)
   {
      if(IsBtnClicked())
      {
         /* Using pageNumber as index, update the display with a demo screen
           Following are the functions that are called in sequence
               ShowProcess_Image()
         */
         (*PageArray[pageNumber])();

         /* Increment page number */
         pageNumber = pageNumber + 1;

         /* If pagenumber exceeds maximum pages, reset */
         if(pageNumber >= NUMBER_OF_PAGES)
         {
            pageNumber = 0;
         }
      }
   }
}


/* [] END OF FILE */
```

Appendix 4 - SPImaster.c

```
/*******************************************************************************
* File Name:  SPIMaster.c
*
* Version:   1.0
*
* Description:  This file contains function definitions for SPI Master.
*          - These functions were provided from Cypress and
*            were altered to fit the Smart Eraser application.
*
* Author:  Chris Quesada
*******************************************************************************/
#include "SPIMaster.h"
#include "Interface.h"
#include "stdio.h"

/*******************************************************************************
* Function Name: initMaster
********************************************************************************
*
* Summary:   This function initializes the SPI Master based on the
*        configuration done in design.modus file.
*
* Parameters:  None
*
* Return:   (uint32) INIT_SUCCESS or INIT_FAILURE
*
*******************************************************************************/
uint32 initSPIMaster(void)
{
   cy_en_scb_spi_status_t initStatus;

  /* Configure SPI block */
  initStatus = Cy_SCB_SPI_Init(mSPI_HW, &mSPI_config, NULL);

  /* If the initialization fails, return failure status */
  if(initStatus != CY_SCB_SPI_SUCCESS)
  {
    return(INIT_FAILURE);
  }

  /* Set active slave select to line 0 */
  Cy_SCB_SPI_SetActiveSlaveSelect(mSPI_HW, CY_SCB_SPI_SLAVE_SELECT0);

  /* Enable SPI master block. */
  Cy_SCB_SPI_Enable(mSPI_HW);

  /* Initialization completed */

  return(INIT_SUCCESS);
}


/*******************************************************************************
* Function Name: Write_SPI
********************************************************************************
```

```
*
* Summary:  This function sends the data to the slave. Note that the below
*        function is blocking until all the bytes are transferred.
*
* Parameters:  (uint32 *) txBuffer - Pointer to the transmit buffer
*        (uint32) transferSize - Number of bytes to be transmitted
*
* Return:  None
*
*******************************************************************************/

uint16_t Write_SPI(uint16_t data)
{
  uint16_t readData;

  /* ----------------Send read command to the camera--------------------- */
  Cy_SCB_SPI_Write(mSPI_HW, data);

  /* -------Wait for RX buffer to get filled with 2 bytes of data----- */
  while ( CY_SCB_SPI_RX_NOT_EMPTY != (Cy_SCB_SPI_GetRxFifoStatus(mSPI_HW) &
     CY_SCB_SPI_RX_NOT_EMPTY)) {}

  readData = Cy_SCB_SPI_Read(mSPI_HW);

   /* -----------------Clear the RX and TX buffers----------------- */
  Cy_SCB_SPI_ClearTxFifo(mSPI_HW);
  Cy_SCB_SPI_ClearRxFifo(mSPI_HW);
  Cy_SCB_SPI_ClearRxFifoStatus(mSPI_HW, CY_SCB_SPI_RX_NOT_EMPTY);

  return(readData);
}


/* [] END OF FILE */
```

Appendix 5 - SPImaster.h

```
/*******************************************************************************
* File Name:  SPIMaster.h
*
* Version:   1.0
*
* Description:  This file contains function prototypes for SPI Master.
*           - These functions were provided from Cypress and
*             were altered to fit the Smart Eraser application.
*
* Author:  Chris Quesada
*******************************************************************************/

#ifndef SOURCE_SPIMASTER_H_
#define SOURCE_SPIMASTER_H_

#include "cy_pdl.h"
#include "cycfg.h"

/*************************************
*            Macros
*************************************/
#define MASTER_ERROR_MASK (CY_SCB_SPI_SLAVE_TRANSFER_ERR |
    CY_SCB_SPI_TRANSFER_OVERFLOW | \
                      CY_SCB_SPI_TRANSFER_UNDERFLOW)

/* -------------Transmit and receive packet information----------------- */
#define NUMBER_OF_SPI_ELEMENTS  (1UL)
#define SIZE_OF_SPI_PACKET    (NUMBER_OF_SPI_ELEMENTS * SIZE_OF_SPI_ELEMENT)
#define SIZE_OF_SPI_ELEMENT    (16UL)

/* ------Delay between successive SPI Master command transmissions------- */
#define CMD_DELAY      (1000)
#define TIMEOUT_1_MS     (1000ul)

/*************************************
*       Function Prototypes
*************************************/
uint32 initSPIMaster(void);
uint16_t Write_SPI(uint16_t txBuffer);


#endif /* SOURCE_SPIMASTER_H_ */
```

Appendix 6 - I2Cmaster.c

```
/*******************************************************************************
* File Name:  I2CMaster.c
*
* Version:   1.0
*
* Description:  This file contains function definitions for I2C Master.
*          - These functions were provided from Cypress and
*            were altered to fit the Smart Eraser application.
*
* Author:  Chris Quesada
*******************************************************************************/

#include "I2CMaster.h"
#include "Interface.h"

/*******************************************************************************
*         Constants
*******************************************************************************/
/* I2C slave address to communicate with */
#define I2C_SLAVE_ADDR (0x3C)

/* Buffer and packet size */
#define RX_PACKET_SIZE  (3UL)

/* Buffer and packet size */
#define RX_PACKET_SIZE (3UL)
#define BUFFER_SIZE    (PACKET_SIZE)

/* Command valid status */
#define STS_CMD_DONE   (0x00UL)
#define STS_CMD_FAIL   (0xFFUL)

/* Command valid status */
#define TRANSFER_ERROR (0xFFUL)
#define READ_ERROR     (TRANSFER_ERROR)

/* Timeout */
#define LOOP_FOREVER   (0UL)
#define I2C_TIMEOUT    (100UL)

/*******************************************************************************
* Global variables
*******************************************************************************/
cy_stc_scb_i2c_context_t mI2C_context;

/*******************************************************************************
* Function Name: Write_I2C
********************************************************************************//**
*
* Buffer is assigned with data to be sent to slave.
* Low level PDL APIs are used to control I2C SCB to send data.
* Errors are handled depending on the return value from the appropriate function.
*
* \param buffer
*
```

```
* \param bufferSize
*
* \return
* returns the status after command is written to slave.
* TRANSFER_ERROR is returned if any error occurs.
* TRANSFER_CMPLT is returned if write is successful.
* \ref uint32
*
*******************************************************************************/
uint8 Write_I2C(uint8* buffer, uint32 bufferSize)
{
   uint8 status = TRANSFER_ERROR;
   cy_en_scb_i2c_status_t errorStatus;

   /* Sends packets to slave using low level PDL library functions. */
   errorStatus = Cy_SCB_I2C_MasterSendStart(mI2C_HW, I2C_SLAVE_ADDR,
       CY_SCB_I2C_WRITE_XFER, I2C_TIMEOUT, &mI2C_context);
   if(errorStatus == CY_SCB_I2C_SUCCESS)
   {

      uint32 cnt = 0UL;

      /* Read data from the slave into the buffer */
      do
      {
         /* Write byte and receive ACK/NACK response */
         errorStatus = Cy_SCB_I2C_MasterWriteByte(mI2C_HW, buffer[cnt], I2C_TIMEOUT,
             &mI2C_context);
         ++cnt;
      }
      while((errorStatus == CY_SCB_I2C_SUCCESS) && (cnt < bufferSize));
   }

   /* Check status of transaction */
   if ((errorStatus == CY_SCB_I2C_SUCCESS) ||
       (errorStatus == CY_SCB_I2C_MASTER_MANUAL_NAK) ||
       (errorStatus == CY_SCB_I2C_MASTER_MANUAL_ADDR_NAK))
   {
      /* Send Stop condition on the bus */
      if (Cy_SCB_I2C_MasterSendStop(mI2C_HW, I2C_TIMEOUT, &mI2C_context) ==
          CY_SCB_I2C_SUCCESS)
      {
         status = TRANSFER_CMPLT;
      }
   }

   return (status);
}

/*******************************************************************************
* Function Name: initI2CMaster
********************************************************************************
*
* This function initiates and enables master SCB
*
* \param None
*
```

```
* \return
* Status of initialization
*
*******************************************************************************/
uint32 initI2CMaster(void)
{
  /* Initialize the master I2C. */

   cy_en_scb_i2c_status_t initStatus;

  /* Configure component. */
  initStatus = Cy_SCB_I2C_Init(mI2C_HW, &mI2C_config, &mI2C_context);
  if(initStatus!=CY_SCB_I2C_SUCCESS)
  {
    return INIT_FAILURE;
  }

  /* Enable I2C master hardware. */
  Cy_SCB_I2C_Enable(mI2C_HW);
  return INIT_SUCCESS;
}
```

Appendix 7 - I2Cmaster.h

```
/*******************************************************************************
* File Name:  I2Cmaster.h
*
* Version:   1.0
*
* Description:  This file contains function prototypes for I2C Master.
*          - These functions were provided from Cypress and
*            were altered to fit the Smart Eraser application.
*
* Author:  Chris Quesada
*******************************************************************************/
#ifndef SOURCE_I2CMASTER_H_
#define SOURCE_I2CMASTER_H_

#include "cy_pdl.h"
#include "cycfg.h"

/*******************************************************************************
* Constants
*******************************************************************************/
#define TRANSFER_CMPLT     (0x00UL)
#define READ_CMPLT         (TRANSFER_CMPLT)
#define NUMBER_OF_I2C_ELEMENTS  (3UL)
#define SIZE_OF_I2C_ELEMENT   (8UL)
#define SIZE_OF_I2C_PACKET   (NUMBER_OF_I2C_ELEMENTS * SIZE_OF_I2C_ELEMENT)
/* Packet positions */

#define I2C_ADDRESS        (0UL)
#define I2C_CONFIG       (1UL)

/*******************************************************************************
* Function prototype
*******************************************************************************/
uint8 Write_I2C(uint8* buffer, uint32 bufferSize);
uint32 initI2CMaster(void);

#endif /* SOURCE_I2CMASTER_H_ */
```

Appendix 8 - Arducam.c

```
/*****************************************************************************
* File Name:  Arducam.c
*
* Version:   1.0
*
* Description: This file holds all the function definitions for the Arducam
*
* Author:  Chris Quesada
*****************************************************************************/

#include <Arducam.h>
#include <SPImaster.h>
#include <I2CMaster.h>
#include <interface.h>
#include <ImProc.h>
#include <math.h>

struct sensor_reg
{
  uint16_t reg;
  uint8 val;
};

struct sensor_reg OV5642_1280x960_RAW[RAWinit] =
{
{0x00ff,0x01},
{0x3008,0x80},
{0x3103,0x93},
{0x3008,0x02},
{0x3017,0x7f},
{0x3018,0xf0},
{0x3615,0xf0},
{0x3000,0xF8},
{0x3001,0x48},
{0x3002,0x5c},
{0x3003,0x02},
{0x3005,0xB7},
{0x3006,0x43},
{0x3007,0x37},
{0x300f,0x06},
{0x3011,0x08},
{0x3010,0x20},
{0x3012,0x00},
{0x460c,0x22},
{0x3815,0x04},
{0x370c,0xA0},
{0x3602,0xFC},
{0x3612,0xFF},
{0x3634,0xC0},
{0x3613,0x00},
{0x3622,0x00},
{0x3603,0x27},
{0x4000,0x21},
{0x401D,0x02},
{0x3600,0x54},
```

```
{0x3605,0x04},
{0x3606,0x3F},
{0x5020,0x04},
{0x5197,0x01},
{0x5001,0xFF},
{0x5500,0x10},
{0x5502,0x00},
{0x5503,0x04},
{0x5504,0x00},
{0x5505,0x7F},
{0x5080,0x08},
{0x300E,0x18},
{0x4610,0x00},
{0x471D,0x05},
{0x4708,0x06},
{0x3710,0x10},
{0x3632,0x41},
{0x3631,0x01},
{0x501F,0x03},
{0x3604,0x40},
{0x4300,0x00},
{0x3824,0x11},
{0x5000,0x4F},
{0x3818,0xC1},
{0x3705,0xDB},
{0x370A,0x81},
{0x3621,0xC7},
{0x3800,0x03},
{0x3801,0xE8},
{0x3802,0x03},
{0x3803,0xE8},
{0x3804,0x38},
{0x3805,0x00},
{0x3806,0x03},
{0x3807,0xC0},
{0x3808,0x05},
{0x3809,0x00},
{0x380A,0x03},
{0x380B,0xC0},
{0x380C,0x0A},
{0x380D,0xF0},
{0x380E,0x03},
{0x380F,0xE8},
{0x3827,0x08},
{0x3810,0xC0},
{0x5683,0x00},
{0x5686,0x03},
{0x5687,0xC0},
{0x3A1A,0x04},
{0x3A13,0x30},
{0x3004,0xDF},
{0x350C,0x07},
{0x350D,0xD0},
{0x3500,0x35},
{0x3501,0x00},
{0x3502,0x00},
{0x350A,0x00},
```

```
{0x350B,0x00},
{0x3503,0x00},
{0x5682,0x05},
{0x3A0F,0x78},
{0x3A11,0xD0},
{0x3A1B,0x7A},
{0x3A1E,0x66},
{0x3A1F,0x40},
{0x3A10,0x68},
{0x3030,0x0B},
{0x3A01,0x04},
{0x3A02,0x00},
{0x3A03,0x78},
{0x3A04,0x00},
{0x3A05,0x30},
{0x3A14,0x00},
{0x3A15,0x64},
{0x3A16,0x00},
{0x3A17,0x89},
{0x3A18,0x00},
{0x3A19,0x70},
{0x3A00,0x78},
{0x3A08,0x12},
{0x3A09,0xC0},
{0x3A0A,0x0F},
{0x3A0B,0xA0},
{0x3A0D,0x04},
{0x3A0E,0x03},
{0x3C00,0x04},
{0x3C01,0xB4},
{0x5688,0xFD},
{0x5689,0xDF},
{0x568A,0xFE},
{0x568B,0xEF},
{0x568C,0xFE},
{0x568D,0xEF},
{0x568E,0xAA},
{0x568F,0xAA},
{0x589B,0x04},
{0x589A,0xC5},
{0x528A,0x00},
{0x528B,0x02},
{0x528C,0x08},
{0x528D,0x10},
{0x528E,0x20},
{0x528F,0x28},
{0x5290,0x30},
{0x5292,0x00},
{0x5293,0x00},
{0x5294,0x00},
{0x5295,0x02},
{0x5296,0x00},
{0x5297,0x08},
{0x5298,0x00},
{0x5299,0x10},
{0x529A,0x00},
{0x529B,0x20},
```

```
{0x529C,0x00},
{0x529D,0x28},
{0x529E,0x00},
{0x5282,0x00},
{0x529F,0x30},
{0x5300,0x00},
{0x5302,0x00},
{0x5303,0x7C},
{0x530C,0x00},
{0x530D,0x0C},
{0x530E,0x20},
{0x530F,0x80},
{0x5310,0x20},
{0x5311,0x80},
{0x5308,0x20},
{0x5309,0x40},
{0x5304,0x00},
{0x5305,0x30},
{0x5306,0x00},
{0x5307,0x80},
{0x5314,0x08},
{0x5315,0x20},
{0x5319,0x30},
{0x5316,0x10},
{0x5317,0x08},
{0x5318,0x02},
{0x5380,0x01},
{0x5381,0x20},
{0x5382,0x00},
{0x5383,0x4E},
{0x5384,0x00},
{0x5385,0x0F},
{0x5386,0x00},
{0x5387,0x00},
{0x5388,0x01},
{0x5389,0x15},
{0x538A,0x00},
{0x538B,0x31},
{0x538C,0x00},
{0x538D,0x00},
{0x538E,0x00},
{0x538F,0x0F},
{0x5390,0x00},
{0x5391,0xAB},
{0x5392,0x00},
{0x5393,0xA2},
{0x5394,0x08},
{0x5301,0x20},
{0x5480,0x14},
{0x5482,0x03},
{0x5483,0x57},
{0x5484,0x65},
{0x5485,0x71},
{0x5481,0x21},
{0x5486,0x7D},
{0x5487,0x87},
{0x5488,0x91},
```

```
{0x5489,0x9A},
{0x548A,0xAA},
{0x548B,0xB8},
{0x548C,0xCD},
{0x548D,0xDD},
{0x548E,0xEA},
{0x548F,0x10},
{0x5490,0x05},
{0x5491,0x00},
{0x5492,0x04},
{0x5493,0x20},
{0x5494,0x03},
{0x5495,0x60},
{0x5496,0x02},
{0x5497,0xB8},
{0x5498,0x02},
{0x5499,0x86},
{0x549A,0x02},
{0x549B,0x5B},
{0x549C,0x02},
{0x549D,0x3B},
{0x549E,0x02},
{0x549F,0x1C},
{0x54A0,0x02},
{0x54A1,0x04},
{0x54A2,0x01},
{0x54A3,0xED},
{0x54A4,0x01},
{0x54A5,0xC5},
{0x54A6,0x01},
{0x54A7,0xA5},
{0x54A8,0x01},
{0x54A9,0x6C},
{0x54AA,0x01},
{0x54AB,0x41},
{0x54AC,0x01},
{0x54AD,0x20},
{0x54AE,0x00},
{0x54AF,0x16},
{0x3406,0x00},
{0x5192,0x04},
{0x5191,0xF8},
{0x5193,0x70},
{0x5194,0xF0},
{0x5195,0xF0},
{0x518D,0x3D},
{0x518F,0x54},
{0x518E,0x3D},
{0x5190,0x54},
{0x518B,0xC0},
{0x518C,0xBD},
{0x5187,0x18},
{0x5188,0x18},
{0x5189,0x6E},
{0x518A,0x68},
{0x5186,0x1C},
{0x5181,0x50},
```

```
{0x5182,0x11},
{0x5183,0x14},
{0x5184,0x25},
{0x5185,0x24},
{0x5025,0x82},
{0x5583,0x40},
{0x5584,0x40},
{0x5580,0x02},
{0x3633,0x07},
{0x3702,0x10},
{0x3703,0xB2},
{0x3704,0x18},
{0x370B,0x40},
{0x370D,0x02},
{0x3620,0x52},

{0xffff,0xff},
};

struct sensor_reg OV5642_320x240_RAW[RAWres] =
{
  /*
{0x3800,0x03},
{0x3801,0xE8},
{0x3802,0x03},
{0x3803,0xE8},
{0x3804,0x38},
{0x3805,0x00},
{0x3806,0x03},
{0x3807,0xC0},
*/
{0x3808,0x01},
{0x3809,0x40},
{0x380A,0x00},
{0x380B,0xf0},
{0xffff,0xff},
};



/*******************************************************************************
* Function Name: MyCam_Test
********************************************************************************
*
* Summary:   Tests SPI communication between PSoC 6 and Arducam
*
* Parameters:  uint16_t *rxBuffer,
*        uint16_t *txBuffer
*
* Return:  Value in test register of Arducam (rxBuffer[0])
*
*******************************************************************************/
void MyCam_Test(uint16_t rxBuffer, uint16_t txBuffer) {

  uint16_t response = 0;

  do {
```

```
  txBuffer = (((uint16_t)WRITE + (uint16_t)TEST_SPI) << 8) + (uint16_t)TEST_VALUE;
  Write_SPI(txBuffer);
  txBuffer = (((uint16_t)READ + (uint16_t)TEST_SPI) << 8) + (uint16_t)DUMMY;
  response = Write_SPI(txBuffer);
  } while ( response != TEST_VALUE);
}

/*******************************************************************************
* Function Name: MyCam_Trigger
********************************************************************************
*
* Summary:   Clears FIFO Flag and Sends trigger signal to have camera
*        capture image.
*
* Parameters:  uint16_t *rxBuffer,
*        uint16_t *txBuffer
*
* Return:  none
*
*******************************************************************************/
void MyCam_Trigger(uint16_t rxBuffer, uint16_t txBuffer) {

  txBuffer = (((uint16_t)WRITE + (uint16_t)FIFO_CONTROL) << 8) +
     (uint16_t)CLEAR_FIFO_FLAG;
  Write_SPI(txBuffer);
  Cy_SysLib_Delay(0.5);

  txBuffer = (((uint16_t)WRITE + (uint16_t)FIFO_CONTROL) << 8) +
     (uint16_t)CLEAR_FIFO_FLAG;
  Write_SPI(txBuffer);
  Cy_SysLib_Delay(0.5);

  txBuffer = (((uint16_t)WRITE + (uint16_t)FIFO_CONTROL) << 8) + (uint16_t)CAPTURE;
  Write_SPI(txBuffer);
  Cy_SysLib_Delay(0.5);
}

/*******************************************************************************
* Function Name: MyCam_Check_Capture_Status
********************************************************************************
*
* Summary:   Check capture flag to see if capture is complete
*
* Parameters:  uint16_t *rxBuffer,
*        uint16_t *txBuffer
*
* Return:  none
*
*******************************************************************************/
uint16_t MyCam_Check_Capture_Status(uint16_t rxBuffer, uint16_t txBuffer) {

  uint16_t response = 0;

  txBuffer = (((uint16_t)READ + (uint16_t)CAPTURE_FLAG) << 8) + (uint16_t)DUMMY;
  response = Write_SPI(txBuffer);

  return response;
```

```
}
/*****************************************************************************
* Function Name: MyCam_Single_FIFO_Read
*****************************************************************************
*
* Summary:   Reads 2 bytes of data from cam and them attempts to demosaic
*        the raw data, still in development
*
* Parameters:  uint16_t *rxBuffer,
*        uint16_t *txBuffer
*
* Return:  none
*
*****************************************************************************/
unsigned short* MyCam_Pixel_Read(uint16_t txBuffer, uint16_t *ptr_PD, int position,
    uint8 *BayerFilter) {

     uint16_t Red = 0;
     uint16_t Green1 = 0;
     uint16_t Green2 = 0;
     uint16_t Blue = 0;
     uint8 *start = BayerFilter;
     int j = 0;
     int k = 0;


     if (position == 0) {
       for (int j = 0; j < 1; j++) {
         for (int k = 0; k < Length; k++) {
         txBuffer = (((uint16_t)READ + (uint16_t)FIFO_READ_SINGLE) << 8) +
             (uint16_t)DUMMY;
         *BayerFilter = Write_SPI(txBuffer);
         BayerFilter = BayerFilter + 1;
         }
       }
       for (int k = 0; k < Length - 1; k++) {
         if (k % 2 == 0) {
           Blue  = *BayerFilter >> 3;
           Green1  = (*BayerFilter + 1) >> 2 << 5;
           Green2  = (*BayerFilter + Length) >> 2 << 5;
           Red  = (*BayerFilter + Length + 1) >> 3 << 11;
           *ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
           ptr_PD = ptr_PD + 1;
           BayerFilter = BayerFilter + 1;
           }
         else if (k % 2 != 0) {
           Green1  = *BayerFilter >> 2 << 5;
           Blue  = (*BayerFilter + 1) >> 3;
           Red  = (*BayerFilter + Length) >> 3 << 11;
           Green2  = (*BayerFilter + Length + 1) >> 2 << 5;
           *ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
           ptr_PD = ptr_PD + 1;
           BayerFilter = BayerFilter + 1;
           }
         }
     ptr_PD = ptr_PD + 1;
     BayerFilter = BayerFilter + 1;
```

```
Green1  = *BayerFilter >> 2 << 5;
Blue  = (*BayerFilter - 1) >> 3;
Red  = (*BayerFilter - Length) >> 3 << 11;
Green2  = (*BayerFilter - Length - 1) >> 2 << 5;
*ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
}

else if (position == 1) {

  for (k = 0; k < Length; k++) {
    *BayerFilter = *BayerFilter + Length;
    BayerFilter = BayerFilter + 1;
  }

  for (int k = 0; k < Length; k++) {
    txBuffer = (((uint16_t)READ + (uint16_t)FIFO_READ_SINGLE) << 8) +
        (uint16_t)DUMMY;
    *BayerFilter = Write_SPI(txBuffer);
    BayerFilter = BayerFilter + 1;
  }

  BayerFilter = start;

  for (int k = 0; k < Length - 1; k++) {
    if (k % 2 == 0) {
      Blue  = *BayerFilter >> 3;
      Green1  = (*BayerFilter + 1) >> 2 << 5;
      Green2  = (*BayerFilter + Length) >> 2 << 5;
      Red  = (*BayerFilter + Length + 1) >> 3 << 11;
      *ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
      ptr_PD = ptr_PD + 1;
      BayerFilter = BayerFilter + 1;
      }
    else if (k % 2 != 0) {
      Green1  = *BayerFilter >> 2 << 5;
      Blue  = (*BayerFilter + 1) >> 3;
      Red  = (*BayerFilter + Length) >> 3 << 11;
      Green2  = (*BayerFilter + Length + 1) >> 2 << 5;
      *ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
      ptr_PD = ptr_PD + 1;
      BayerFilter = BayerFilter + 1;
      }
    }
ptr_PD = ptr_PD + 1;
BayerFilter = BayerFilter + 1;
Green1  = *BayerFilter >> 2 << 5;
Blue  = (*BayerFilter - 1) >> 3 << 11;
Red  = (*BayerFilter - Length) >> 3 << 11;
Green2  = (*BayerFilter - Length - 1) >> 2 << 5;
*ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
}

else if (position == 2) {

  for (k = 0; k < Length; k++) {
    *BayerFilter = *BayerFilter + Length;
    BayerFilter = BayerFilter + 1;
```

```
        }

        for (int k = 0; k < Length; k++) {
          txBuffer = (((uint16_t)READ + (uint16_t)FIFO_READ_SINGLE) << 8) +
              (uint16_t)DUMMY;
          *BayerFilter = Write_SPI(txBuffer);
          BayerFilter = BayerFilter + 1;
        }

        BayerFilter = start;

        for (int k = 0; k < Length - 1; k++) {
          if (k % 2 == 0) {
            Green1  = *BayerFilter >> 2 << 5;
            Red  = (*BayerFilter + 1) >> 3 << 11;
            Blue  = (*BayerFilter + Length)>> 3;
            Green2  = (*BayerFilter + Length + 1)>> 2 << 5;
            *ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
            ptr_PD = ptr_PD + 1;
            BayerFilter = BayerFilter + 1;
            }
          else if (k % 2 != 0) {
            Red  = *BayerFilter >> 3 << 11;
            Green1  = (*BayerFilter + 1) >> 2 << 5;
            Green2  = (*BayerFilter + Length) >> 2 << 5;
            Blue  = (*BayerFilter + Length + 1) >> 3;
            *ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
            ptr_PD = ptr_PD + 1;
            BayerFilter = BayerFilter + 1;
            }
          }
      ptr_PD = ptr_PD + 1;
      BayerFilter = BayerFilter + 1;
      Red  = *BayerFilter >> 3 << 11;
      Green1  = (*BayerFilter - 1) >> 2 << 5;
      Green2  = (*BayerFilter - Length) >> 2 << 5;
      Blue  = (*BayerFilter - Length - 1) >> 3;
      *ptr_PD = Blue + ((Green1 + Green2) / 2) + Red;
      }
      return ptr_PD;
}

/*****************************************************************************
* Function Name: MyCam_Single_Dummy_Read
******************************************************************************
*
* Summary:   Handles the first dummy byte of RGB565 data
*
* Parameters:  uint16_t *rxBuffer,
*        uint16_t *txBuffer
*
* Return:  none
*
*****************************************************************************/
void MyCam_Single_DUMMY_Read(uint16_t txBuffer, uint16_t *ptr_PD) {
   Write_SPI(txBuffer);
}
```

```
/*******************************************************************************
* Function Name: MyCamInit
********************************************************************************
*
* Summary:   Initializes camera sensor to RGB565 320x240
*
* Parameters:  None
*
* Return:  None
*
*******************************************************************************/

void MyCam_Init(void) {

  int k                     = 0;
  uint8 buffer[NUMBER_OF_I2C_ELEMENTS]  = {0};

  for (k = 0; k < RAWinit; k++) {
    buffer[0] = OV5642_1280x960_RAW[k].reg >> 8;
    buffer[1] = OV5642_1280x960_RAW[k].reg;
    buffer[2] = OV5642_1280x960_RAW[k].val;
    Write_I2C(buffer, NUMBER_OF_I2C_ELEMENTS);
  }
  Cy_SysLib_Delay(1000);

  for (k = 0; k < RAWres; k++) {
    buffer[0] = OV5642_320x240_RAW[k].reg >> 8;
    buffer[1] = OV5642_320x240_RAW[k].reg;
    buffer[2] = OV5642_320x240_RAW[k].val;
    Write_I2C(buffer, NUMBER_OF_I2C_ELEMENTS);
  }
  Cy_SysLib_Delay(250);
};

/*******************************************************************************
* Function Name: handle_error
********************************************************************************
*
* Summary:   This is a blocking function. It disables the interrupt and waits
*        in an infinite loop. This function is called when an error is
*        encountered during initialization of the blocks or during
*        SPI communication. This was provided by Cypress
*
* Parameters:  None
*
* Return:  None
*
*******************************************************************************/
void handle_error(void)
{
   /* Disable all interrupts. */
  __disable_irq();

  /* Infinite loop. */
  while(1u) {}
}
```

Appendix 9 - Arducam.h

```
/*******************************************************************************
* File Name:  Arducam.h
*
* Version:   1.0
*
* Description: This file holds all the function prototypes for the Arducam
*
* Author:  Chris Quesada
*******************************************************************************/

#ifndef ARDUCAM_H
#define ARDUCAM_H

#include "cy_pdl.h"
#include "cycfg.h"
#include "ImProc.h"

#define RAWinit             (274UL)
#define RAWres              (5UL)

/* --------------------SPI Command Addresses for Arducam----------------- */

#define TEST_SPI       (0x0)
#define TEST_VALUE       (0x59)
#define SET_FRAME_COUNT     (0x01)
#define FIFO_CONTROL    (0x04)
#define CAPTURE_FLAG    (0x41)
#define FIFO_READ_SINGLE     (0x3d)

/* ---------------SPI Command operations for Arducam---------------------- */
#define WRITE          (0x80)
#define READ           (0x00)
#define DUMMY          (0x00)

/* ------------------SPI Command Data for Arducam------------------------ */
#define CLEAR_FIFO_FLAG     (0x01)
#define CAPTURE          (0x02)
#define CAPTURE_COMPLETE    (0x08)

void MyCam_Test(uint16_t rxBuffer, uint16_t txBuffer);
void MyCam_Trigger(uint16_t rxBuffer, uint16_t txBuffer);
void MyCam_Init(void);
unsigned short* MyCam_Pixel_Read(uint16_t txBuffer, uint16_t *ptr_PD, int position,
    uint8 *BayerFilter);
void MyCam_Single_DUMMY_Read(uint16_t txBuffer, uint16_t *ptr_PD);
uint16_t MyCam_Check_Capture_Status(uint16_t rxBuffer, uint16_t txBuffer);

#endif
```

Appendix 10 - Improc.c

```
/*****************************************************************************
* File Name:  ImProc.c
*
* Version:   1.0
*
* Description: This file contains the function definitions for image processing.
*        Only 80 rows of an image can be evaluated at a time. The expected
*        resolution is 320 x 240.
*
* Author:  Chris Quesada
*****************************************************************************/

#include <ImProc.h>

/*****************************************************************************
* Function Name: conv2gray(void)
*****************************************************************************
*
* Summary:   Converts an image to grayscale
*
* Parameters: uint16_t *ptr_Image_PD (points to Image data, unprocessed pixels),
*          uint16_t *ptr_PD (points to array holding processed pixels),
*          uint16_t *ptr_GD (points to array holding grayscale pixels)
*
* Return:  Current pointer position to orignal pixel data (*ptr_Image_PD)
*****************************************************************************/
unsigned short* conv2gray( uint16_t *ptr_Image_PD, uint16_t *ptr_PD, uint16_t *ptr_GD
    ) {

  uint16_t  pixel     = 0;                          // original pixel data ->
     processed pixel data
  uint8  R        = 0;                            // Red intensity
  uint8  G        = 0;                            // Green intensity
  uint8  B        = 0;                            // Blue intensity
  uint16_t R_processed  = 0;                        // "Gray" red intensity
  uint16_t G_processed  = 0;                        // "Gray" green intensity
  uint16_t B_processed  = 0;                        // "Gray" blue intensity
  double  Gray_pixel   = 0;                         // Stores calculated gray
     intensity
  int    k        = 0;                            // counter

  for (k = 0 ; k < Length*Height ; k++) {
    pixel      = *ptr_Image_PD;                     // Pull image data
    R          = ((pixel & 0b1111100000000000) >> 11 << 3);    // Isolate red
       intensity, scale to 8-bits (0-255 scale)
    G          = ((pixel & 0b0000011111100000) >> 5 << 2);     // Isolate green
       intensity, scale to 8-bits (0-255 scale)
    B          = (pixel & 0b0000000000011111) << 3;      // Isolate blue intensity,
       scale to 8-bits (0-255 scale)
    Gray_pixel    = (R * 0.2126) + (G * 0.7152) + (B * 0.0722);    // Grayscale
       conversion algorithm, Luminance method (BT.709)
    R_processed   = ((uint16_t)Gray_pixel)>> 3 << 11;       // descale to 5-bits,
       deisolate and store "gray" red intensity
    G_processed   = ((uint16_t)Gray_pixel)>> 2 << 5;       // descale to 6-bits,
       deisolate and store "gray" green intensity
```

```
    B_processed   = (uint16_t)Gray_pixel >> 3;          // descale to 5-bits,
       deisolate and store "gray" blue intensity
    pixel         = (uint16_t)(R_processed + G_processed + B_processed);  // add gray
       intensities together to form grayscale pixel
    *ptr_GD       = pixel;                             // update grayscale data array
    *ptr_PD    = pixel;                              // update pixel data array
    ptr_GD        = ptr_GD + 1;                          // increment grayscale pointer
    ptr_PD        = ptr_PD + 1;                          // increment pixel pointer
    ptr_Image_PD   = ptr_Image_PD + 1;                   // increment image pointer
  }
  return ptr_Image_PD;                                 // returns current position in
     image array
}

/*****************************************************************************
* Function Name: sobel(void)
*****************************************************************************
*
* Summary:   Takes image data, calls conv2gray(), and detects edges using
*        Sobel operator.
*
* Parameters: uint16_t *ptr_Image_PD (points to Image data, unprocessed pixels),
*          uint16_t *ptr_PD (points to array holding processed pixels),
*          uint16_t *ptr_GD (points to array holding grayscale pixels)
*
* Return:  Current pointer position to orignal pixel data (*ptr_Image_PD)
*****************************************************************************/
unsigned short* sobel( uint16_t *ptr_Image_PD, uint16_t *ptr_PD, uint16_t *ptr_GD ) {

  int k                 = 0;
  int bound             = Length*Height;             // Specifies how many rows are
     being evaluated
  uint16_t *end         = conv2gray(ptr_Image_PD, ptr_PD, ptr_GD);  // last row
     evaluated

  /* ************************************************************************
   * Sobel kernel variant, negatives will be accounted for
   * in actual calculation. By using an array of {1,2,1} instead of all 9
   * values, as shown below, you can use the same kernel for both vertical and
      horizontal
   * gradients.
   *
   *          | -1| 0 | 1 |
   *          | -2| 0 | 2 |
   *          | -1| 0 | 1 |
   *
   * ************************************************************************/
  int sobel_kernel[3]     = { 1, 2, 1};

  float Gx              = 0;                         // Horizontal gradient
  float Gy              = 0;                         // Vertical gradient
  float G               = 0;                         // Magnitude of gradient

  /* ************************************************************************
   * Start kernel in correct location (not on a bound/edge of image array)
   *
   *          |bnd|bnd|bnd|
```

```
 *          |bnd| X | |
 *          |bnd| |   |
 *
 * ************************************************************************/
ptr_GD                  = ptr_GD + (Length + 1);

/* ************************************************************************
 * Evaluate area next to upper bound to keep image consistent
 * ************************************************************************/
for (k = 1; k < Length; k++){
  if (*(ptr_PD + Length) == 0xFFF){
       *ptr_PD = 0xFFF;
       }
       else {
         *ptr_PD = 0x0000;
         ptr_PD = ptr_PD + 1;
       }
  }

ptr_PD = ptr_PD + 2;                                  // Align pointer after upper
   bound evaluation

/* ************************************************************************
 * Account for top, bottom and sides of gray pixel array data so that the
 * sobel kernel convolution does not go out of bounds.
 * ************************************************************************/
for (k = Length + 1; k < bound - Length; k++){

  if ((k + 1) % Length == 0) {
    ptr_GD = ptr_GD + 2;
    ptr_PD = ptr_PD + 2;
    k = k + 2;
  }

  /* ----------------Horizontal gradient calculation----------------- */
  Gx = (sobel_kernel[0])*(*(ptr_GD - Length + 1))  +  (sobel_kernel[1])*(*(ptr_GD
     + 1))     +
     (sobel_kernel[2])*(*(ptr_GD + Length + 1))  -  (sobel_kernel[0])*(*(ptr_GD -
        Length - 1))  -
     (sobel_kernel[1])*(*(ptr_GD - 1))    -  (sobel_kernel[2])*(*(ptr_GD + Length
        - 1));

  /* ----------------Vertical gradient calculation------------------- */
  Gy = (sobel_kernel[0])*(*(ptr_GD - Length + 1))  +  (sobel_kernel[1])*(*(ptr_GD
     - Length))    +
     (sobel_kernel[2])*(*(ptr_GD - Length - 1))  -  (sobel_kernel[0])*(*(ptr_GD +
        Length + 1))  -
     (sobel_kernel[1])*(*(ptr_GD + Length))   -  (sobel_kernel[2])*(*(ptr_GD +
        Length - 1));

  /* -------------------Magnitude of gradient----------------------- */
   G = (sqrt(pow(Gx,2) + pow(Gy,2)));

   /* -----------store gradient to pixel data array----------------- */
  *ptr_PD = (uint16_t)G;

  /*************************************************************************
```

```
     * Check gradient against threshold value (threshold can be adjusted
     * in ImProc.h). Depending on whether or not the gradient is less than
     * or greater than, pixels will be set to either black or white.
     ********************************************************************/
    if (*ptr_PD > Threshold) {
           *ptr_PD = 0xFFFF;
         }
         else {
           *ptr_PD = 0x0000;
         }

    /* --------------------Increment necessary pointers---------------- */

    ptr_GD = ptr_GD + 1;
    ptr_PD = ptr_PD + 1;

  }

  /* ***************************************************************************
   * Evaluate area next to lower bound to keep image consistent
   * ***************************************************************************/

  for (k = bound - Length ; k < bound; k++){
    if (*(ptr_PD - Length) == 0xFFF){
      *ptr_PD = 0xFFF;
      }
      else {
        *ptr_PD = 0x0000;
        ptr_PD = ptr_PD + 1;
      }
  }
  return end;

}

/* [] END OF FILE */
```

Appendix 11 - Improc.h

```
/*****************************************************************************
* File Name:  ImProc.h
*
* Version:   1.0
*
* Description:  This file contains function prototypes for image processing.
*
* Author:  Chris Quesada
*****************************************************************************/
#ifndef IMPROC_H
#define IMPROC_H


#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <time.h>
#include <stdint.h>
#include "cy_pdl.h"
#include "cycfg.h"

/* Image Processing Parameters */
#define Max_Length       (320)
#define Max_Height       (240)
#define Length           (320)
#define Height         (80)
#define Pixel_Count_1    (25600)
#define Pixel_Count_2    (16960)
#define Threshold      (40000)

//Prototype of functions

//allocation of memory
unsigned short* conv2gray( uint16_t *ptr_Image_PD, uint16_t *ptr_PD,uint16_t *ptr_GD
    ) ;
unsigned short* sobel( uint16_t *ptr_Image_PD, uint16_t *ptr_PD, uint16_t *ptr_GD ) ;

#endif
```

Appendix 12 - interface.h

```
/*******************************************************************************
* File Name:  SPIMaster.c
*
* Version:   1.0
*
* Description:  This file contains macros for various files.
*           - This file was provided by Cypress and modified to fiy
*             the Smart Eraser System.
*
* Author:  Chris Quesada
*******************************************************************************/
#ifndef SOURCE_INTERFACE_H_
#define SOURCE_INTERFACE_H_

#include "cy_pdl.h"
#include "cycfg.h"

/* I2C & SPI statuses */
#define INIT_SUCCESS    (0UL)
#define INIT_FAILURE    (1UL)

/* Communication status */
#define TRANSFER_COMPLETE   (0)
#define TRANSFER_FAILURE  (1)
#define TRANSFER_IN_PROGRESS (2)
#define IDLE         (3)

/* Element index in the packet */
#define PACKET_CMD_POS   (0UL)
#define PACKET_DAT_POS   (1UL)

void handle_error(void);

#endif
```

Appendix 13 - square_detection.c

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#define MAX_NAME_SZ 256

int main() {
   /* Initalize variables */
   int picture[10][10]= {
     {0, 0, 0, 0, 0, 0, 0, 0, 0, 0}, //row 1
     {0, 0, 0, 0, 0, 0, 0, 0, 0, 0}, //row 2
     {0, 0, 0, 0, 1, 1, 1, 1, 0, 0}, //row 3
     {0, 0, 0, 0, 0, 1, 1, 1, 0, 0}, //row 4
     {0, 0, 0, 0, 0, 1, 1, 1, 0, 0}, //row 5
     {0, 0, 0, 0, 0, 1, 1, 0, 0, 0}, //row 6
     {0, 0, 0, 0, 1, 1, 1, 0, 0, 0}, //row 7
     {0, 0, 0, 0, 1, 1, 1, 1, 0, 0}, //row 8
     {0, 0, 0, 0, 0, 1, 1, 1, 0, 0}, //row 9
     {0, 0, 0, 0, 0, 0, 0, 0, 0, 0} //row 10
     };
  int  coord[4]; //will contain the final coordinates (coord[top, left, bottom,
     right])
  int top = 11;   //top-most row (11 is because it will never be 11; used as a
     comparison value to see if initial 1 has been found yet)
  int left = 11;  //left-most column
  int bottom = 11;  //bottom-most row
  int right = 11;  //right-most column
  int i, j;

  for(i = 0; i < 10; i++){ //row loop (matters for top and bottom)
    for(j = 0; j < 10; j++){ //column loop (matters for left and right)
      if(picture[i][j] == 1){
        if(top == 11 && left == 11 && bottom == 11 && right == 11){ //if the coord
           don't have values yet (start as NULL), give them the first coord to base
           the rest of the comparisons off of
          top = i;
          left = j;
          bottom = i;
          right = j;
        }
        else{ //if the coord do have values in them, begin comparing to find the
           outermost values
          if(i < top) top = i;
          else if (i > bottom) bottom = i;
          else if (j < left) left = j;
          else if (j > right) right = j;
        }
      }

    }

  }
/* top++;  //indexes values to where they would be on scale of 1 - 10
  left++;
  bottom++;
```

```
  right++; */
  coord[0]= top;
  coord[1]= left;
  coord[2]= bottom;
  coord[3]= right;
   /* Prints matrix. */
   printf("Here is your matrix:\n");
  for (i=0; i<10; i++)
  {
     for(j=0; j<10; j++)
        {
         printf("%d ", picture[i][j]);
        }
     printf("<< row %d", i);
    printf("\n");
   }

   printf("\nThese are the values that were found: \ntop-most = %d \nleft-most = %d
       \nbottom-most = %d \nright-most = %d\n\n", top, left, bottom, right);

   printf("Therefore, the coordinates to be sent to the Arduino are:\nCoord = [");
  for (i=0; i<4; i++)
  {
     printf("%d ", coord[i]);
   }
   printf("].");

   /* Print Message. */
   printf("\n\nI hope your values are what they were supposed to be!\n\n");

   /* Pause the Console */
   system("pause");

   /* Free memory and exit. */
   return 0;
}
```

Appendix 14 - serpentine.c

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

#define MAX_NAME_SZ 256

int main() {
   /* Initalize variables */
   int top = 2;
   int bottom = 8;
   int left = 4;
   int right = 9;
   int coord[4];
   coord[0]= top;
  coord[1]= left;
  coord[2]= bottom;
  coord[3]= right;
  printf("top space: %d. ", top);
  printf("left space: %d. ", left);
  printf("bottom space: %d. ", bottom);
  printf("right space: %d. \n", right);

   /* here, when x= something and y= something, that is the number of rotations
      needed for that axis (i.e. the number that would be sent to the stepper
      motors)*/

   int x = left; /*moves eraser to beginning x position*/
   printf("starting x position=%d\n", x);
   int y = top; /*moves eraser to beginning y position*/
   printf("starting y position=%d\n", y);

   int rotateX = right - left; // should be positive
   printf("rotateX=%d\n", rotateX);
   int countY = bottom - top; // should be positive
   int temp = rotateX;
   x = rotateX;
   printf("x =%d\n", x);
   while(countY != 0){
         y = 1;
     printf("y =%d\n", y);
     /*delay(time_to_move);*/
     y = 0;
     printf("y =%d\n", y);
     countY = countY - 1;

     x = temp;
     x = -x;
     printf("x =%d\n", x);
     /*delay(time_to_move*abs(rotateX));*/
     temp = x;
     x = 0;
     printf("x =%d\n", x);

  }
  if(x < 0){
```

```
    x = -left;
    printf("x =%d\n", x);
    /*delay(time_to_move*left)*/
    x = 0;
    printf("x =%d\n", x);
    y = -bottom;
    printf("y =%d\n", y);
    /*delay(time_to_move*bottom)*/
    y = 0;
    printf("y =%d\n", y);
  }
  else{ //x > 0
    x = -right;
    printf("x =%d\n", x);
    /*delay(time_to_move*right)*/
    x = 0;
    printf("x =%d\n", x);
    y = -bottom;
    printf("y =%d\n", y);
    /*delay(time_to_move*bottom)*/
    y = 0;
    printf("y=%d\n", y);
  }



  /* Pause the Console */
  system("pause");

  /* Free memory and exit. */
  return 0;
}
```

Appendix 15 - stepper_motors.py

```
import machine
import time

pins = [
   machine.Pin(12, machine.Pin.OUT), # 1
   machine.Pin(13, machine.Pin.OUT), # 2
   machine.Pin(14, machine.Pin.OUT), # 4
   machine.Pin(15, machine.Pin.OUT), # 8
]

phases = [ 10, 6, 5, 9 ]
x = -3.5;
number_of_rotations = x*1600
x = 0;

if number_of_rotations < 0: #changes order of phases for CCW
  phases.reverse()
  number_of_rotations = number_of_rotations*-1
while x < number_of_rotations:
  for phase in phases:
    for n, p in enumerate(pins):
      pins[n](phase & 1<<n)
    time.sleep(0.0001)
    x = x + 1
```

Appendix 16 - SMserver.py

```
import socket
import sys
import time
import network
import network
import socket
from UART import *
from _thread import *

class server:
 List1 = []
 List2 = []
 List3 = []
 NW = 'esp32-network'
 password = 'esp32esp32'
 def start(self):
  station = network.WLAN(network.STA_IF)
  station.active(True)
  try:
   station.connect(self.NW,self.password)
  except KeyboardInterrupt:
   print('Connection Failed')
   sys.exit()

  time.sleep(10)
  station_info = station.ifconfig()
  HOST = station_info[0]
  PORT = 8888 # Arbitrary non-privileged port

  s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
  #Bind socket to local host and port
  try:
   s.bind((HOST, PORT))
  except:
   print('Bind failed')
   sys.exit()

  print('Socket created at ' + str(HOST) + ' with port ' + str(PORT) )
  print('Socket bind complete')

  #Start listening on socket
  s.listen(10)
  print('Socket now listening')

  #Function for handling connections. This will be used to create threads
  def clientthread(conn, addr):
   #Sending message to connected client
    message = 'Welcome to the server.'
    conn.sendall(message.encode())
    mes = [b'ACK: ']
    data = ''
   #infinite loop so that function do not terminate and thread do not end.
    lock = _thread.allocate_lock()

    while self.List1 == []:
```

```
      pass
    while not lock.acquire():
      pass
    print(self.List1)
    #Send first set of instructions
    conn.sendall(self.List1)
    time.sleep(2)
    lock.release()

    while self.List2 == []:
      pass
    while not lock.acquire():
      pass
    print(self.List2)
    #Send second set of instructions
    conn.sendall(self.List2)
    time.sleep(2)
    lock.release()

    while self.List3 == []:
      pass
    while not lock.acquire():
      pass
    print(self.List3)
    #Send third set of instructions
    conn.sendall(self.List3)
    time.sleep(2)
    lock.release()

    conn.close()
    return

#now keep talking with the client
while 1:
  k = 0

    #wait to accept a connection - blocking call
  while (k < 2):
    conn, addr = s.accept()
    print('Connected with ' + str(addr[0]) + ' : ' + str(addr[1]))

    #start new thread takes 1st argument as a function name to be run, second is
       the tuple of arguments to the function.
    start_new_thread(clientthread ,(conn, addr))
    k = k + 1

  self.List1 = []
  self.List2 = []
  self.List3 = []
  self.List1 = UARTread()
  self.List2 = UARTread()
  self.List3 = UARTread()
  time.sleep(5)
  self.List1 = []
  self.List2 = []
  self.List3 = []
```

```
      k = 0

    s.close()

server = server()
```

Appendix 17 - SMclientX.py

```
import socket
import sys
import time
import network
import network
import socket
from UART import *
from _thread import *

class server:
 List1 = []
 List2 = []
 List3 = []
 NW = 'esp32-network'
 password = 'esp32esp32'
 def start(self):
  station = network.WLAN(network.STA_IF)
  station.active(True)
  try:
   station.connect(self.NW,self.password)
  except KeyboardInterrupt:
   print('Connection Failed')
   sys.exit()

  time.sleep(10)
  station_info = station.ifconfig()
  HOST = station_info[0]
  PORT = 8888 # Arbitrary non-privileged port

  s = socket.socket(socket.AF_INET, socket.SOCK_STREAM)
  #Bind socket to local host and port
  try:
   s.bind((HOST, PORT))
  except:
   print('Bind failed')
   sys.exit()

  print('Socket created at ' + str(HOST) + ' with port ' + str(PORT) )
  print('Socket bind complete')

  #Start listening on socket
  s.listen(10)
  print('Socket now listening')

  #Function for handling connections. This will be used to create threads
  def clientthread(conn, addr):
   #Sending message to connected client
    message = 'Welcome to the server.'
    conn.sendall(message.encode())
    mes = [b'ACK: ']
    data = ''
   #infinite loop so that function do not terminate and thread do not end.
    lock = _thread.allocate_lock()

    while self.List1 == []:
```

```
      pass
    while not lock.acquire():
      pass
    print(self.List1)
    #Send first set of instructions
    conn.sendall(self.List1)
    time.sleep(2)
    lock.release()

    while self.List2 == []:
      pass
    while not lock.acquire():
      pass
    print(self.List2)
    #Send second set of instructions
    conn.sendall(self.List2)
    time.sleep(2)
    lock.release()

    while self.List3 == []:
      pass
    while not lock.acquire():
      pass
    print(self.List3)
    #Send third set of instructions
    conn.sendall(self.List3)
    time.sleep(2)
    lock.release()

    conn.close()
    return

#now keep talking with the client
while 1:
  k = 0

    #wait to accept a connection - blocking call
  while (k < 2):
    conn, addr = s.accept()
    print('Connected with ' + str(addr[0]) + ' : ' + str(addr[1]))

    #start new thread takes 1st argument as a function name to be run, second is
       the tuple of arguments to the function.
    start_new_thread(clientthread ,(conn, addr))
    k = k + 1

  self.List1 = []
  self.List2 = []
  self.List3 = []
  self.List1 = UARTread()
  self.List2 = UARTread()
  self.List3 = UARTread()
  time.sleep(5)
  self.List1 = []
  self.List2 = []
  self.List3 = []
```

```
      k = 0

    s.close()

server = server()
```

Appendix 18 - SMclientY.py

```
import socket
import sys
import _thread
import time
import utime
import struct
import network
import machine


# ------------------------------------------------------------------
# Class Client that will be able to connect to a network, send user
# inputted messages, and send ultrasonic and sound sensor readings
# ------------------------------------------------------------------
class client:
  AllBounds = []
  # ------------------------------------------------------------------
  # Initializations for variables to be used in the 'client' class
  # ------------------------------------------------------------------
  NW = ''                # NW = NetWork

  # ------------------------------------------------------------------
  # host and port are used in creating a socket connection to a server,
  # Change according to the server you are tryin to connect to.
  # ------------------------------------------------------------------
  host = '192.168.1.100'
  port = 8888

  password = ''          # Network password
  flag = 0               # On/Off flag for sound sensor

  # ------------------------------------------------------------------
  # Function Name: wif_con
  # Description : Enables the HUZZAH32 to connect to a specified
  #            network as a station.
  # ------------------------------------------------------------------
  def wifi(self):
    NW = 'esp32-network'
    password = 'esp32esp32'
    station = network.WLAN(network.STA_IF)
    station.active(True)
    try:
      station.connect(NW,password)
    except KeyboardInterrupt:
      print('Connection Failed')
      sys.exit()

  # ------------------------------------------------------------------
  # Function Name: send_US
  # Description : Sends readings from the ultrasonic sensor to a
  #            web server.
  # ------------------------------------------------------------------
  def SerpentineInit(self):
    def serpentine(top, left, bottom, right, delayx, delayy):
      def steppermotors(TopBound):
```

```
  pins = [
    machine.Pin(12, machine.Pin.OUT), # 1
    machine.Pin(13, machine.Pin.OUT), # 2
    machine.Pin(14, machine.Pin.OUT), # 4
    machine.Pin(15, machine.Pin.OUT), # 8
  ]

  phases = [ 10, 6, 5, 9 ]
  y = TopBound;
  number_of_rotations = y*57
  y = 0;

  if number_of_rotations < 0: #changes order of phases for CCW
    phases.reverse()
    number_of_rotations = number_of_rotations*-1
  while y < number_of_rotations:
    for phase in phases:
      for n, p in enumerate(pins):
        pins[n](phase & 1<<n)
      time.sleep(0.0001)
      y = y + 1

Xdelay = delayx
Ydelay = delayy
LeftBound = left
X_rotations = right - left
TopBound = top
Y_rotations = bottom - top


setDelayX = Xdelay*(Y_rotations/240)
setDelayY = Ydelay*(X_rotations/320)

print('Starting position X = ', LeftBound)
time.sleep(setDelayY)

print('Starting position Y = ', TopBound)
steppermotors(TopBound)

print('Number of rotations for X = ', X_rotations)
print('Number of rotations for Y = ', Y_rotations)
rotateX = X_rotations

print('X starts by rotating: ', X_rotations)
time.sleep(setDelayY)

Numb_of_Y_pix_Rot = 20
y_pos = 0

while Y_rotations > 0:
  print('Y should rotate ', Y_rotations)
  steppermotors(Numb_of_Y_pix_Rot)
  Y_rotations = Y_rotations - Numb_of_Y_pix_Rot
  y_pos = Y_rotations
  X_rotations = -X_rotations
  LeftBound = X_rotations
  print('X should rotate ', X_rotations)
```

```
    time.sleep(setDelayY)
  if X_rotations < 0:
    X_rotations = -left
    y_pos = y_pos*-1
    print('X stopped at the bottom left corner, so it will rotate: ', -left)
    Y_rotations = -(bottom + y_pos)
    print(' and Y will rotate', -bottom)
    steppermotors(Y_rotations)
    time.sleep(setDelayY)
  else: #X_rotations > 0
    X_rotations = -right
    y_pos = y_pos*-1
    print('X stopped at the bottom right corner, so it will rotate: ', -right)
    Y_rotations = -(bottom + y_pos)
    print(' and Y will rotate', -bottom)
    steppermotors(Y_rotations)
    time.sleep(setDelayY)

  time.sleep(setDelayY)
  time.sleep(setDelayX)

instr1 = self.AllBounds[0]
self.top1 = (instr1[0] << 8) + instr1[1]
self.left1 = (instr1[2] << 8) + instr1[3]
self.bottom1 = (instr1[4] << 8) + instr1[5]
self.right1 = (instr1[6] << 8) + instr1[7]

print('top1 = ',self.top1)
print('left1 = ',self.left1)
print('bottom1 = ',self.bottom1)
print('right1 = ',self.right1)

time.sleep(2)

instr2 = self.AllBounds[1]
self.top2 = (instr2[0] << 8) + instr2[1]
self.left2 = (instr2[2] << 8) + instr2[3]
self.bottom2 = (instr2[4] << 8) + instr2[5]
self.right2 = (instr2[6] << 8) + instr2[7]
self.top2 = self.top2 + 80
self.bottom2 = self.bottom2 + 80

print('top2 = ',self.top2)
print('left2 = ',self.left2)
print('bottom2 = ',self.bottom2)
print('right2 = ',self.right2)

time.sleep(1)

instr3 = self.AllBounds[2]
self.top3 = (instr3[0] << 8) + instr3[1]
self.left3 = (instr3[2] << 8) + instr3[3]
self.bottom3 = (instr3[4] << 8) + instr3[5]
self.right3 = (instr3[6] << 8) + instr3[7]
self.top3 = self.top3 + 160
self.bottom3 = self.bottom3 + 160
```

```
  print('top3 = ',self.top3)
  print('left3 = ',self.left3)
  print('bottom3 = ',self.bottom3)
  print('right3 = ',self.right3)

  time.sleep(3)

  serpentine(self.top1, self.left1, self.bottom1, self.right1, 1, 4)
  print('check1')
  serpentine(self.top2, self.left2, self.bottom2, self.right2, 1, 4)
  print('check2')
  serpentine(self.top3, self.left3, self.bottom3, self.right3, 1, 4)

  return

# ------------------------------------------------------------------
# Function Name: send_user
# Description : Takes user input and sends whatever the user types
#            to a web server.
# ------------------------------------------------------------------
def WaitForInstructions(self):
  try:
    clisock = socket.socket( socket.AF_INET, socket.SOCK_STREAM )
  except:
    print('Failed to create socket')
    sys.exit()

  try:
     clisock.connect((self.host, self.port))
     print('Socket connected to ' + self.host + ' on port ' + str(self.port))
     print(self.receive(clisock, 5).decode())
  except:
     print(self.receive(clisock, 5).decode())
     print('Connection closed')
     sys.exit()
  inst = 0
  self.AllBounds = []
  while(inst < 3):
    data = clisock.recv(4096)
    Bounds = list(data)
    self.AllBounds.append(Bounds)
    inst = inst + 1

  clisock.close()
  return

    #clieprint(self.receive(clisock, 5).decode())

# ------------------------------------------------------------------
# Function Name: receive
# Description : handles any received data from a web server.
# ------------------------------------------------------------------
def receive(self, the_socket,timeout):

  #total data partwise in an array
  total_data=[]
  data = ''
```

```
    #beginning time
    begin = time.time()
    while 1:
      #if you got some data, then break after timeout
      if total_data and time.time() - begin > timeout:
        break

      #if you got no data at all, wait a little longer, twice the timeout
      elif time.time() - begin > timeout*2:
        pass
      #recv something
      try:
        data = the_socket.recv(1024)
        if data:
          total_data.append(data)
          #change the beginning time for measurement
          begin = time.time()
        else:
          #sleep for sometime to indicate a gap
          time.sleep(0.1)
      except:
        pass
       #join all parts to make final string
      return b''.join(total_data)

client = client()

client.wifi()

time.sleep(7)

while (True):

  client.WaitForInstructions()

  time.sleep(5)

  client.SerpentineInit()
```

Appendix 19 - ultrasonic.py

```
from machine import Pin
import utime
import np_lights as f1
while True:
  trig=Pin(12,Pin.OUT)
  trig.off()
  utime.sleep_us(2)
  trig.on()
  utime.sleep_us(10)
  trig.off()
  echo=Pin(13,Pin.IN)
  while echo.value() == 0:
    pass
  t1 = utime.ticks_us()
  while echo.value() == 1:
    pass
  t2 = utime.ticks_us()
  cm = (t2-t1)/148.0
  utime.sleep_ms(1000)
  print(cm)
  if cm < 10:
    f1.lights(1)
  elif cm > 10:
    f1.lights(0)
  utime.sleep(0.1)
```

Appendix 20 - np_lights.py

```
from machine import Pin
from neopixel import NeoPixel
pin = Pin(5, Pin.OUT)
np = NeoPixel(pin, 32)
color = (10,0,0)
off = (0,0,0)
def lights(value):
  if value == 1:
    for i in range(0, 32):
     np[i] = color
    np.write()

  elif value == 0:
   for i in range(0,32):
      np[i] = off
  np.write()
```