Smart Eraser

Final Project Report

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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 I2C communications, updated information on image processing implementation. Modified components used to build prototype stand.

Version #	Date Finalized	Name of Editor	Changes Made
			Removed movement detection while eraser in motion to 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 HUZZAH23 Feather Board microcontrollers for the wireless communications.
5	4/21/19	Heather Libecki Chris Quesada	Updated Milestone Schedule, GANTT Charts, and Test Plan.

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.

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I. Introduction

The idea of the Smart Eraser originated from the need to allow class time to be 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. The camera is mounted across from the whiteboard, and sends the image of the whiteboard to a microcontroller which processes the image, detects where the markings are, and traverses a path to erase all of these markings via an algorithm. 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.

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

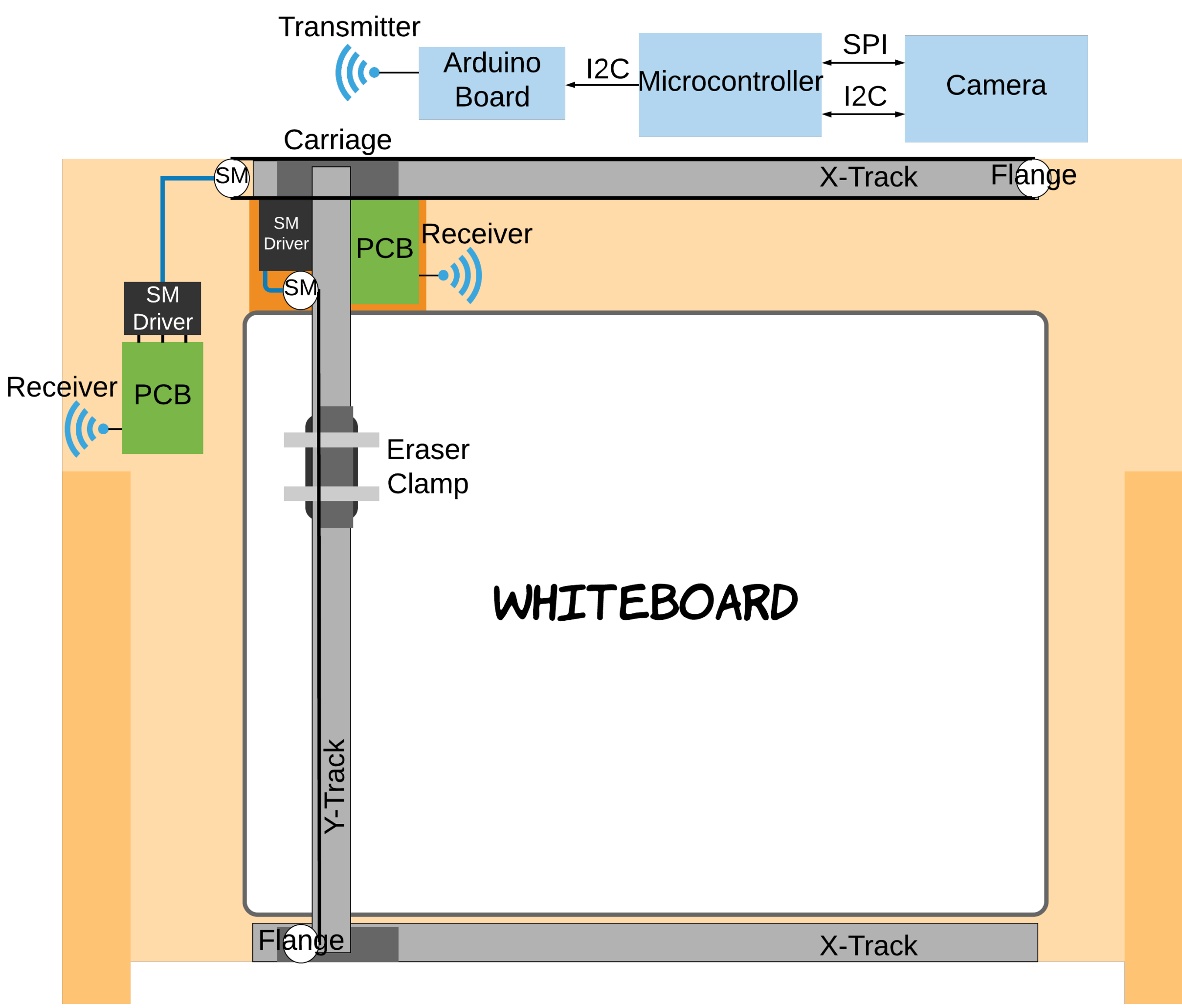


Fig. 1: Design overview of the final product

Figure 1 shows an overview of the final deliverable's mechanical and electrical components put together 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 will take in an image of a predefined (fixed) area on the whiteboard.
- Microcontroller: the PSoC 6 microcontroller will take in the image from the camera and perform image processing to detect edges, indicating where there are markings on the whiteboard. It will then convert the array of edges that have been detected and find the top-most, left-most, bottom-most, and right-most locations of the markings. These four values are then put into an array. An array of instructions to be given to the stepper motors is then created, and this array is then sent to the Feather board.
- SPI: one of two communication protocols used to communicate with the camera through the micro-controller and trigger a capture of an image.
- I2C: the other of two communication protocols used to initialize the resolution and compression type of the image that is being captured by the camera. It is also the same type of communication method that is used to send data from the microcontroller to the Feather board.
- Feather Board: acts as an in-between for the microcontroller and the stepper motors, and is connected to the wireless transceivers (a.k.a. Adafruit's HUZZAH32 microcontroller boards) that allow wireless communication between the board and the stepper motors.
- Transmitter: reads in the stepper motor instruction array from the microcontroller and sends the instructions to the stepper motors wirelessly, one at a time.
- Receiver: receives the instructions sent by the transmitter and uses the proper libraries to move the stepper motors accordingly.
- SM: stepper motors that will 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.
- PCB: connects the stepper motors, their drivers, the wireless transceivers, and the power supplies needed for all of these components.
- Flange: connected to the stepper motors via a pulley belt in order to allow movement.
- 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 move the eraser in the X-axis direction.
- Y-Track: the track that moves the eraser 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 will be written on and erased.

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, their power system, and the PCBs needed to connect them together. She also created the wireless connections between the receiver stepper motor Feather boards and the transmitter Feather board. She assisted Chris with creating the SPI communication between the transmitter Feather board and the PSoC 6. Finally, she was in charge of the algorithms used to find the instructions for the stepper motors needed to move the eraser to the markings found on the whiteboard, before moving back to its standby position. Therefore, she was in charge of the movement of the Smart Eraser.

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 I2C communication between the PSoC 6 to configure the image sensor(I2C) to output RGB565 with a 320x240 resolution and then read in image data (SPI). After an image is received, he was to develop an image processing program which takes in an image, converts it to grayscale, then uses a sobel edge detection algorithm to detect 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 I2C communication between the HUZZAH32 and the PSoC 6 with assistance from Heather. 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. Therefore, he was in charge of the entire physical prototype construction of the Smart Eraser. He also assisted in setting up the Arducam via an Arduino platform to analyze the SPI and I2C being sent from the camera.

During the project's life cycle, there were a number of deliverables that needed to be turned in to Dr. Stillmaker which were worked on by all three members to ensure a consistent flow of information throughout all written documentation.

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 processed image to move eraser to specific markings.
- Create an algorithm to sort the order in which the markings should be erased to ensure the shortest path is taken.
- Create a motion-detection program to check for people obstructing the whiteboard.

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 found through an edge-detection image processing program.
- Image captured can be processed to find markings on board.
- Array with locations of markings 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.

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.
  - The camera wound up needing to be hardwired to the microcontroller. Because of format being output by the camera to the controller (JPEG rather than RGB565), the camera being hardwired had to be scrapped as well. The "camera" wound up being a smartphone image which was then 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, no 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 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 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, especially because the first attempt at creating the wireless system ended in failure, so 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.

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
    - SPI and I2C 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 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 a specific degree that has yet to be determined) to the right on the x-axis motor and 178 partial rotations (to a specific degree that has yet to be determined) down on the y-axis motor. As mentioned, further configuration at the time of testing needs to be done towards how many degrees of rotation the stepper motor would need to rotate in order to represent 1 pixel length. 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 spaghetti 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 scrapped, 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 I2C 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 sent 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.

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 [15]
- IEEE Editorial Style Manual
  - Standards to follow when writing this Project Charter and any other reports that were written for this project [16]
- NEMA Standards Publication ICS 16 Motion/Position Control Motors, Controls, and Feedback Devices
  - Applies to the stepper motors being used and their operation [17]
- SPI Communications
  - Defacto standard

- I2C Communications
  - Defacto standard
- ITU-R Recommendation BT.709
  - Applies to the coefficients used in the grayscale algorithm conversion [18]

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 to be 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

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.

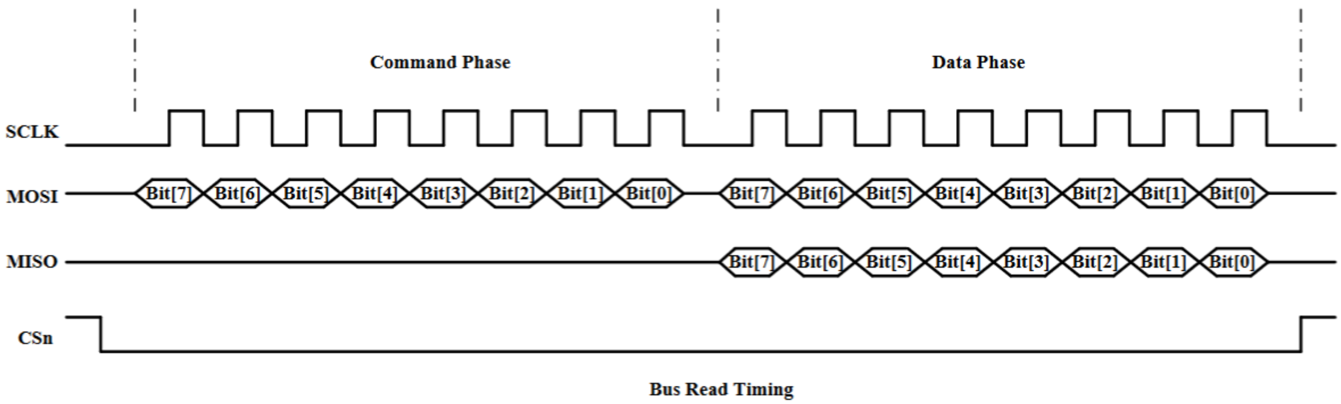


Fig. 2: Bits corresponding to a system SPI read [1]

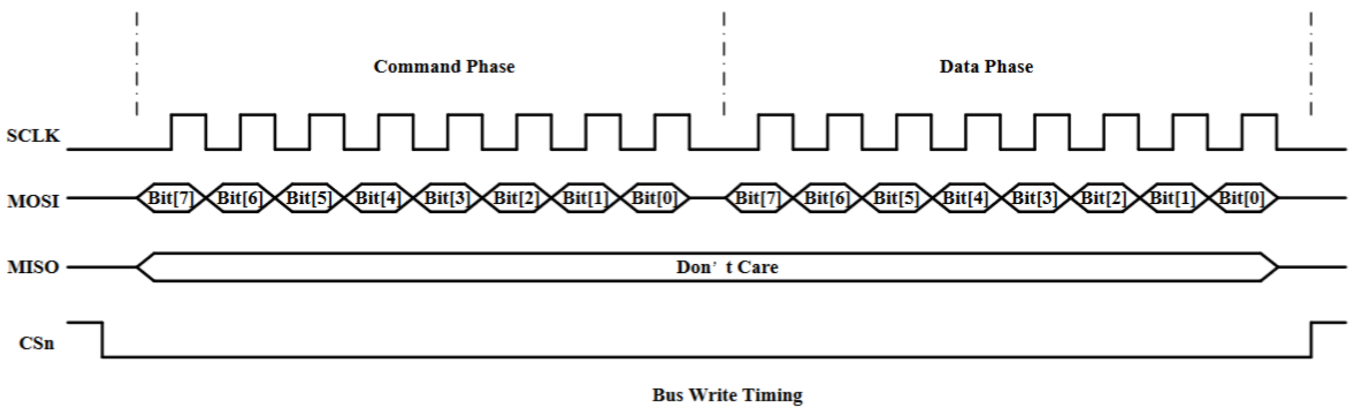


Fig. 3: Bits corresponding to a system SPI write [1]

2) I2C Communication: The purpose of including I2C communication is both to initialize and configure the image sensor of the Arducam-5MP-mini-plus as well as providing an interface between the PSoC 6 and HUZZAH32 microcontrollers. 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 tacked 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 tacked 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.

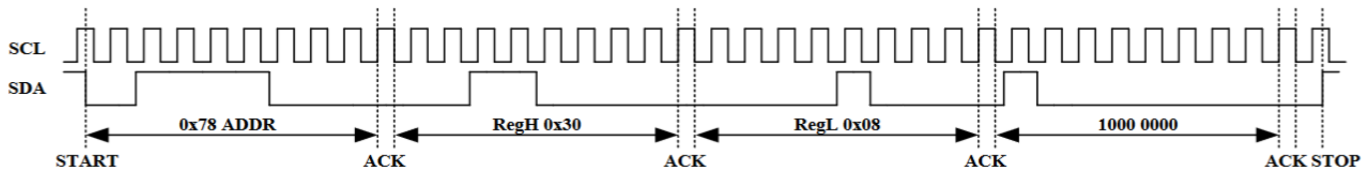


Fig. 4: Bits corresponding to a system I2C write [1]

3) 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.

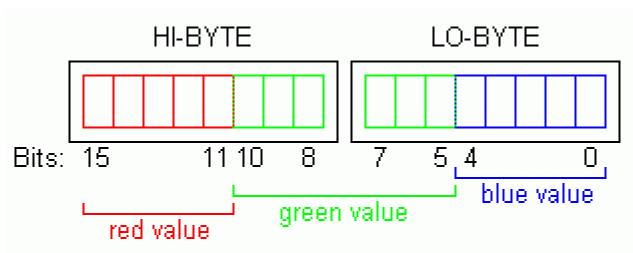


Fig. 5: How an RGB565 pixel value is stored in memory [2]

4) 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 Y and X direction which is eventually be used in PythagorasâĂŹ 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).

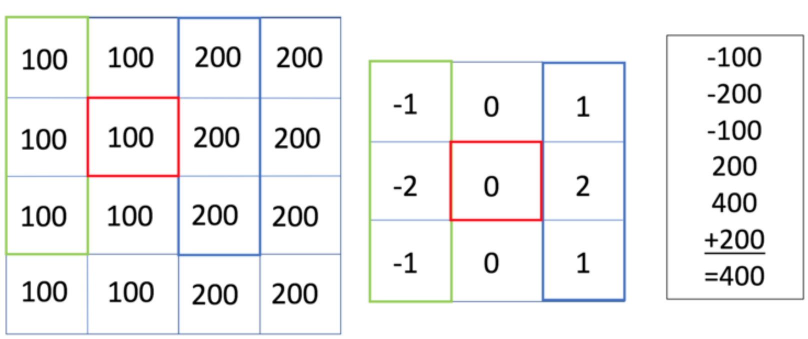


Fig. 6: Kernel convolution used in sobel edge detection [3]

5) 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 scrapped. 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 Feather board is initialized as a transmitter (server) that connect to the PSoC 6 via an I2C connection and take in the stepper motor instructions, then send these instructions to the stepper motors. Two other Feather boards act as receivers (clients); one is attached to each stepper motor, and receive the instructions for the stepper motors. They then give them the directions to move according to the instructions received.

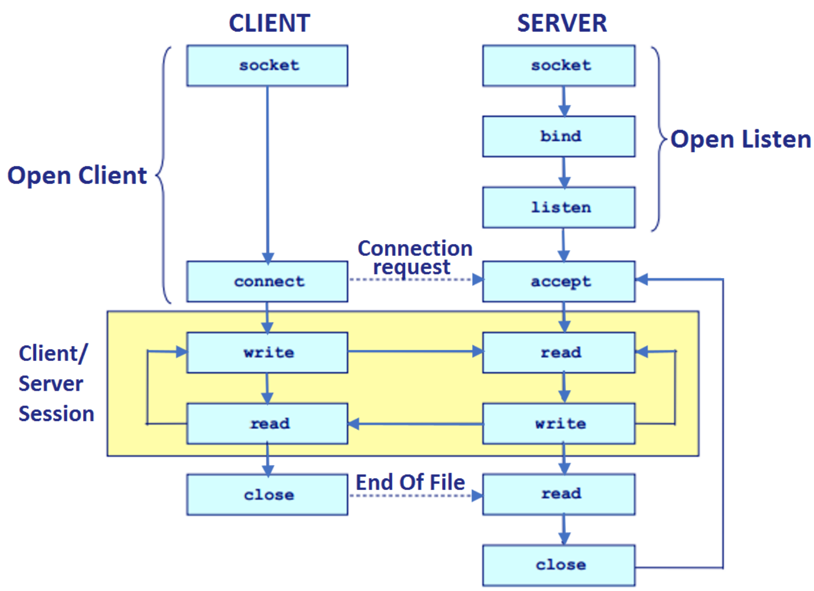


Fig. 7: Socket communication protocol between server and client [4]

6) Stepper Motor Operations: In order for the stepper motors to move, they must be programmed to receive the right signals at the right time to move the magnetic coils within the motor properly. They were programmed in Python and connected to the Feather boards, which provides the necessary signals to allow the motors to move. Figure 8 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\	CW	CCW
1	+	+	-	-	↓	↑
2	-	+	+	-		
3	-	-	+	+		
4	+	-	-	+		

Fig. 8: Rotation instructions for the stepper motor [5]

7) 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 9 shows the concept behind these two algorithms, if the whiteboard was divided into an 8x8 matrix. Figure 10 shows the flowchart of the *square_detection.c* program that detects the square around the markings, and Figure 11 shows the flowchart of the *serpentine.c* program that moves the eraser to erase the markings.

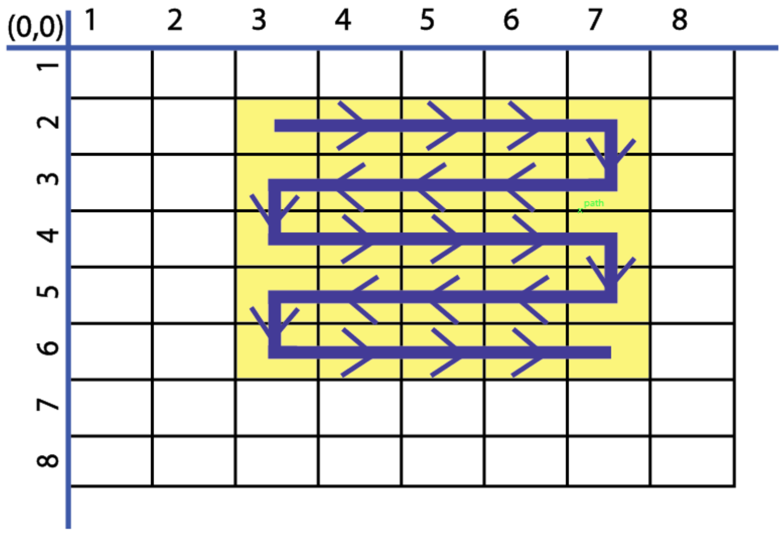


Fig. 9: Concept behind the two algorithms that move the eraser to the markings

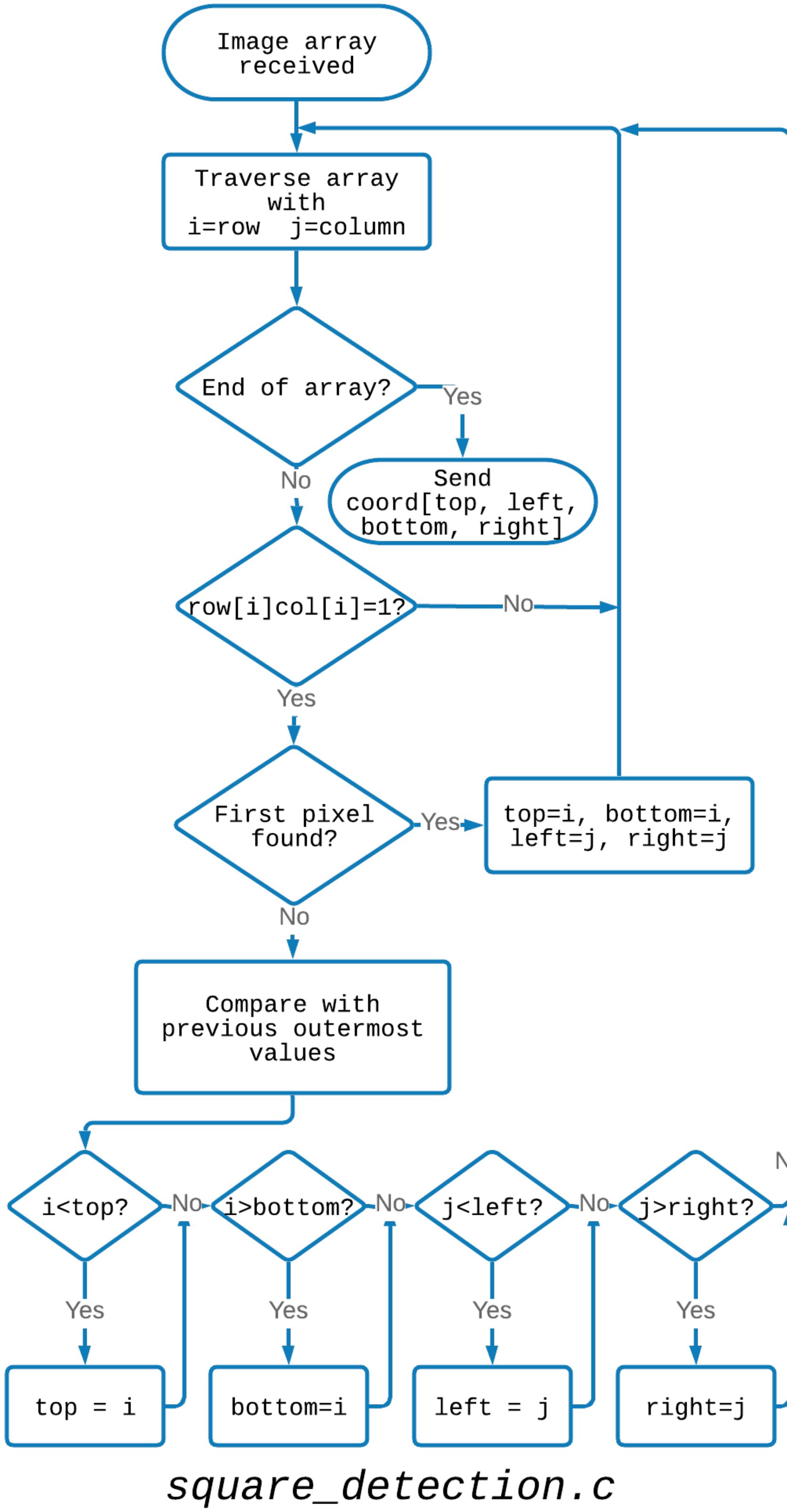


Fig. 10: Flowchart of the logic behind the *square_detection.c* program

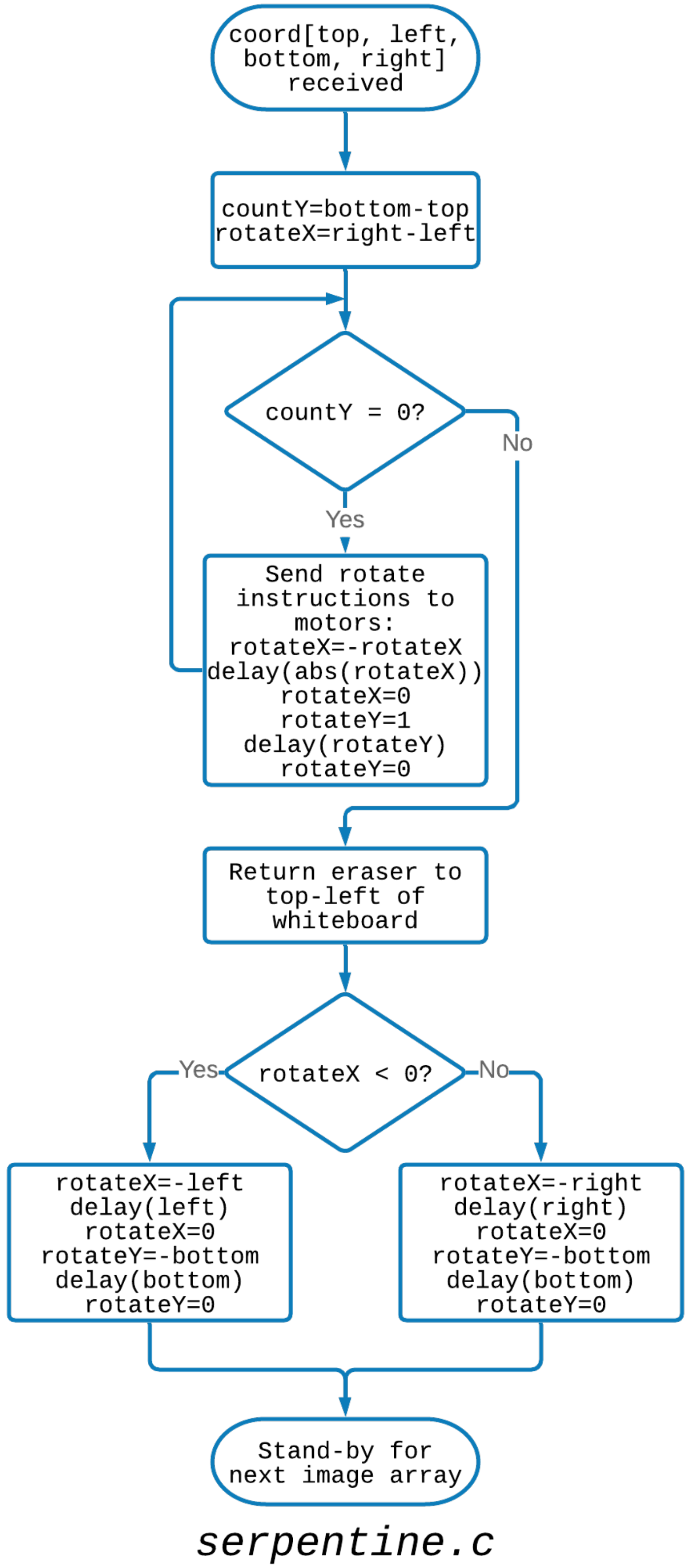


Fig. 11: Flowchart of the logic behind the *serpentine.c* program

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 I2C communication to both configure the image sensor (I2C) and initiate data transfer (SPI). Although it is referred to as a camera it is more accurately defined as a module which has an I2C interface to configure the image sensor and a SPI interface to handle data transfer.

Fig. 12: The Arducam Mini Module 5MP OV5642 Camera [5]

2) PSoC 6 Microcontroller: Due to the processing capabilities that the Smart Eraser needs to be able to handle, and due to the peripheral devices that need to be attached, the PSoC 6 was found to be the best microcontroller to use for the brains behind 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 I2C, 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.

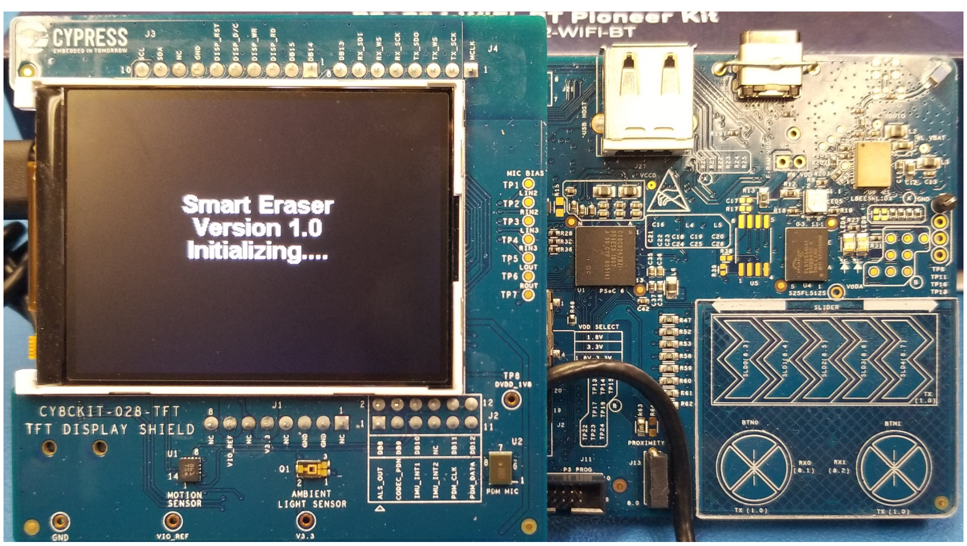


Fig. 13: The PSoC 6 microcontroller by Cypress

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.

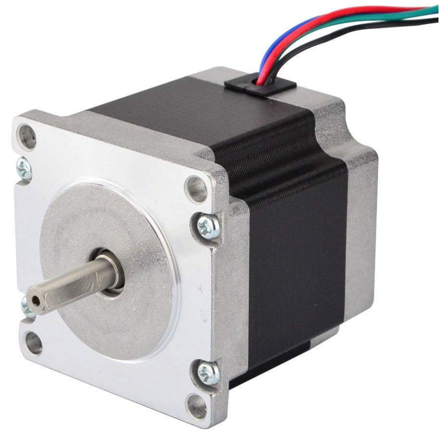


Fig. 14: 4-lead bipolar NEMA23 stepper motor [6]

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 15 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 8 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. 15: Limited parameters of the DM542T stepper motor drivers [7]

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.

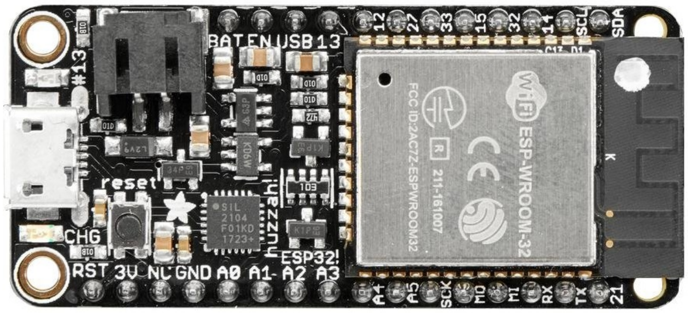


Fig. 16: Adafruit's HUZZAH32 Feather Board with ESP32 chip [8]

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. *Because the wireless system has to be redone, there is no image to place here at the moment*

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 PCB, which the stepper motors are connected to. With this in mind, the 9V rechargeable lithium batteries were chosen for the additional power source. Three of these batteries are 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 run out of charge, which allow them to be reusable many times for the prototype as well.

Fig. 17: 9V lithium rechargeable batteries [9]

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.

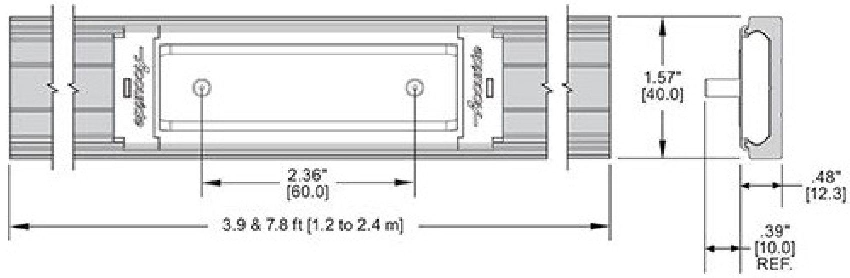


Fig. 18: Linear track system specifications [10]

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. 19: Mounting brackets for the stepper motors [11]

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 21 is black in order to show the details of the teeth, but the actual belt that was used is white.

Fig. 20: Pulley flange [12]

Fig. 21: Pulley belt [13]

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 on what used for this prototype and how it was built are explained after it.

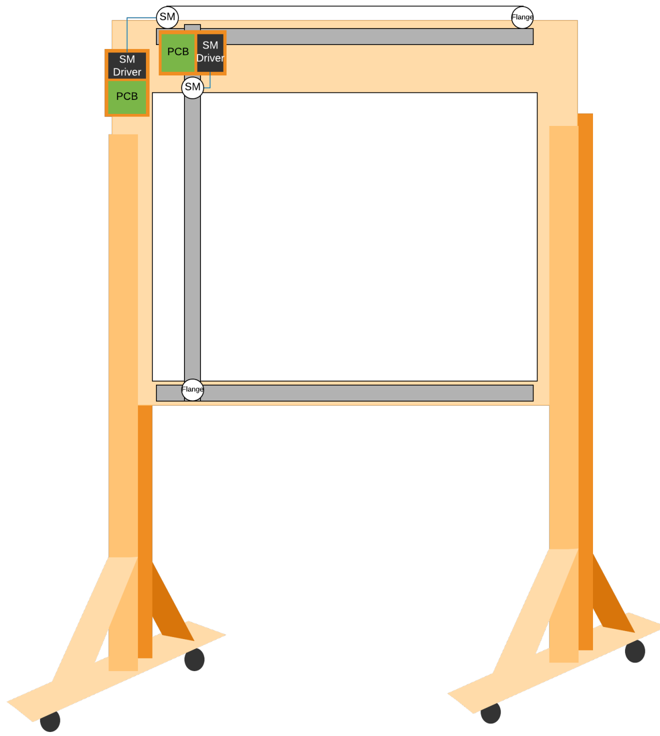


Fig. 22: Rough image of the prototype stand

The main screws used were 3 inch T-25 star-headed screws. These were used to attach the horizontal tracks to the 2x3 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 2x3 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 2x3 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 2x4 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.

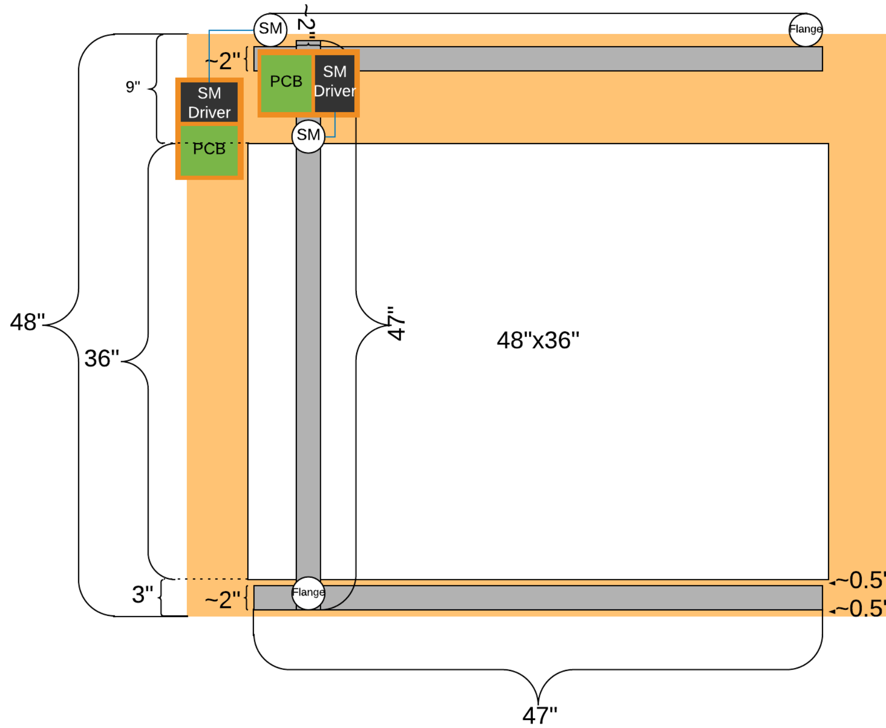


Fig. 23: Front view of the SMART ERASER system with dimensions

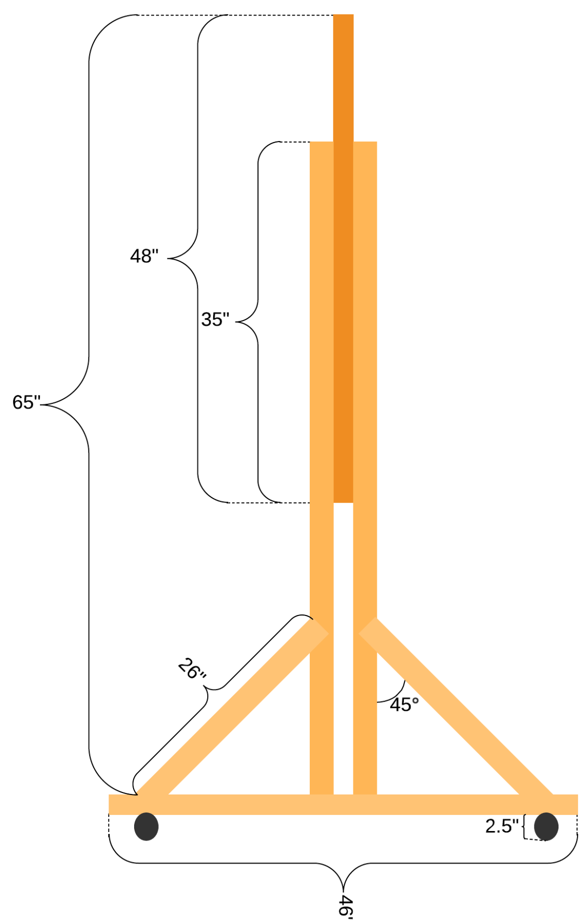


Fig. 24: Side view of the SMART ERASER system with dimensions

G. Boundaries

Because of the problems that were had with the wireless communication via the Arduino and the Kuman wireless transceivers, the wireless communication system has to be completely redesigned using the HUZZAH32 Feather boards. This is a boundary, as this part essentially has to be completely redone with Python, and the PCBs that were designed for the other system are not usable, and must be redesigned as well.

Unfortunately, configuration of the camera sensor proved to be a project all in itself. It involves 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 is possible to take a picture with a phone, run it through software to convert it to the desired resolution and output format and pre loaded 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 connections of wires complete before the power is applied
  - If connections cannot be completed before power is applied, double-check then triple-check that the pin will be going into the right port
- Moving parts attached to whiteboard:
  - Always stand away from whiteboard when in motion
  - Always callout when it is about to start moving
  - Identify the failsafe wire to unplug in order to emergency shutdown the moving parts
- 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).

TABLE I: Senior Design Semester 1 - Research Phase - Part 1

Member Assign.	Start-End Date	Description
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 II: Senior Design Semester 1 - Research Phase - Part 2

Member Assign.	Start-End Date	Description
Chris Q.	1/1-1/20/19	Develop the code for the image processing program.
Juan C.	1/1-1/15/19	Configure the power system for the mechanical parts of the Smart Eraser.
Juan C.	1/1-1/15/19	Build the mechanical system the eraser will be attached to.
Heather L.	1/15-2/15/19	Develop the coordinate system.
Chris Q.	1/15-1/30/19	Develop the algorithm to determine the quickest path to erase markings on the board.
All	1/15-1/30/19	Integrate the microcontroller with the mechanical system.
All	1/20-1/30/19	Test the newly formed microcontroller-mechanical system.
Heather L.	2/1-2/10/19	Set up the wireless communication between camera and DE1_SoC.
Chris Q.	2/1-2/25/19	Test the image processing program with the camera.
Chris Q.	2/25-3/25/19	Create the motion-detecting program.
All	3/26-4/15/19	Integrate the motion-detecting program with the camera and microcontroller-mechanical system.
All	4/1/-4/20/19	Test the motion-detecting program.
All	4/20-5/13/19	Add potential additional features to be decided upon at a later time (if ahead of schedule).
All	4/20-5/13/19	Final Project Presentation.

TABLE III: Senior Design Semester 2 - Implementation Phase.

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
wireless_conn_SM.s	**Heather**
If the signal is not received, stop tests.	
Wireless Connectivity to Stepper Motor Receivers	**Heather**
The signal being broadcast from the wireless Raspberry Pi module is successfully received by the wireless receiver that will be placed on the stepper motor PCBs.	
The Raspberry Pi's wireless signal should be received by another entity to show proof of broadcast (like a computer).	Heather
The wireless signal from the stepper motor's transceiver should be discoverable on another entity to show proof of broadcast (like a computer).	Heather
The Raspberry Pi should be configured to connect to the stepper motor's transceiver.	Heather
Proof of connection: a signal should be sent to the stepper motor transceiver with a touch of the pushbutton.	Heather
Proof of connection: a signal to rotate the stepper motors clockwise and counter clockwise should be received, and it should successfully move the stepper motors as specified.	Heather
A series of instructions to move the stepper motors should be sent to the transceiver in order to determine it's ability to work properly.	Heather
wireless_conn_camera.s	**Heather**
If the camera connection signal is not received, stop tests.	
Wireless Connectivity to Camera	**Heather**
The signal being broadcast from the DE1_SoC and from the camera connect in order to allow data transfer from the camera to the DE1_SoC.	
A signal from the camera should be received by a wireless entity (such as a computer).	Heather
A signal from the DE1_SoC should be received by a wireless entity (such as a computer).	Heather
A signal from the camera should be received by the DE1_SoC.	Heather
The data from the camera should be shown on another entity through the wireless connection (like a computer).	Heather
The data from the camera should be received by the DE1_SoC and sent to the computer to prove a successful transfer of data.	Heather
Im_proccessing.c	**Chris**
If Pixels other than true values (stored in the image processing array) are displayed through VGA, then stop all tests	
VGA display	**Chris**
Pixels with only true values (stored in the image processing array) are displayed through VGA	
A signal should be sent to the VGA from a microcontroler (such as the DE1_SoC)	Chris
A greyscale image should be displayed via VGA	Chris
A greyscale image should be evaluated in different lighting intensities	Chris
A greyscale image should be evaluated with different objects intentionally put in the image	Juan
Linear Tracking system	**Juan**
If either the horizontal or the verical tracking systems detach from the the board, then stop all tests	

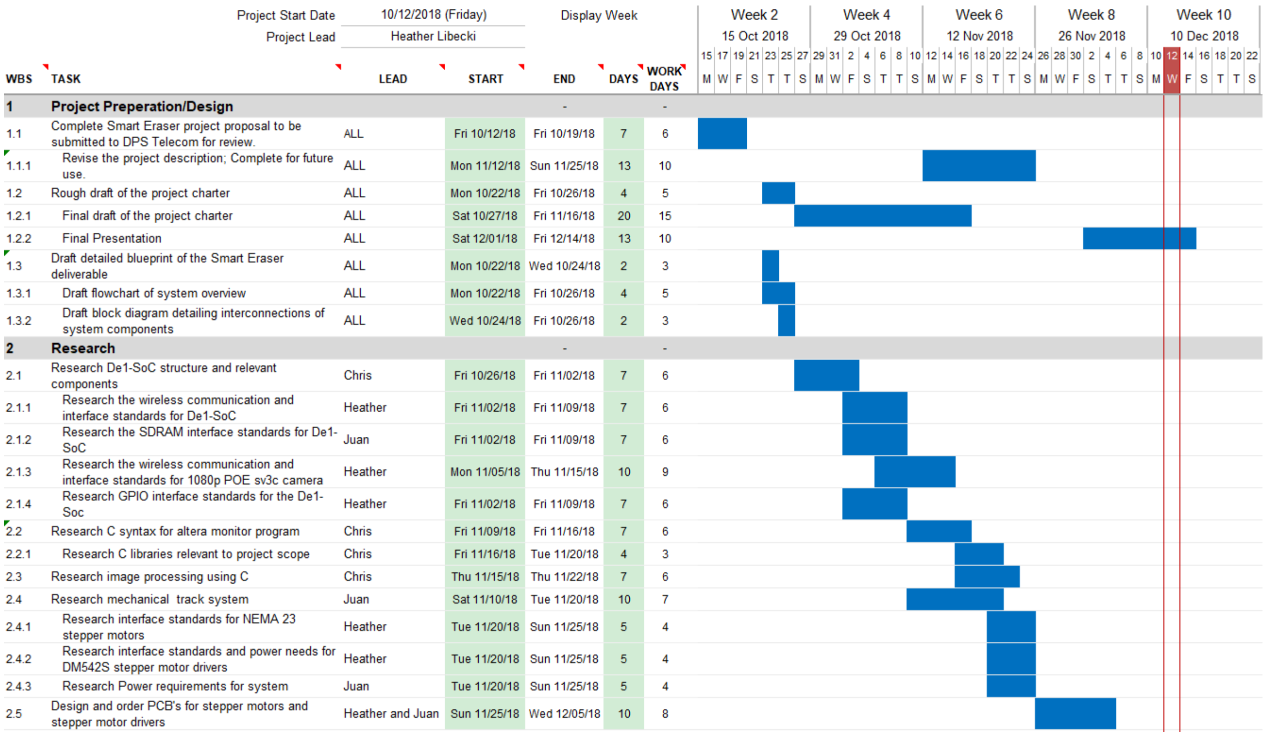
Fig. 25: Test Plan for the Smart Eraser - Part 1

Linear Motion	**Juan**
Smooth operation of both the horizontal and veritcal linear motion systems	
Rapid rotation of stepper motors	Juan
Run for long periods of use	Juan
Run at voltage that provides proficient movement of the linear motion system while still maintaining fluidty	Chris
shortestPath.c	**Chris**
If the shortest path is not found, then stop all tests	
Dijkstra's Algorithm	**Chris**
Developement of shortest path is found between all true values in the array containing the processed image information	
Run the algorithm on a smaller scale with a test 2-d array	Chris
Apply multiple different starting locations and check for similar results amongst them	Juan
stepMotPath.c	**Heather**
If the x-axis or y-axis Stepper motor's degree of rotation does not represent 1 pixel, then stop all tests	
Correctness of Stepper Motor Rotations	**Heather**
Physical movement accross the board that represents the same length and position of movement across the digital image	
With the Linear motion system assembled, 1 point should move no more than 5 inches in 360 degrees of rotation from the stepper motor	Chris
With the Linear motion system assembled, 1 point should move exacly the length of 1 pixel per stepper motor rotation	Heather
Erasing Markings on Whiteboard	**Juan**
If the eraser fails to erase any marks, then stop all tests	
Correctness of Path that Eraser Follows	**Chris**
All markings on the board being erased	
The erasers movements should match the results of the shortest path algorithm	Chris
Eraser movement should be smooth	Juan
Movement Detection	**Juan**
If the system does not stop when moving in front of the board, then stop all tests	
System Stops with Detection of Person	**Chris**
All markings on the board being erased	
A signal from the sensor should be received by a microcontroller (such as the DE1_SoC) when movement is detected	Chris
A signal from the DE1_SoC should be received by a wireless receiver (such as a the Kuman transreceiver).	Heather
System should cease execution when the signal is received	Heather

Fig. 26: Test Plan for the Smart Eraser - Part 2

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.

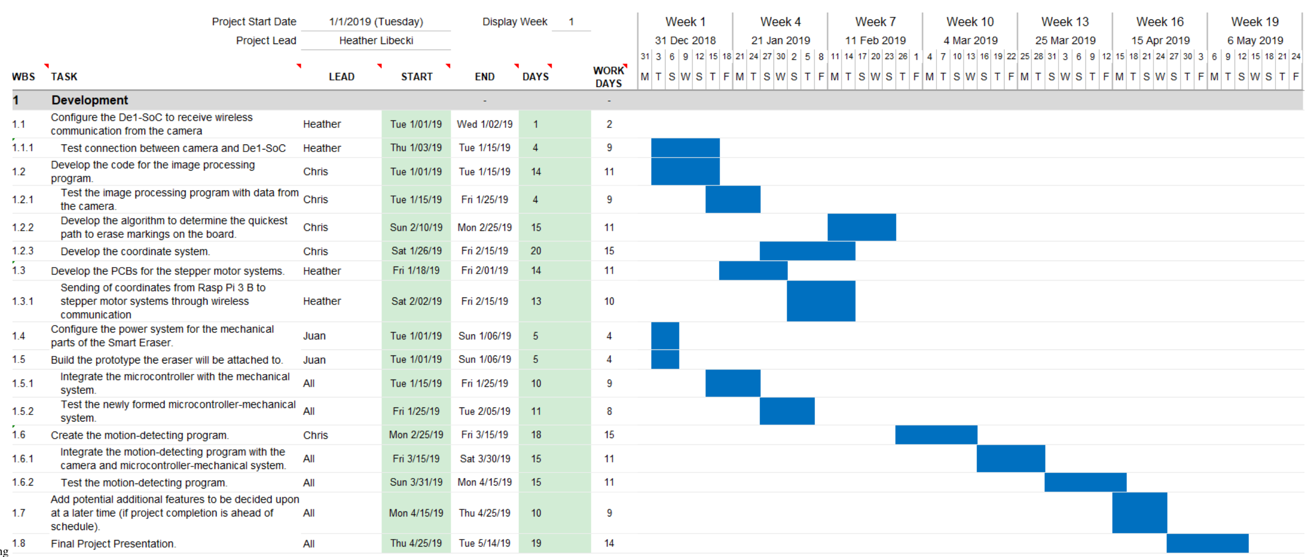


Project Start Date: 10/12/2018 (Friday) | Display Week
Project Lead: Heather Libecki

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

chart 186A 1.png

Fig. 27: 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	Configure the De1-SoC to receive wireless communication from the camera	Heather	Tue 1/01/19	Wed 1/02/19	1	2
1.1.1	Test connection between camera and De1-SoC	Heather	Thu 1/03/19	Tue 1/15/19	4	9
1.2	Develop the code for the image processing program.	Chris	Tue 1/01/19	Tue 1/15/19	14	11
1.2.1	Test the image processing program with data from the camera.	Chris	Tue 1/15/19	Fri 1/25/19	4	9
1.2.2	Develop the algorithm to determine the quickest path to erase markings on the board.	Chris	Sun 2/10/19	Mon 2/25/19	15	11
1.2.3	Develop the coordinate system.	Chris	Sat 1/26/19	Fri 2/15/19	20	15
1.3	Develop the PCBs for the stepper motor systems.	Heather	Fri 1/18/19	Fri 2/01/19	14	11
1.3.1	Sending of coordinates from Rasp Pi 3 B to stepper motor systems through wireless communication	Heather	Sat 2/02/19	Fri 2/15/19	13	10
1.4	Configure the power system for the mechanical parts of the Smart Eraser.	Juan	Tue 1/01/19	Sun 1/06/19	5	4
1.5	Build the prototype the eraser will be attached to.	Juan	Tue 1/01/19	Sun 1/06/19	5	4
1.5.1	Integrate the microcontroller with the mechanical system.	All	Tue 1/15/19	Fri 1/25/19	10	9
1.5.2	Test the newly formed microcontroller-mechanical system.	All	Fri 1/25/19	Tue 2/05/19	11	8
1.6	Create the motion-detecting program.	Chris	Mon 2/25/19	Fri 3/15/19	18	15
1.6.1	Integrate the motion-detecting program with the camera and microcontroller-mechanical system.	All	Fri 3/15/19	Sat 3/30/19	15	11
1.6.2	Test the motion-detecting program.	All	Sun 3/31/19	Mon 4/15/19	15	11
1.7	Add potential additional features to be decided upon at a later time (if project completion is ahead of schedule).	All	Mon 4/15/19	Thu 4/25/19	10	9
1.8	Final Project Presentation.	All	Thu 4/25/19	Tue 5/14/19	19	14

chart 186B.png

Fig. 28: GANTT chart for Senior Design Semester 2 - Implementation Phase

X. Equipment and Budget

The following table lists the components that are expected for the completion of this project, as well as the production company responsible for the creation of the product listed, and the prices of each component before tax and shipping costs. The "estimated" listed prices will be known with more design implementation of the project. The total budget price at the bottom of the table includes shipping and tax costs.

Component	Production Company	Est. Price
DE1_SoC FPGA Development Board	Terasic	$175
115RC Cassette with Stainless Steel Bearings - model SS0115-CASSRC	Accuride	$135 ($45.00 x3)
115RC 47in Medium-Duty Aluminum Linear Track System - model AL0115-0120RC	Accuride	$108.66 ($36.22 x3)
CNC Stepper Motor Driver - model DM542T	STEPPERONLINE	$67.90 ($33.95 x2)
WiFi 1080P HD Camera with IR LED Motion Detection and 128GB SD Card Support	sv3c	$59.99
Magnetic Whiteboard/Dry Erase Board 48in x 36in, Silver Aluminum Frame	VIZ-PRO	$55.89
Nema 23 CNC 2.8A Stepper Motor 1.26Nm Holding Torque - model 23HS22-2804S	STEPPERONLINE	$52.00 ($26.00 x2)
Arduino MKR1000 WiFi	Arduino	$33.95
6.35mm GT2 40 Teeth Bore Timing Belt Pulley Flange	Uxcell	$28.76 ($7.19 x4)
9 Volt 600mAh Li-ion Rechargeable Batteries Lithium-ion, 6 Pack - model 6F22	EBL	$25.99
10 meter long, 6mm Timing Belt White GT2 Open Synchronous Belt with Steel Core	Hilitand	$16.79
3 pcs Antenna Wireless Transceiver RF Transceiver Module - model nRF24L01+PA+LNA	Kuman	$13.99
9 Volt Li-ion Battery Charger 5 Bay-use with model 6F22 Lithium-ion Rechargeable Batteries	EBL	$12.99
PCBs for stepper motor connections	Varies	$10 - $20 (estimated)
4pcs Nema 23 Stepper Motor Steel Mounting Bracket with Screws	HobbyUnlimited	$10.99
USB Wifi Dongle Xiaomi Mi Portable WiFi	Terasic	&8.00
Dry Erase Board Eraser - model 81505	Expo	$3.58
Plywood, 4x4 posts, wheels, and camera pole for mobility of product	Home Depot	$76.93 (estimated)
Total Budget with Shipping and Taxes		**$928.49**

TABLE IV: Estimated costs of components for project

Along with the components listed in the budget, the following resources will also be needed to ensure the completion of this project.

- A DC power source to provide the appropriate voltage to the stepper motors
- A power outlet for the DE1_SoC board
- Various connections and jumper cables between the power system and the Smart Eraser

- A place to store the components we will be using when they are not being utilized, to ensure their safety and reliability
- Testing items:
  - DC power source
  - Digital multimeter
  - Solderless breadboard
  - A monitor to display the camera feed
  - A computer with the Altera Monitor Program installed in order to write, run, and debug the ARM assembly language on the DE1_SoC and the C language

XI. Roles of Team Members

A. Heather Libecki

She will take on the responsibility of being the project manager for the Smart Eraser. She has experience with programming the DE1_SoC that will be used in this project, as well as connecting the physical devices to it and controlling them via the GPIO ports, which will come in handy when connecting the Raspberry Pi to the board and controlling the data transfer between the devices. This project will be dependent on translating data from the camera into information that the microcontroller will be able to process, and her previous experience with the board plus her ability to learn and adapt quickly will help in that implementation. She is adept at solving problems, debugging and error detection, and technical writing, which will be an integral part in the completion of this project. A solid understanding of the microcontroller's full capabilities will need to be further ascertained, as well as how the coordinate system will work in conjunction with the stepper motors, which will be connected to the DE1_SoC via a wireless connection.

- Strengths: programming (assembly, some verilog), DE1_SoC programming, mathematics, debugging, circuit implementation, problem solving, technical writing, public speaking
- Weaknesses: circuitry design, coding algorithms, power systems, PCB design

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 take in data, analyze it, and then send an output. He also developed the UART, SPI, and I2C 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 I2C 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, I2C).
- 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 will be dependent on learning the physical mechanical aspects of the design, and how the connected parts will be powered. Therefore, he will need to further his understanding of how the parts should be connected in order to ensure the most spatial efficiency, as well as the connection of the power system that will allow all parts of the system to work properly and move the way they need to.

- Strengths: electrical systems, circuitry design, problem solving, power systems, public speaking/relations
- Weaknesses: programming (assembly, verilog), technical writing and spelling

XII. Analysis and Design

A. SPI communication

Serial Peripheral Communication(SPI) is a common form of wired communication between different systems. It is distastefully referred to as a master - slave relationship where there is one master and one or more slaves. 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).

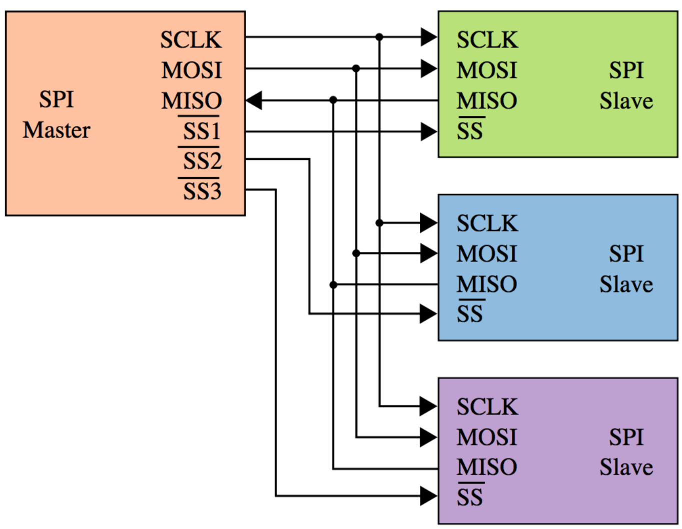


Fig. 29: Simple overview of SPI communication [14]

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 and 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. There is a test function that tests whether or not the SPI is working correctly, a MyCam_Trigger() function that initiates a capture and a MyCam_Check_Capture_Status() function that polls the capture ready flag in register 0x41 of the Arducam module. The Write_I2C() function itself uses a combination of the APIs provided by Cypress in order to interact with the Serial Control Block(SCB) that has been configured as an SPI master.

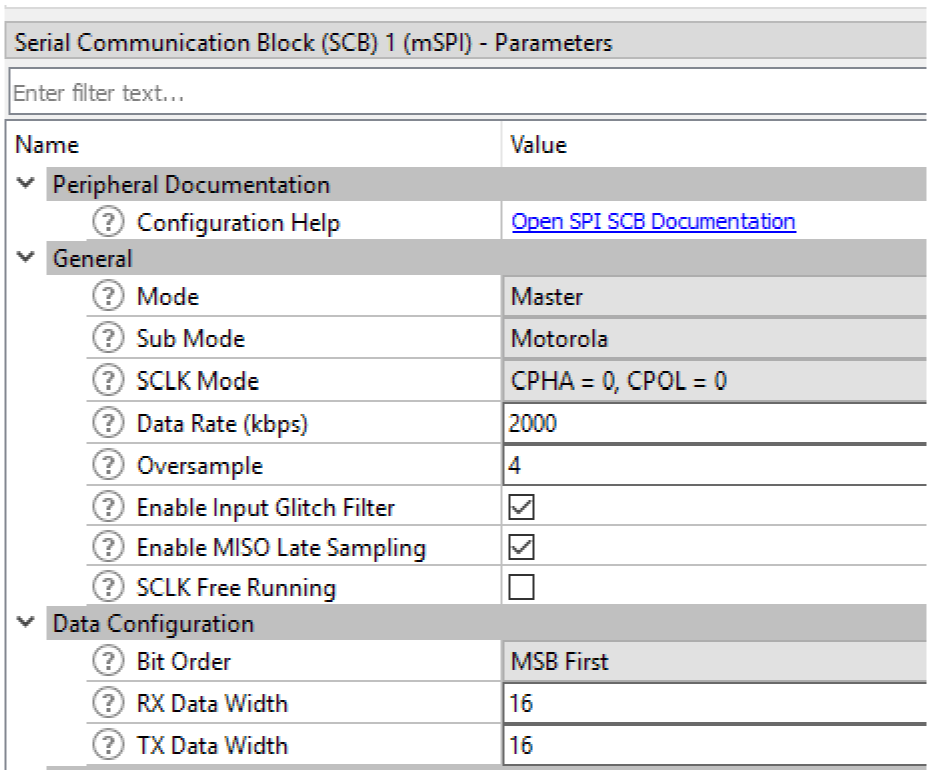


Fig. 30: Hardware configuration of SPI (1)

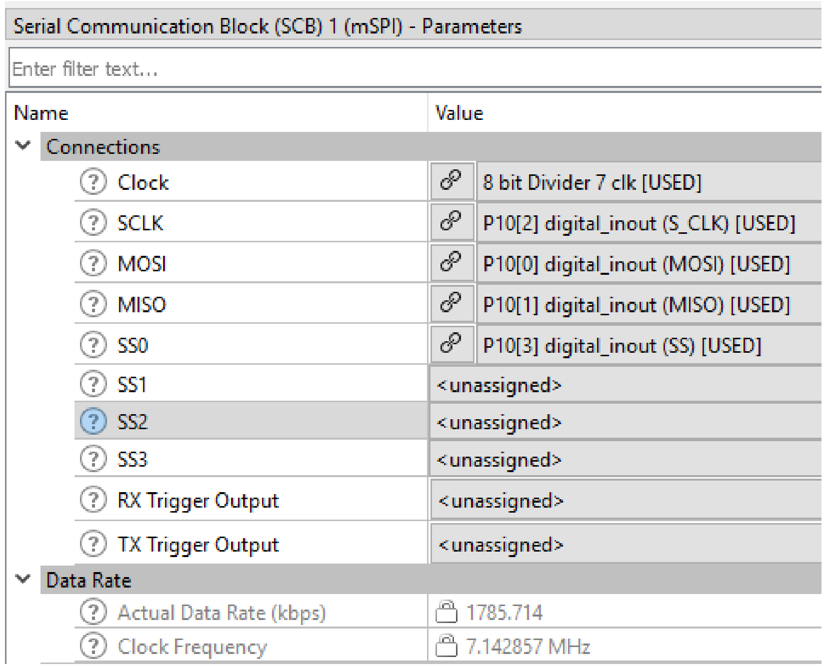


Fig. 31: Hardware configuration of SPI (2)

B. *I2C Communication*

C. *Image Processing*

1) Resolution: The original idea was to use a HD 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.

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.

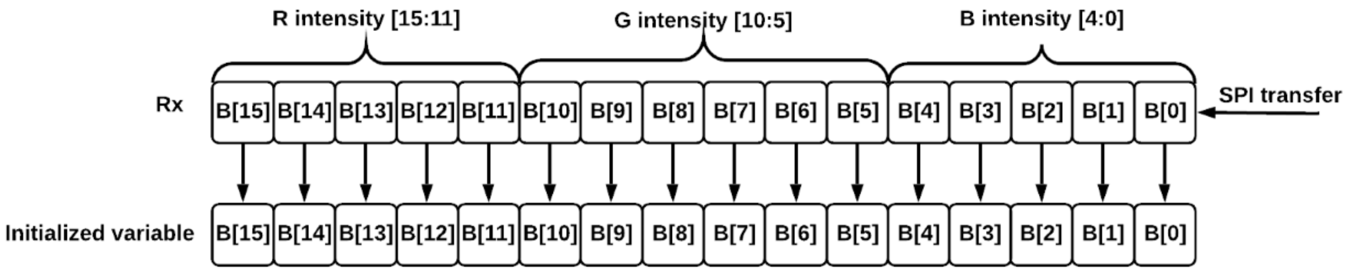


Fig. 32: Pixel Information being received through SPI from Arducam

3) Resolution: here 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
  - $Gray = (Red + Green + Blue)$ [19]
- Luminance Method
  - $Gray = (Red \times 0.2126 + Green \times 0.7152 + Blue \times 0.0722)$ [19]
- Desaturation
  - $Gray = (Max(Red, Green, Blue) + Min(Red, Green, Blue))/2$ [19]
- Decomposition (Max or Min)
  - $Gray = Max(Red, Green, Blue)$ [19]
  - $Gray = Max(Red, Green, Blue)$ [19]
- Single Color Channel
  - $Gray = Red$ [19]
  - $Gray = Green$ [19]
  - $Gray = Blue$ [19]

Once again, which method that is used isnâĂŹt important, it is seperating 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 (the one right below) if the pixel data variable is ANDed with the Red Mask variable, only bits[15:11] will be retained.

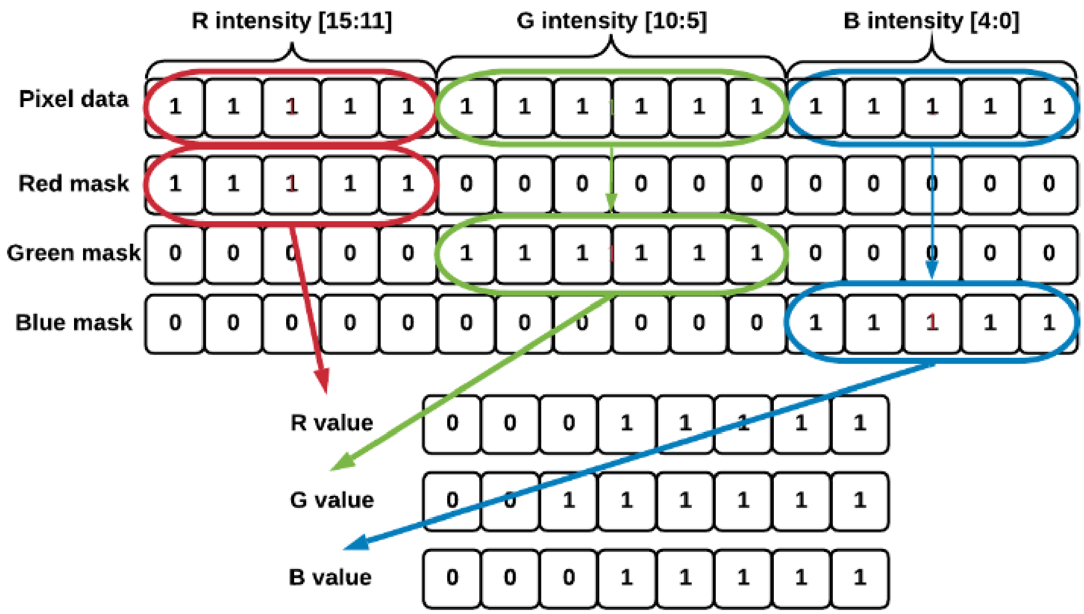


Fig. 33: How red, green, and blue intensities are seperated from one another

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 tossed into 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).

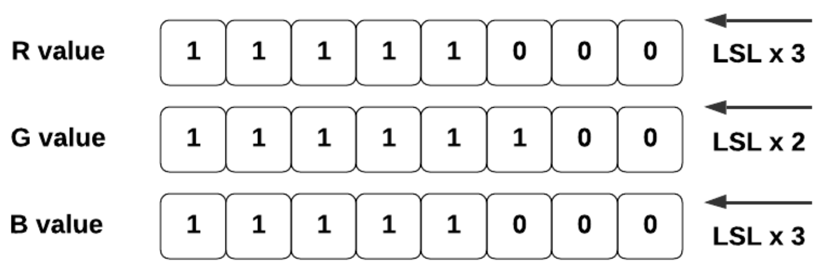


Fig. 34: Scaling seperated red green and blue intensities up to 8 bit numbers

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.

$$\text{Gray} = (\text{Red} * 0.2126 + \text{Green} * 0.7152 + \text{Blue} * 0.0722)$$

Fig. 35: Luminance method for converting RGB to grayscale

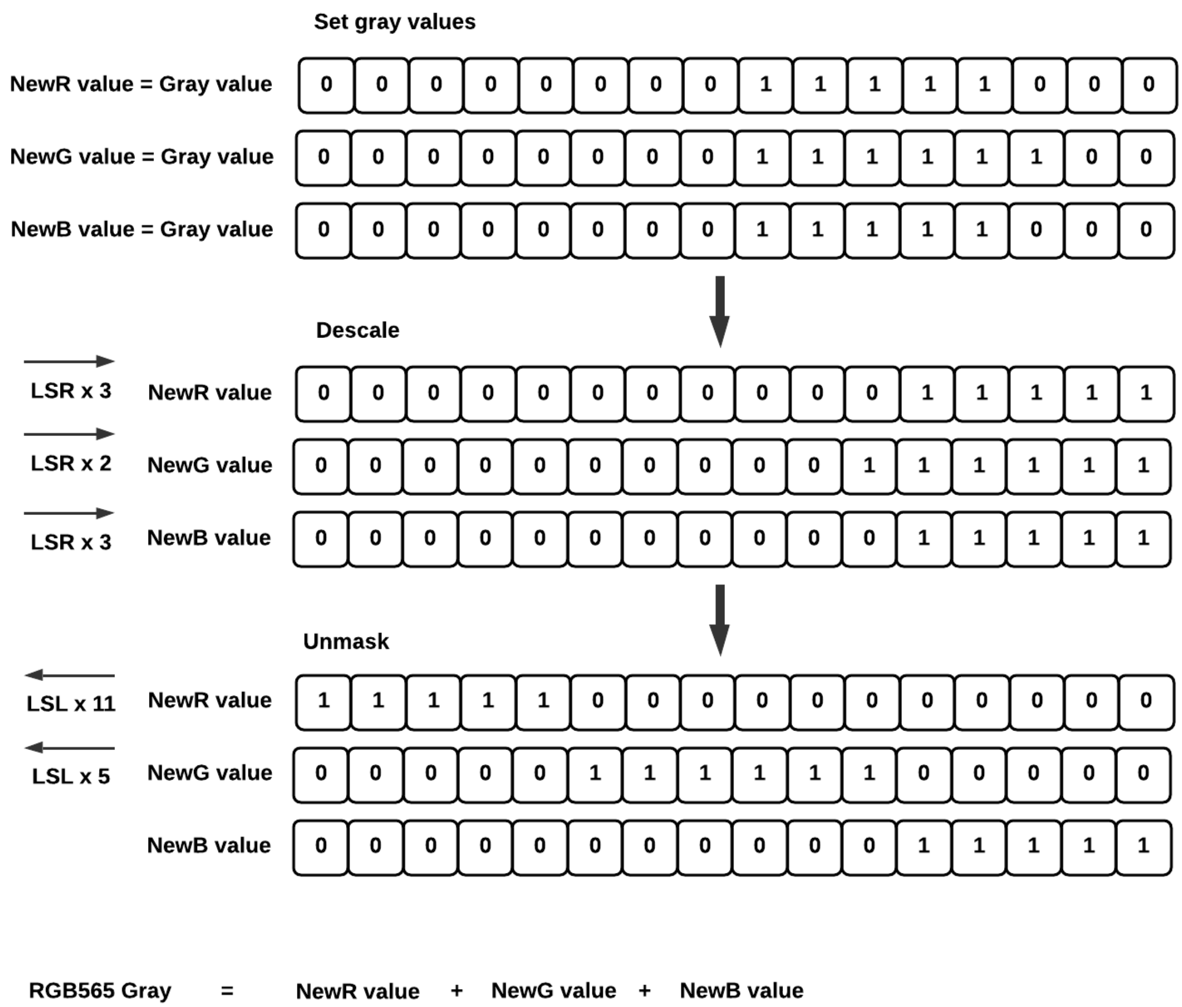


Fig. 36: Process in reverse: In order to create gray RGB pixel

4) Grayscale Results:

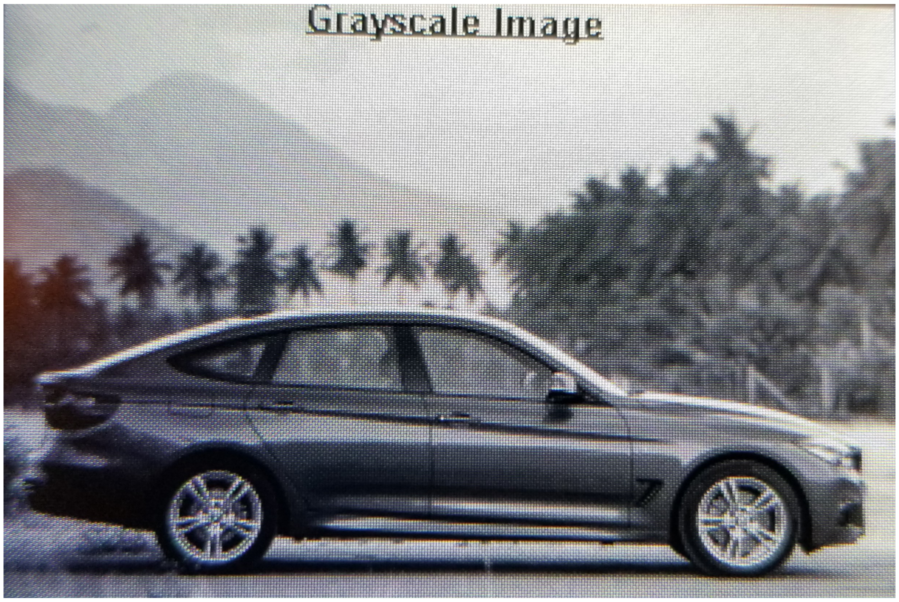


Fig. 37: Reuslts of grayscale algorithm from PSoC 6 (1)

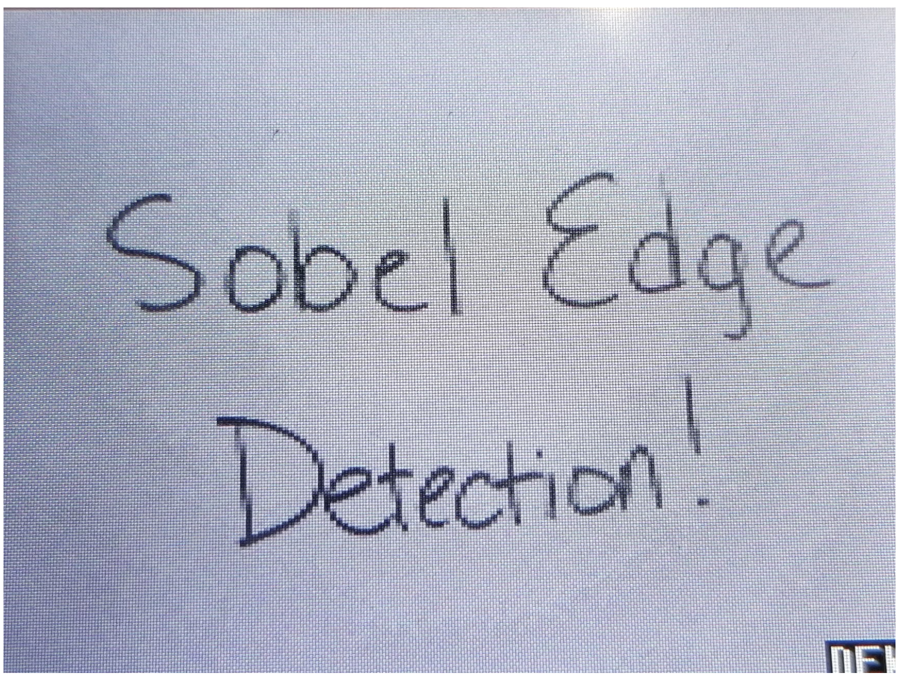


Fig. 38: Reuslts of grayscale algorithm from PSoC 6 (2)

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.

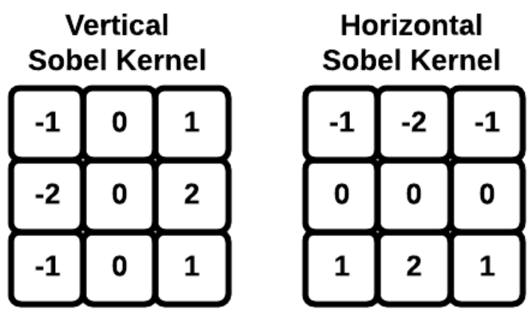


Fig. 39: Sobel Kernels

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 40.

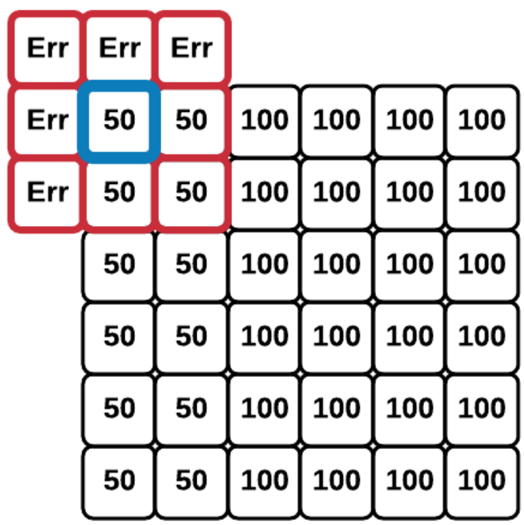


Fig. 40: Visual of what happens if the the sobel kernel is convolved along a boundary

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.

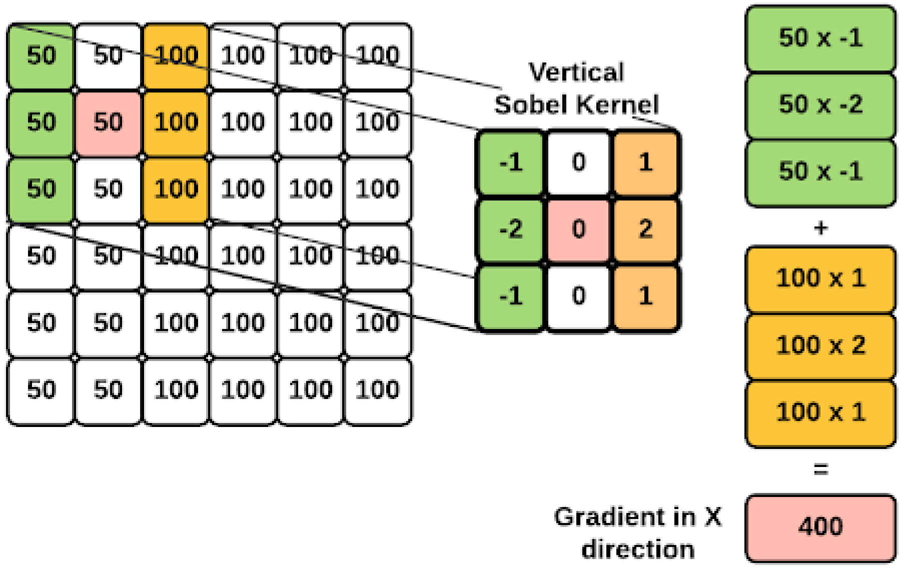


Fig. 41: Operation of the vertical kernel

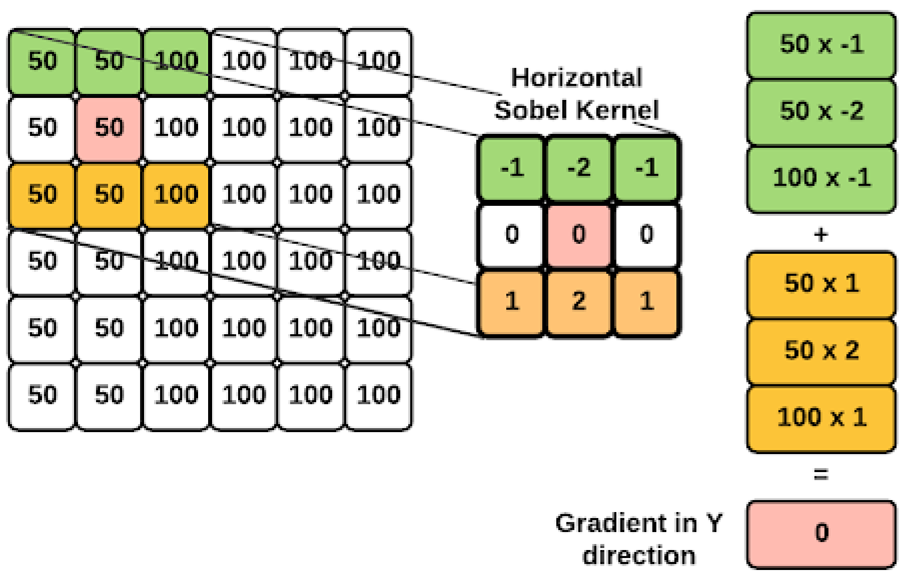


Fig. 42: Operation of the Horizontal kerne

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. 43: Using Pythagorean theorom to determin the magnitude of the gradient

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. ItâĂŹs 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).

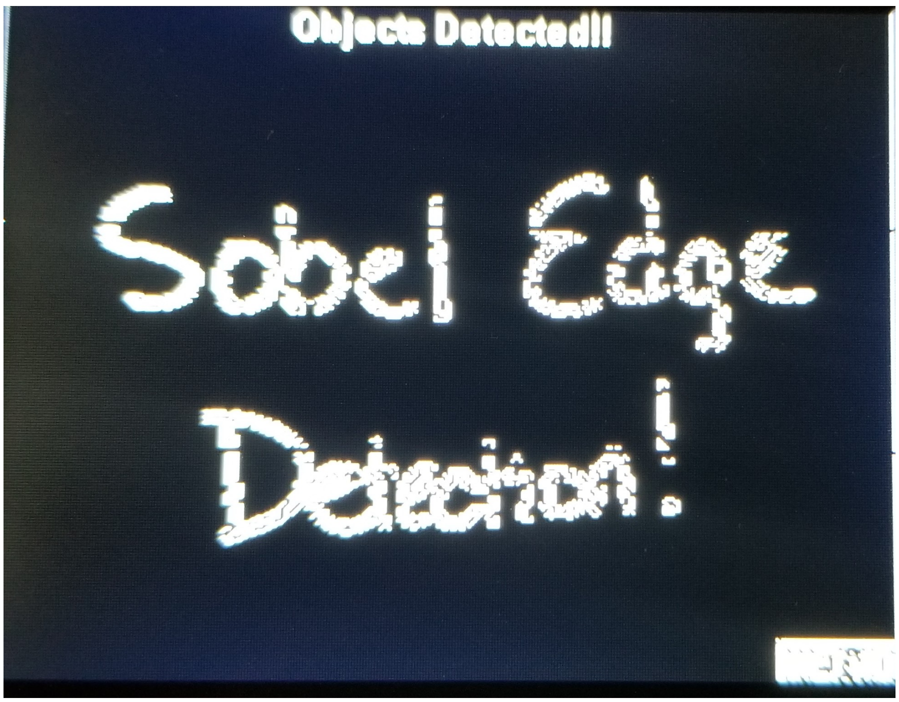


Fig. 44: Results of Sobel edge detection

6) *Results of Sobel Edge Detection:*
7) *Results of Sobel Edge Detection:*
8) *Results of Sobel Edge Detection:*

XIII. Stakeholder List

1) Aaron Stillmaker, Ph.D.: He is the professor of the Senior Design course, therefore wants to guide the students working on the Smart Eraser toward success through the completion of this project. He is also the manager of the project deliverable deadlines.

2) Hovannes Kulhandjian, Ph.D.: He is the technical advisor of this project, and he 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) Heather Libecki: Project Manager, Team Member
4) Chris Quesada: Team Member
5) 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

References

[1] ArduCAM.com, “ArduCAM-Mini-5MP-Plus OV5642 Camera Module,” http://www.arducam.com/downloads/shields/ArduCAM_Mini_5MP_Plus_OV5642_Camera_Module_Hardware_Application_Note.pdf.

[2] gnovice, “How can I convert between RGB565 and RGB24 image formats in MATLAB?” https://stackoverflow.com/questions/3578265/how-can-i-convert-between-rgb565-and-rgb24-image-formats-in-matlab.

[3] S. Sodha, “An Implementation of Sobel Edge Detection,” https://www.projectrhea.org/rhea/index.php/An_Implementation_of_Sobel_Edge_Detection.

[4] A. Anand, “Client and Server Chatting Application in Python,” https://www.kodefork.com/articles/client-and-server-chatting-application-in-python/.

[5] STEPPERONLINE, “Stepper Motor,” https://www.omc-stepperonline.com/download/23HS22-2804S.pdf.

[6] ——, “Nema 23 CNC Stepper Motor 2.8A 178.5oz.in/1.26Nm CNC Stepping Motor DIY CNC Mill,” https://www.amazon.com/dp/B00PNEPF5I/?coliid=I3APKEM9Y17HEP&colid=22YAOKWOJAKA9&psc=0&ref_=lv_ov_lig_dp_it.

[7] ——, “User’s Manual for DM542T,” https://www.omc-stepperonline.com/download/DM542T.pdf.

[8] Adafruit.com, “Assembled Adafruit HUZZAH32 âĂŞ ESP32 Feather Board - with Stacking Headers,” https://www.adafruit.com/product/3619.

[9] EBL, “EBL Li-ion 9V Battery Charger 5 Bay 9V 6F22 Lithium-ion Rechargeable Batteries,” https://www.amazon.com/dp/B07GB3TSKH/?coliid=I3FJDEJ8MXP6RY&colid=22YAOKWOJAKA9&ref_=lv_ov_lig_dp_it&th=1.

[10] Accuride, “Instructions Manual,” https://www.accuride.com/amfile/file/download/file_id/155/product_id/2909/.

[11] Amazon.com, “4pcs Nema 23 Stepper Motor Steel Mounting Bracket with Mounting Screws,” https://www.amazon.com/dp/B073V77VLD/?coliid=I3S0XHJ6LUPARP&colid=22YAOKWOJAKA9&psc=0&ref_=lv_ov_lig_dp_it.

[12] Uxcell, “uxcell Aluminum GT2 40 Teeth 6.35mm Bore Timing Belt Pulley Flange Synchronous Wheel for 3D Printer,” https://www.amazon.com/dp/B0728PDWY5/?coliid=I3K7SWFRMQ3A2F&colid=22YAOKWOJAKA9&psc=0&ref_=lv_ov_lig_dp_it.

[13] Mercury, “Mercurry 5 Meters GT2 timing belt width 6mm Fit for RepRap Mendel Rostock Prusa GT2-6mm Belt ,” https://www.amazon.com/dp/B071K8HYB4/?coliid=I3KCLVNOTYFU5Y&colid=22YAOKWOJAKA9&psc=0&ref_=lv_ov_lig_dp_it.

[14] S. VHDL, “How to Design SPI Controller in VHDL),” https://surf-vhdl.com/how-to-design-spi-controller-in-vhdl/.

[15] I. S. Association, “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,” https://standards.ieee.org/standard/802_15_3e-2017.html.

[16] IEEE, “IEEE Editorial Style Manual ,” https://www.ieee.org/content/dam/ieee-org/ieee/web/org/conferences/style_references_manual.pdf.

[17] N. E. M. Association, “NEMA Standards Publication ICS 16 Motion/Position Control Motors, Controls, and Feedback Devices,” https://www.nema.org/Standards/SecureDocuments/ICS16.pdf.

[18] W. contributors, “Rec. 709,” https://en.wikipedia.org/wiki/Rec._709.

[19] T. Helland, “Seven grayscale conversion algorithms (with pseudocode and VB6 source code),” http://www.tannerhelland.com/3643/grayscale-image-algorithm-vb6/.