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Annotate

A Portable Digital Pen that Can Be Used Anytime, Anywhere

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Disclaimer

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Abstract

The most common and significant of all visual tools is the boards. A classroom without a whiteboard is impossible to envision. It is crucial in ensuring the effectiveness of the educational process.A student's hair may stand on end from the scratching of chalk against the traditional boards. Dry-erase markers are quiet and gentle, but they can produce vapors in the classroom and contribute to indoor pollution. Annotate project not only get rid off the clutter of chalk and markers that may clog up a traditional classroom, but it also reduces the amount of paper necessary to teach. Instead than utilizing paper handouts.

Annotate is built and created by combining several techniques, such as processing the images required to track the pen's movements and transferring them via WiFi to the microcontroller, which then transfers the set of processed and extracted points from the images to a special software via USB, which then draws and displays them on the board. It supports multi-threading, which allows it to do numerous tasks at once, such as receiving signals from the pen and the keypad, processing them, and sending the processed signals to the software.

Chapter 2

Introduction

2.1 Background

During classrooms/lectures, teachers/professors tend to use the provided whiteboard to explain the subject discussed in the class in a better way. It is a common way that most, if not all, students and familiar with, they even prefer explaining the important details on the whiteboard rather than explaining using video-graphic content or PowerPoint presentations. Students tend to understand better when the explained subject is being presented to them from the zero structure, step by step. Moreover, the only way for some ideas or concepts to be explained is to grab a pen and start illustrating the concept. Finally, it might be the preferred way for a lot of teachers to demonstrate topics to their students.

2.2 Problem Statement

Even though using the whiteboard can be the "perfect" way to explain academic materials, it comes with a cost. It is a common issue that students would complain that the teacher is writing information way too quickly, in a way that students themselves are unable to keep up with taking their own notes and understanding the subject discussed at the same time. Requesting pauses during class for students to keep up can be time consuming and not the ideal way to solve the issue, since the issue is still present and nothing was solved. Moreover, some students suffer from a bad sight and refuse to acknowledge that, this might keep them from taking in-class notes as efficiently, causing them to always be behind when writing down the explanations on their notebooks. Finally, in a modernized world, carrying a dozen of notebooks to classes can be tiresome, a nuisance, and sometimes, extra exhaustion for people with weak physical abilities and people who tend to travel long distances to reach their collage/school.

2.3 Significance

Education is a sensitive matter, any obstacles that lie on the path of knowledge is definitely an issue that has to be dealt with, no matter how naive it can be. We have seen in the past few years how the education ministries all over the world put their hands together to face the COVID-19 pandemic for the sake of learning. Poor families were provided with personal computers and a stable internet connection for free so that the students can follow up with their fellow classmates [1]. In the same matter, any technologies or creative ideas that can help enhance the learning experience for students is welcome [2]. Annotate approaches that side of the problem by providing a better way for students to focus on the learning side of education during classes.

2.4 Objectives and Scope

Annotate aims to create a portable digital whiteboard/pen that can be used anytime and anywhere. It provides multiple features that achieve portability and the ability to be used at any surface with as little error as possible. Additionally, the pen shall be able to handle a high accuracy and as low response time as possible to achieve a comfortable writing/drawing experience. The pen shall also implement all of the features to solve the problem that the pen was created to solve to begin with:

1. The whiteboard shall behave like a real whiteboard, the user shall be able to configure the used area for the whiteboard easily.
2. The ability to erase the written text and change the used color.
3. Additional features that makes it superior to using a normal whiteboard, such as the ability to create pages and the ability to navigate between them, the ability to erase an entire page easily and quickly, and the ability to save the written text digitally as simply as clicking a button.

Chapter 3

Constraints and Earlier Coursework

3.1 Constraints Limitations

3.1.1 Acceptable Tracking Accuracy and Response Time

Image processing techniques were used for the purpose of tracking the position of the pen. When dealing when image processing, it is important to consider the processing speed and accuracy of consecutive images. The hardware should be able to achieve an acceptable tracking accuracy and response time regardless of the processing speed.

3.1.2 Portability

Annotate should be used regardless of the time and the place.

3.1.3 Power Supplying and Power Consumption

The pen should be able to run on a battery, and the battery should rechargeable to enhance the usage experience. Using a cable to power the pen is not ideal, due to the fact that the pen user moves a lot in different directions, making the usage of any cables a bad idea. Additionally, the battery should be able to run for an acceptable time. The pan shall survive for the duration of at least the entire class duration.

3.1.4 Lack of Resources

Dealing with hardware components is not very simple, it is hard to "google" the functionality of the component and expect to find the desired component with a straight forward explanation on how to use it. Additionally, it is not guaranteed to find every component available in local electronic stores.

3.1.5 Time Limit

To finalize a project with the desired features and constraints, it takes a notable amount of time. The project has multiple stages that should go through, including the learning stage, designing stage, the building stage, the debugging stage in case any issues appear with the design, the enhancement stage to improve the performance and the latency of the built hardware, and, finally, the testing stage. Going through each stage a lot of time, and it is important to note that dealing with sensitive hardware takes a lot of penitence to ensure that non of the components would burn or break during any of the previous stages.

3.2 Earlier Coursework

- Microcontrollers:
  The Microcontroller course focused on the microcontroller architecture and its peripherals, the timers and the ideal behind system interrupts, the interfacing of different devices, and the idea behind serial communication. The course had most of the important information that allowed us to implement most of the hardware features in the project.
- Microcontrollers Lab:
  The Mircconntrollers Lab emphasises on practical application using a microcontroller development platform. The most important part of the lab was the usage of the Arduino microcontroller as the logic of the pen controller was written and uploaded using the Arduino IDE with the help of external libraries and an Arduino UNO as a device programmer. Additionally, the serial communication techniques used in the project were performed practically in the course, which were employed in the pen to ensure portability and low latency.
- Electrical Circuits:
  The Electrical Circuits course focused on many fields, including techniques of circuit analysis. Since the hardware project uses a handful of resistors and sensors, the course was necessary to understand the idea behind the choice of picking the right resistance and the sensor connectivity with the microcontroller.
- Digital Circuit Design:
  The topics discussed in the Digital Circuits Design course were employed in multiple locations. The most employed topic was Algorithmic State Machine design. The controllers were written in a state-like architecture and the techniques discussed in the course were beneficial in that regard. Additionally, the software push-button debouncing techniques discussed in the course were necessary to construct a reliable hardware without unintentional side effects.
- Computer Networks:
  As the Computer Networks course focused mainly on the bigger picture of how the internet networks were formed and their internal protocols, the course discussed on the most important networking ideal that was used heavily in our project to ensure pen portability, which is the serial communication technique.
- Digital Image Processing:
  The course explained a lot of useful topics that were employed in our project, including digital image fundamentals, image enhancement, color image processing, and object recognition. All of these techniques were used in order to create a reliable pen position detection with acceptable performance.
- Critical Thinking Scientific Research:
  It took a lot of study across websites to prepare for constructing this application,

which was practiced in this course. On the other hand, it was the first place where the talent of utilizing latex and producing scientific papers was presented.

Chapter 4

Literature Review

Annotate aims to create a user-friendly and comfortable smart board for both the teachers and the students. However, it is not the first product that was created to achieve the same purpose, there are some other different products that are already live. Some of these applications are presented below:

4.1 Wacom Pen Displays

Wacom is a new type of creative pen display with a feature set tailored at creative beginners. Colors, clarity, and ergonomic design, in combination with the super-responsive Pen, provide a natural experience that will enable you take your creative ideas and illustrations to the next level [3].

Advantages

1. Pen Pressure Sensitivity: Wacom Pens are great for sketching and grading digital pictures. These pens detect the amount of pressure you apply, allowing you to easily manage the size of your brush while using your preferred program.
2. These pens do not require batteries.
3. The Wacom tablet allows you to quickly point to any part of the screen and retouch comfortably and quickly.
4. It is possible to reach a high level of precision.
5. Works just as fine in free open source apps like Gimp as in PS.

Disadvantages

1. Not suitable for common selection tasks like pointing and clicking on menu items.
2. Graphics tablets are far more expensive, and using one forces you to purchase all of the necessary equipment.
3. The Pens from previous versions are incompatible with the new boards.
4. A little expensive price.

4.2 Huion

Huion is well-known for its digital drawing software. They are popular among artists because they offer top-of-the-line features at extremely low costs. This sort of tablet has the benefit of replacing your computer and dedicated drawing tablet with a single device that serves as both a computer and a drawing tablet [4].

Advantages

1. Huion collection does tend to be able to withstand a lot of bumps and bangs when in use or in transportation.
2. Huion tablets can be used as a drawing surface for virtual whiteboards and other applications.

Disadvantages

1. The Huion tablets' weak point is the pen.
2. There are some response issues when the tablet settings window on the screen.
3. There are a lot of bugs and issues that are constantly being reported by the users.

4.3 How is Annotate Better?

Annotate was built with what other products offer and what they don't offer in mind. The big selling point for Annotate is that it doesn't require a special board to operate, the board can be any surface, and it can be with any dimensions. Not to mention that Annotate was purposefully built to be used on bigger boards as a replacement of whiteboards. Annotate was built with smaller body, more portable, and automatic calibration. Additionally, it contains most of the important features that other products offer and what they don't offer. Finally, Annotate was able to achieve acceptable latency and performance compared to high-end products that were being sold on the market.

Chapter 5

Methodology

5.1 Equipment and Components

5.1.1 ATtiny85

The ATtiny85 is a tiny, hence the name, microcontroller in a similar vein to the Arduino, with much less input/output ports and a smaller memory [5]. The ATtiny85 can be programmed using the Arduino IDE just like any Arduino controller. By default, the Arduino IDE does not support the ATtiny85. It is required to install additional support for the ATtiny85 to the Arduino Board Manager. We have installed the ATtiny by David. A Mellis library so that the Arduino IDE can support the ATtiny85 chip we have in our hands.

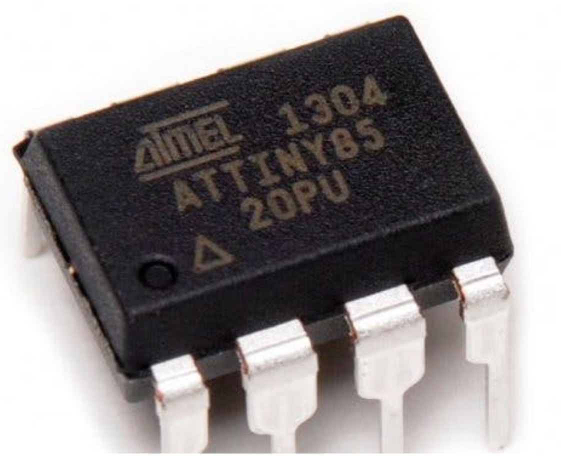

Figure 5.1: ATtiny85 Controller

The chip was chosen as the primary controller for the pen, mostly due to its size and the perfect amount of input/output ports provided. The size of the board is very small, which makes it perfect to be installed inside a portable pen. Additionally, we don't require a lot of input/output ports for the circuit of the pen, since the pen is required to do simple operations and nothing expensive to preserve low power consumption and to reduce any form of heat that might dissipate from the pen.

5.1.2 Arduino Uno

The Arduino Uno is an open-source microcontroller board that is based on the Microchip ATmega328P microcontroller, the chip was developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that can be interfaced with multiple different circuits [6].

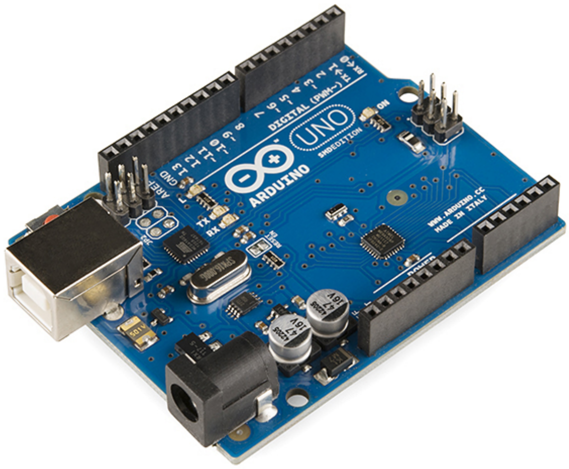

Figure 5.2: Arduino Uno

The Arduino Uno was not employed in the project directly. The Arduino Uno was used as a programmer for the ATtiny85 microcontroller. First of all we have uploaded the ArduinoISP example provided by the Arduino IDE to the Arduino UNO, then we connected the ATtiny85 to the Arduino Uno as explained in the figure below. Finally, we burnt the boot-loader on the ATtiny85 chip. After doing that, it was possible to easily upload the code to the ATtiny85 using the Arduino Uno.

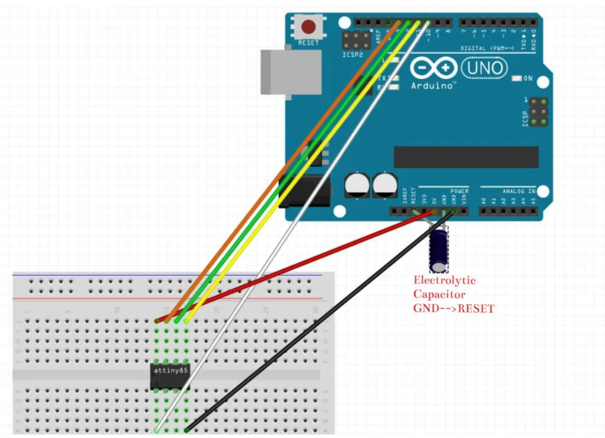

Figure 5.3: Arduino Uno as an ISP

It is good to note that the Ardunio Uno was also used to debugging purposes once the circuit of the pen was complete.

5.1.3 Force Sensor

A Force Sensor can be considered as a transducer that has the ability to convert incoming mechanical load, weight, tension, compression or pressure into an electrical output signal. There are several types of Force Sensors based on size, geometry and capacity.

Figure 5.4: Force Sensor

The force sensors was used as a primary pressure point for the pen. The sensor can provide different readings according to how much pressure the user puts at the tip of the pen. This way, we can simulate the ink density that leaves the tip of real pens which increases upon pressing the pen on the surface extra power. This sensor was used specifically to provide realistic and satisfying experience to the user rather than a traditional touch sensor. It is important to note that most pen products contain that feature.

5.1.4 HC-12

The HC-12 is a half-duplex Radio Frequency (RF) transmitter/receiver paired with an external antenna. The HC-12 transceivers is capable of communicating up tom and possibly slightly beyond, 1 kilometer in the open and are more than adequate for providing coverage throughout a typical house.

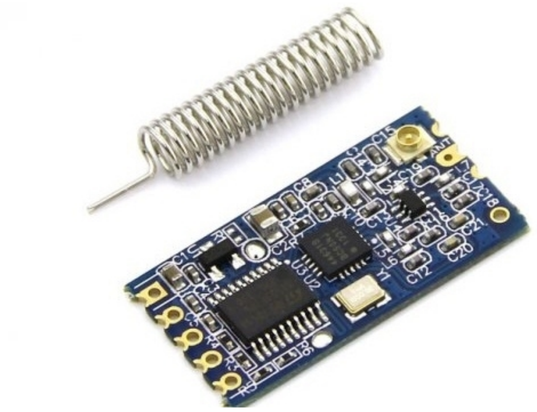

Figure 5.5: Force Sensor

The HC-12 module was used twice. Once internally inside the pen, directly connected with the ATtiny85 controller, and another with the Raspberry Pi controller to provide a reliable and super-fast serial communication between both controllers to achieve a low response time.

5.1.5 Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B is the first of the fourth generation of Raspberry Pi computers. The latest model brings with it a more powerful Broadcom BCM2711B0 quad-core ARM processor and the 4K-capable Broadcom VideoCore VI video processor, along with the move to faster USB 3.0 ports and USB Type-C for power [7].

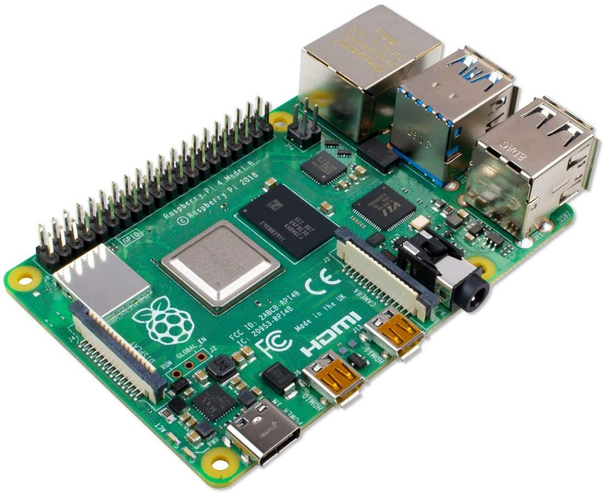

Figure 5.6: Raspberry Pi 4 Model B

The Raspberry Pi 4 Model B was specifically used due to its low-price, small size, high performance. The image processing techniques were implemented on this controller using OpenCV with Python on consecutive captures from an IR Camera. The Raspberry Pi was also used to interface the keypad that will be used by the user to perform the whiteboard operations.

5.1.6 IR Camera

An infrared camera (or an IR camera) detects and measures the infrared energy dissipated from objects. The IR camera converts the infrared data gathered from objects into an electronic image that demonstrates the apparent surface temperature of the object being measured/captured. The Raspberry Pi offers a dedicated input bus for cameras including an IR camera.

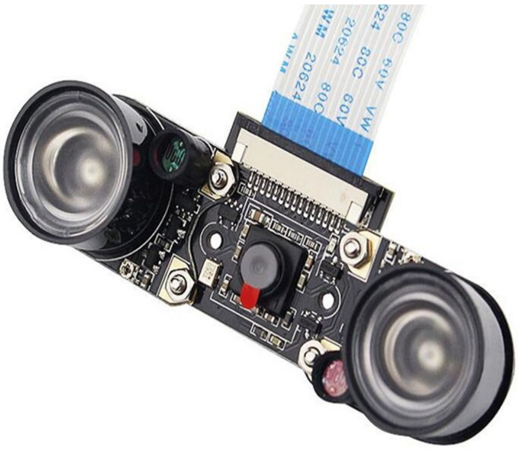

Figure 5.7: IR Camera

The camera comes with additional lenses to enhance the quality of taken images in darker areas, but those lenses were not needed due to the fact that the camera will not be used in completely dark areas. The pen was provided with a special IR LED at the top, which will be the main object that indicates the position of the pen, hence why a special IR camera was needed. As long as the IR LED is seen by the IR camera, the camera will capture the IR LED as a bright white spot that can be used to determine the position of the pen using image processing techniques.

5.1.7 Keypad

A keypad is a essentially block of buttons with an arranged set of of digits and symbols. Pads are used in many applications, for example, keypads that contain mostly numbers are used with calculators, television remotes, vending machines, ATMs, combination locks, and digital door locks. The keypad behaves as the input interface used by the user to input data/different commands.

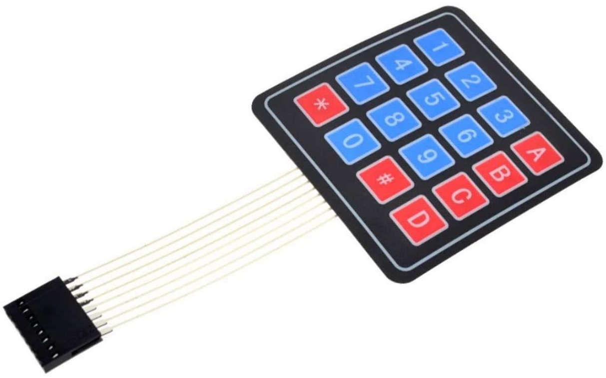

Figure 5.8: 4x4 Keypad

A 4x4 membrane keypad was employed in the project to allow the user to easily communicate with the Raspberry Pi. The keypad offers a set of numbers from 0 to 9 and 4 different alphabetical letters from A to D, and lastly, two symbols which are the asterisk (*) and the hashtag (#). Each key was mapped to a different functionality, some keys are used to determine the color of the ink used to draw, a special key was used to determine the area used by the pen, and lastly, other keys were used to add/erase/delete pages on the board with a special key added to save the final board as a portable document.

5.1.8 Additional Components

The components listed above where the main components that we needed to directly communicate with, but additional components were necessary for the rest of the components to operate:

1. An IR LED was used at the top of the pen as an indicator used by the IR Camera to determine the position of the pen using image processing techniques.
2. A battery was installed inside the pen to allow the pen to be used without a power cable and an additional charging board was installed to charge the battery with a micro-USB cable.
3. Push buttons were used on the pen to switch between writing/erasing modes, and additional resistors with appropriate values for certain connections and protection purposes.
4. A Multi-meter was used for debugging purposes.
5. Software applications, technologies, and libraries were used to communicate with the Raspberry Pi either for the creation of the controller or to interface the already built controller with other devices.

5.2 Components Design & Features Implementation

Designing a circuit for hardware components requires experience a lot of patience to ensure that components would not break or burn during the designing phase. This section will focus on the implementation of the project features and the circuits designed for each controller.

5.2.1 The Circuit of the Pen

The pen had to take multiple factors in consideration before the designing phase. First of all, the components must be compact to fit inside a small pen, this was the main focus when building the circuit of the pen. We have concluded the the pen is not supposed to do a lot work and any additional work has to be moved to the Raspberry Pi controller. Additionally, the pen has to operate like a normal pen, which means that the pen should be allowed to do the following without any issues:

1. The pen should look like a normal pen, the body must have the right thickness and the right length to ensure a comfortable writing/drawing experience.
2. The tip of the pen should be sensitive to the pressure put by the user to simulate how normal pens work.
3. The pen should come with erasing/typing features to switch between mods, a software debounced push-button was used for that purpose.

4. A mean for the pen to communicate wirelessly with the Raspberry Pi controller.
5. A switch to turn the pen on and off to save power.
6. A micro-USB port to charge the battery inside the pen.

Taking all of these factors in consideration, we have designed the circuit of the pen using the components mentioned before, the internal circuit of the pen looks like the following:

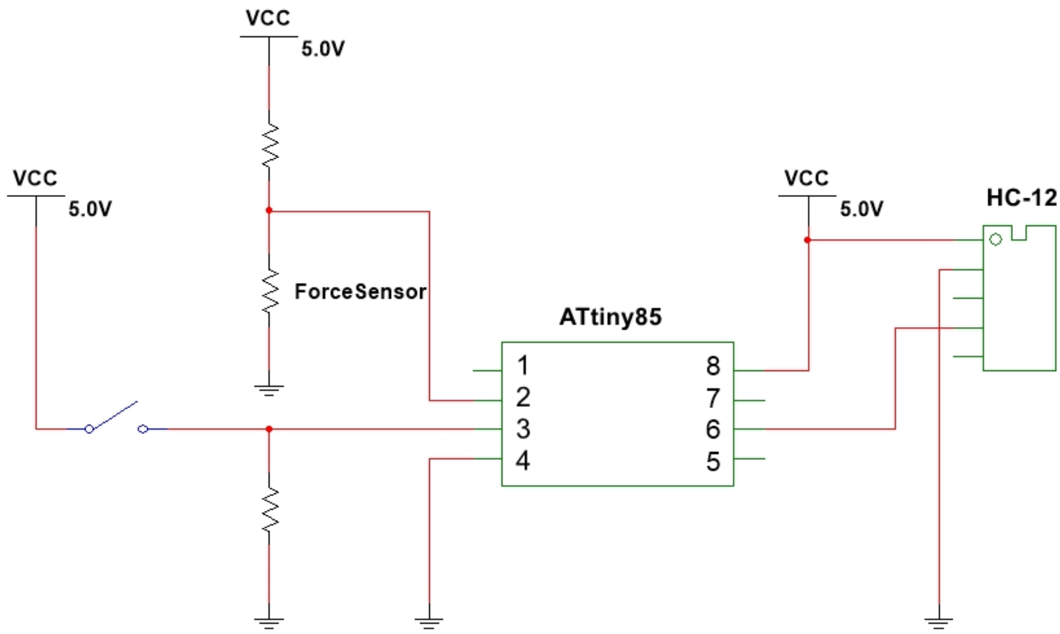

Figure 5.9: The Internal Circuit of the Pen

The pen has 2 main modules, the ATtiny85 and the HC-12, where the ATtiny85 is the controller that controls the pen, and the HC-12 is the modules that communicates with the Raspberry Pi controller. Additionally, The push-button added to the circuit was used to indicate the typing mode/the erasing mode. Finally, the force sensor is connected in way that whenever the resistance of the sensor increases, the voltage across pin 3 decreases, the technique used is called Voltage Division, the figure below explains the concept behind the technique:

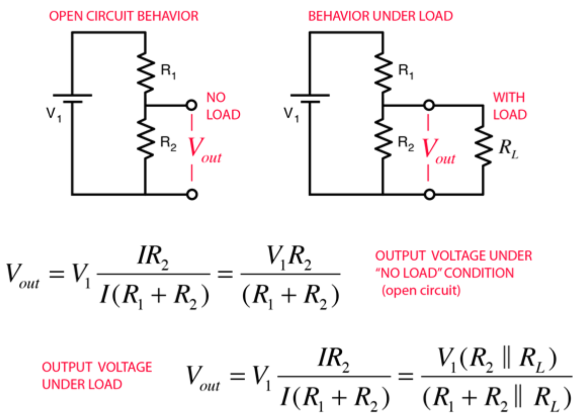

Figure 5.10: Voltage Division

When the force sensor is being pressed on, the sensor will increment its own resistance, meaning that the voltage between the force sensor and the first resistor is going to decrease. The ATtiny85 is capable of reading analog signals with 8-bits precision, the voltage value will be read by the ATtiny85 as an analog signal to simulate the pressure at the tip of the pen.

The controller of the pen is responsible of doing the following:

1. Reading the analog signal from the force sensor.
2. Read the change of state from the mode push-button.
3. Perform a non-blocking software debounce on the push-button.
4. Send the processed data from the pen to the HC-12 module to communicate with its peer on the Raspberry Pi controller.

Additionally to that circuit, an IR LED was attached directly to the VCC with a protection resistor that will be placed at the top of the pen. Finally, the VCC ports were connected to the battery and a switch was added to turn the circuit on and off.

5.2.2 ATtiny85 Controller Behaviour

The controller of the pen will read the data from the input ports and send the data to the Raspberry Pi through the HC-12 module.

First of all, the pen will read the analog value from the force sensor. The value from the force sensor will be read as an 8-bit unsigned integer by the ATtiny85 controller, and the value will decrease when more force is put at the sensor. The controller will keep the data as an 8-bit integer but the value will be reversed, so that when more pressure is put at the tip of the pen the higher the value of the pressure sent from the ATtiny85 controller to the Raspberry Pi controller.

Secondly, the Controller is responsible of preforming a software debouncing on the push-button. Whenever the push-button is pressed, the push-button will switch between the typing/drawing mode and the erasing mode. The drawing mode is resposible of allowing the pen to type at the current position and the erasing mode will remove any data drawn previously on the current position. The software deboucing was necessary because the push-button will toggle a certain state, and if the state was toggled multiple times on a single click, it will emit an unexpected and an unintended behavior.

The change state of the push-button was also used later to determine the area used by the pen for drawing. The force sensor is not reliable in that regard due to the fact that every user his own unique pressure values. More on that will be explained later.

We have decided that the value of the erasing and typing mode was better represented as a single bit, since the change of that bit was necessary in later stages of the design.

Since we have the value of the force sensor and the value of the typing/erasing mode, we have concatenated both values as an ASCII string, and were sent serially to the HC-12 module using the default settings of 9600 baud rate, 8-bit data, 1 stop bit and no parity bits. The value of the force and the mode were sent once every 50 ms to the HC-12 module in a non-blocking fashion. This allows the controller to read the value of the pen 20 times per second, which is ideal to the speed of the IR camera and the image processing speed that were used in later stages of the design.

The HC-12 module will in-turn re-transmit the data over to its peer on the Raspberry Pi, the pen data will then be decoded by the Raspberry Pi and will be used to produce the final result when the image processing techniques determine the position of the pen.

5.2.3 The Pen

Once the circuit of the pen was ready, the logic of the controller was written, the circuit was finally re-designed on a Printed Circuit Board (PCB) to reduce its size to the minimum. At the same time, the pen skeleton was designed on a special software with appropriate dimensions and comfortable experience taken in consideration. The pen was eventually 3D printed and the all the components were placed inside the skeleton of the pen.

The figures below demonstrate the pen. The first figure shows the general shape of the pen. The second figure shows the top of the pen where the IR LED and the on/off switch are located

Figure 5.11: The Shape of the Pen

Figure 5.12: The Top of the Pen

The figures below demonstrates the tip of the pen where the force sensor is located. Since the forces sensor is very sensitive, we did not want the pressure to be directly pushed on the sensor itself, for that matter, we have designed a simple 3D printed plate that's connected with the tip of the pen which, by itself, creates the pressure on the force sensor.

Figure 5.13: The Tip of the Pen

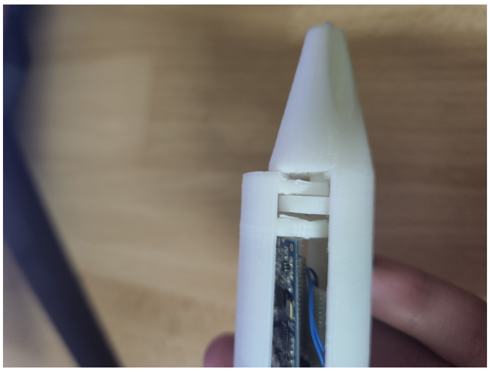

Figure 5.14: The Internal Skeleton of The Pen Tip

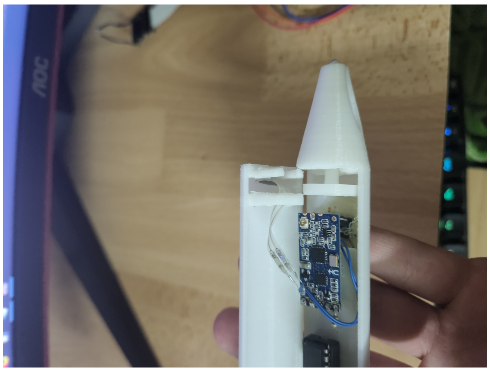

Figure 5.15: The Position of the Force Sensor

The figure below demonstrates the final internal circuit of the pen, we can see that the entire circuit is located inside the pen.

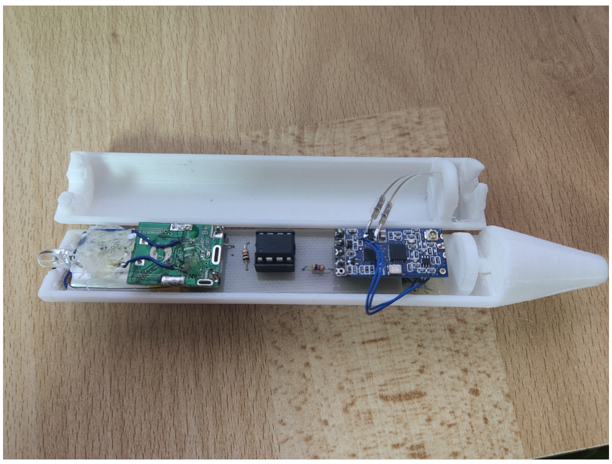

Figure 5.16: The Tip of the Pen

5.2.4 Raspberry Pi Connections

The Raspberry Pi is connected with multiple modules to operate. The first and the most important module is the IR Camera. Secondly, we have the other module of the HC-12 that is responsible of reading the data coming from the pen. Finally, the 4x4 keypad that will be used for user inputs.

The overall connections with the Raspberry Pi are demonstrated in the figure below:

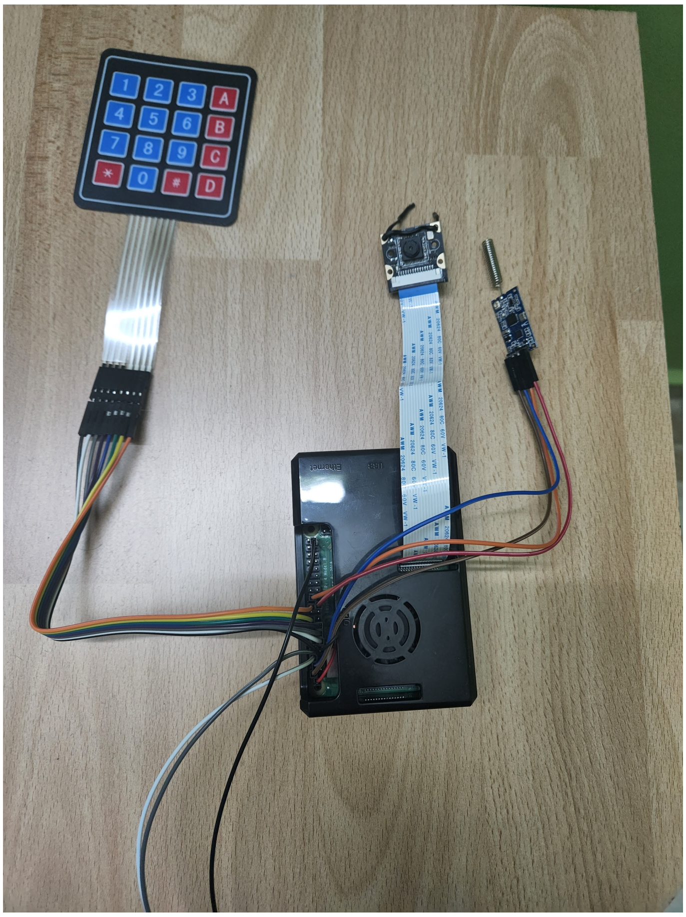

Figure 5.17: Raspberry Pi Connections

5.2.5 Raspberry Pi Controller

In this section we will discuss the behaviour of the Raspberry Pi controller. The controller was not easy to implement as some functionalities should work regardless of what the controller is doing at any given time. For example, if the controller is processing an incoming image from the IR Camera, and the user clicked on the keypad, the keypad functionality should be called and the image should remain in its processing stage. For that regard a multi-threaded system was introduced.

Additionally, the image processing and the keypad functionalities do not have a certain set of time to execute. The keys on the keypad can be pressed on any given time and there's no way to expect when the keys will be pressed. For the image processing part, it is hard to expect when the images might be ready for processing, and each image will take a different period of time to process. This means that the image processing part can lag/spike the performance of the controller, due to this fact, the controller should handle each task on its own and send the final data to the pen once all data is ready from each process.

The controller has four main tasks to perform. The first task is to read the data coming from the pen, the second task is to process the images coming from the IR LED, the third task is to monitor the keypad and read the incoming inputs coming from the keypad, and lastly, the controller should combine all of the previous tasks to produce the final output.

Reading Data From the Pen

We have discussed earlier that the pen will send the data in the form of a single bit representing the typing/erasing mode and a an 8-bit integer representing the force value at the tip of the pen.

We have connected the HC-12 to the Raspberry Pi as shown earlier to read data from the pen. The HC-12 was not able to use the default TX/RX pins provided by the Raspberry Pi due to the fact that those pins were used to visualize the final output on a device such as a personal computer or a laptop. The Raspberry Pi allows the user to configure additional ports as new software "UART" modules that are disabled by default. One of these modules was enabled in our regard to read the data from the pen. The serial port was configured with its default settings, 9600 baud rate, 8-bit data, 1 stop bit, and no parity bits.

The data read from the pen is finally stored in a global state that can be accessed by different threads, because other threads might need to determine the state of the pen to send the final output to the connected device.

The data is expected to change once every 50ms, a global state was used because once an image is processed, the data is sent directly to the connected device, where the sending task will read the whatever data that is available in the global state. The 50ms delay between each state is trivial and can be neglected when considering noise that might occur from the delay.

Reading Data From the Keypad

The keypad was interfaced with the Raspberry Pi, a special task thread was assigned to take care of the keypad. To work with the keypad, the columns are required to be a digital output and the rows are required to be a digital input.

This task is responsible of processing each row when a column is activated to determine whether a key is pressed or not. Once a key was determined to be pressed, the task will trigger the appropriate command for the corresponding pressed key.

Each key from the keypad is bound to perform a simple operation. The operations range from color selection, border determination and page addition, deletion and navigation.

IR Camera & Image Processing

A special thread was assigned to perform all of the image processing techniques required to determine the position of the pen. The IR Camera required some configuration before processing any of the incoming images. The resolution of the IR Camera images were selected to be of size 864x480. The IR Camera is capable of producing higher resolution images, but we had to take into consideration that images with greater resolution are bound to take much longer time to process even though it might produce higher accuracy when determining smaller working areas for the pen. We had to find the perfect balance between performance and accuracy to create a smoother user experience.

After trial and error, we have noticed that using a resolution of 864x480 can achieve acceptable accuracy when determining a working area of half the screen, and the Raspberry Pi is able to process images an average of 10 images per second when working with that resolution.

The first operation that has to be performed is to capture an image from the IR Camera. The image captured follows the resolution that was set previously in the camera configuration part. Once that's done, the image will be converted into a numpy array that will be processed using the OpenCV library. More on the techniques used to process the image to obtain the final position of the pen is explained in the next section. Once the position of the pen is ready, the data will be sent by the "Output Transmission" task to the connected device for visualization.

Output Transmission

The position produced by the previous task is combined with data produced from the HC-12 that reads the incoming data from the pen. Finally, the data is transmitted to the connected device for visualization.

The following flow chart summarizes the functionality of the Raspberry Pi controller:

Figure 5.18: Flowchart summary for the Raspberry Pi Controller

5.2.6 Image Processing

OpenCV is a free software library for computer vision and machine learning. OpenCV was created to offer a standard infrastructure for computer vision applications and to let commercial goods incorporate machine perception faster. Because OpenCV is a BSD-licensed software, it is simple for companies to use and alter the code.

Since the OpenCV library is huge and widely supported by the community, it was an obvious choice to be used by the Raspberry Pi along with the Python programming language to apply the image processing techniques on the images taken by the IR camera.

In interactive media applications, real-time and precise input signal localisation is a major topic. An IR LED detecting technique, such as an interactive board, will discussed in this section. An IR LED is used as an input signal, whose laser is invisible to the naked eye but visible to an IR camera. The IR pixels are separated from the collected video pictures using a threshold approach. A specific range of pixels are always present in the approved IR locations. The segmented results are divided into multiple distinct blobs using a linked component labeling technique. The noise in the segmented output is removed by filtering tiny blobs of a specified pixel count. The IR spot position is determined by the center of the IR blob.

Figure 5.19: Captured Image

We discussed a real-time IR LED detection approach in video captures for input signal localisation to provide a cheap device for interactive boards. The IR spots, which are not visible and sensitive to human eyes, are captured using a webcam. The IR areas are segregated with noise induced by illumination variation of the environment or object particle using a threshold approach. A small or big number of linked pixels make up the noisy area. The input IR blobs, which always contain a specific number of pixels, are segregated from these noisy areas. We use a connected component labeling approach to arrange the segmented findings into numerous connected clusters as a result of this phenomena. The IR blobs of a specified number of pixels are filtered out by counting the pixels of each cluster. The input location is identified as the center point of the IR blob. We also use a WIFI and USB connection to send the calculated input locations to software programs.

Figure 5.20: Gray Image

In this part, we'll go through an IR LED detection approach for UI localization in web camera video sequences. The light from an IR LED fitted in a standard television remote controller is not visible to human eyes, but it has a high brightness in camera captures. The areas of high brightness that include IR LED pixels are segregated using a threshold approach. In practice, the IR LED light source has a modest number of pixels and a spot form. The segmented pixels were divided into many separate blobs using the CCL method. As the input IR LED position, blobs of a specified number of pixels are filtered out.The input position is recognized as the coordinate of center pixel in each blob, which is easy for search so as to reduce computation consumption.

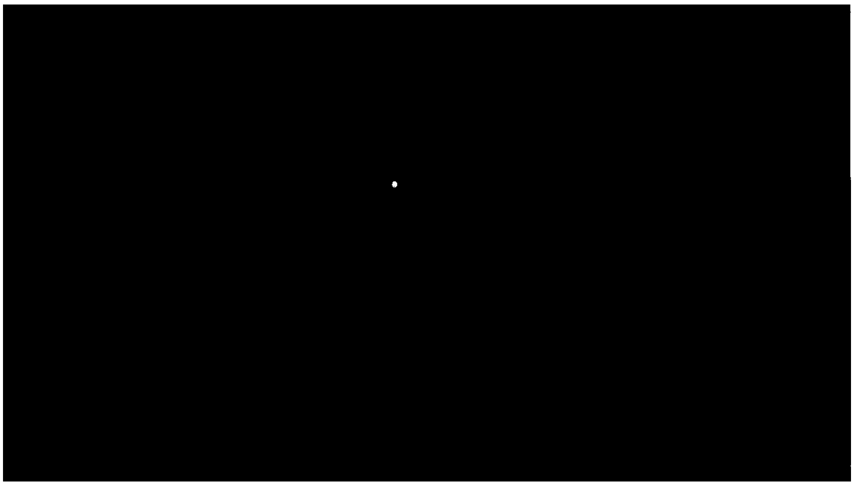

Figure 5.21: Binary Image

Row–column and multipass scanning are the most often used CCL methods to discern isolated blobs. The row column scanning algorithms look for the smallest label among all valid grids in a row and column, then label all valid grids with that label. The scanning procedure is repeated until all grids remain unchanged. For low-resolution photos, these row–column algorithms work well, but for high-resolution images, they produce computational overload. The minimal label is searched among the nearby grids in multi-pass scanning methods. Because the highlight zones in this project are never huge, a multi-pass scanning CCL approach is provided for labeling the isolated blobs.

Figure 5.22: Center Point

5.2.7 Keypad Functions

In this section we will talk about the functionality for each key on the keypad provided to the user

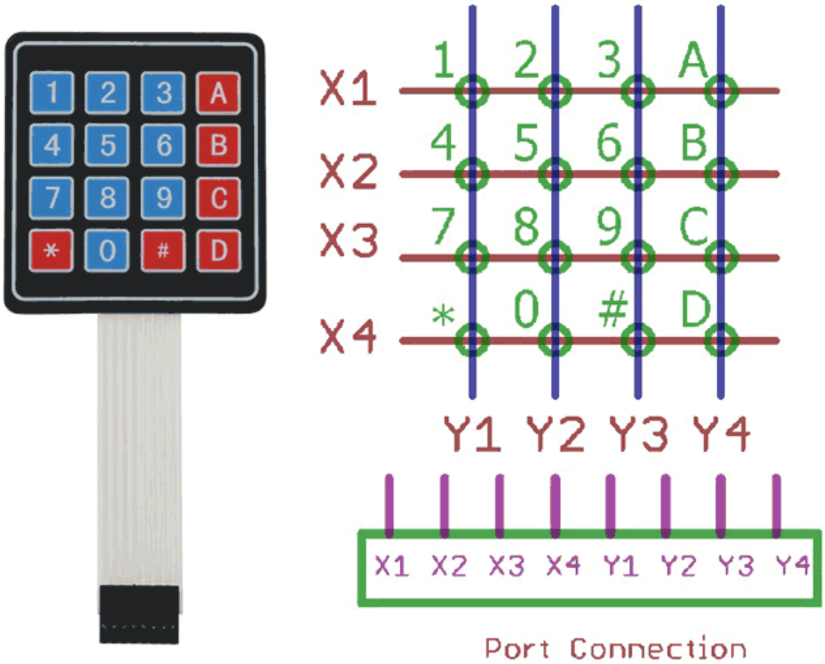

Figure 5.23: Keypad Pin Diagram

The keypad consists of 16 different keys, each of which we have associated with a specific function. The digits from 1 to 9 have been tied such that each one represents a different color. When the user presses these numbers, the color of the font changes, giving the user a total of nine different colors to choose from. The digit 0 has been connected to clear the current page's content. The current page will be cleared when the user presses it, allowing the user to clear the pages as needed. The letter A has been connected to represent the function of adding a new page. When the user presses it, a new page is created, allowing the user to add as many pages as he needs. The letter B has been attached to delete the current page. If there are additional pages, the current page will be deleted when the user presses it, allowing the user to delete them as needed.The letters * and # have been connected to navigate between pages. The * letter will navigate the pages in backward direction, while the # letter will change the pages in forward direction.The letter C has been connected to the function of saving all pages as a single PDF file. When the user presses the button, a new PDF file is created, allowing the user to save his work in several stages as needed.The letter D has been connected to the function of determining the area of a working space.When the user presses the button, the application begins to wait for four points that represent the corners of borders. The user should then go to the desired points and click on the button which is located in the pen's body. Every time the user presses this button, the camera records the point location, so, when user finish the four points, the working area will formed by connecting these points in the form of rectangle.Note that the direction of defining the points is very critical, since we must begin at the upper left corner and then go counterclockwise to determine the rest of the points, and the user is advised to be very precise in specifying the points so that the projection matches with the pen's location.

Once the 4 points were selected, we needed to relocate the location of the pen relative to the rectangle formed by the new 4 points:

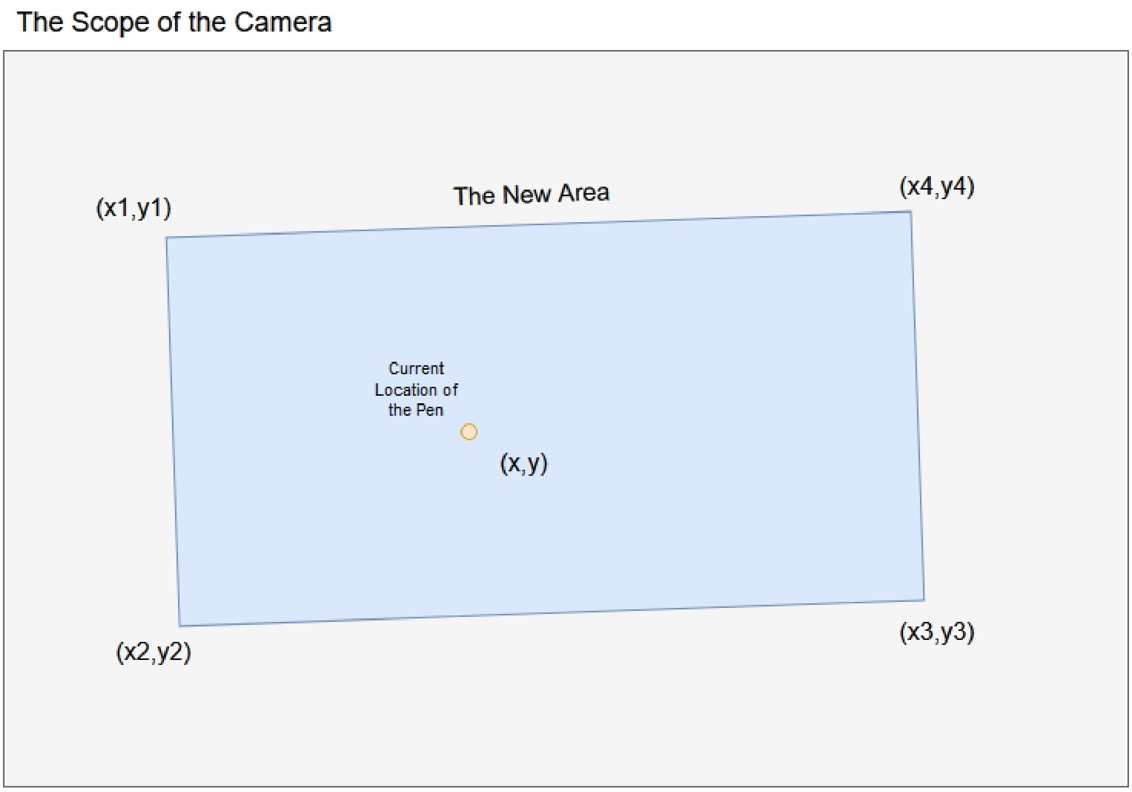

Figure 5.24: The New Working Area on the Camera Scope

To determine the new location of the pen relative to the upper corner of the rectangle (considering (x_1, y_1) will become $(0, 0)$), we will find the perpendicular distance between the point (x, y) and each of the 4 sides of the rectangle:

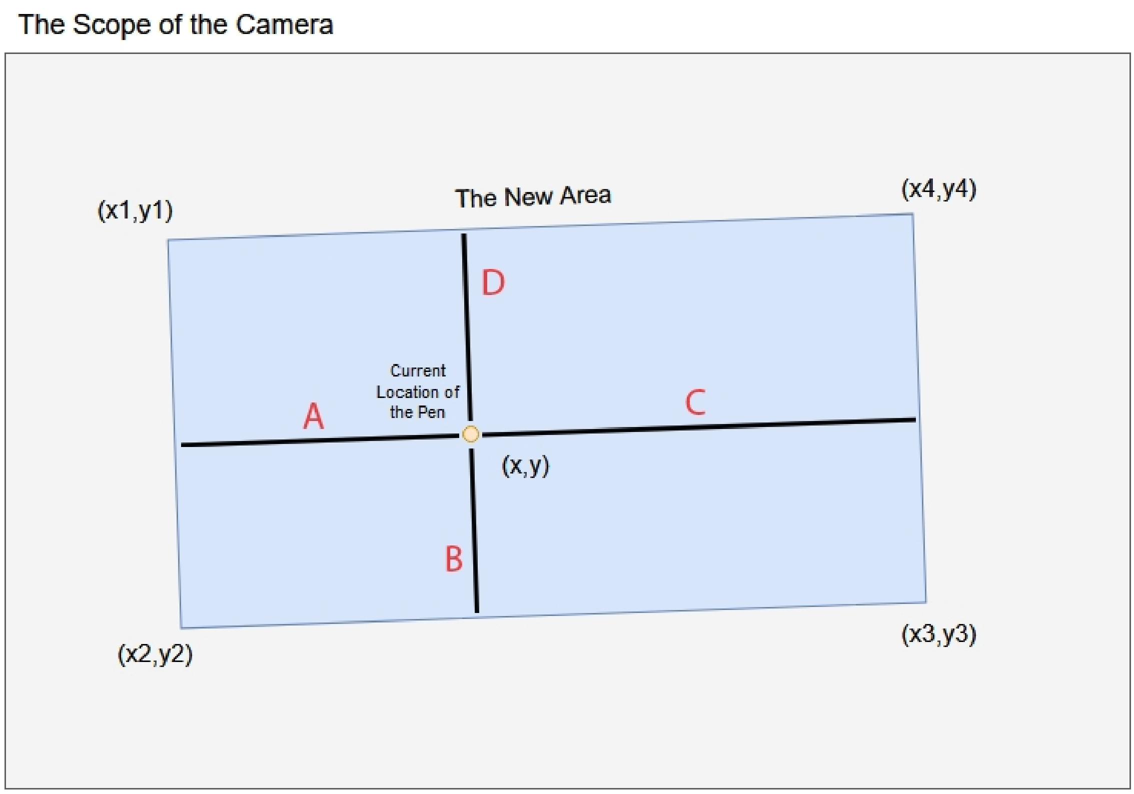

Figure 5.25: The Perpendicular Distances Between the Point and The Sides of the Rectangle

We have denoted that the perpendicular distance between the point and each side of the rectangle with symbols A, B, C, D respectively. To compute the perpendicular distance between a point (x, y) and a line that passes through the points (x_1, y_1) and (x_2, y_2):

$$distance(P_1, P_2, (x_0, y_0)) = \frac{|(x_2 - x_1)(y_1 - y_0) - (x_1 - x_0)(y_2 - y_1)|}{\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}}$$

Once we have all the distances A, B, C, D, we can compute the values of the new (x, y) using relative distances:

$$\frac{A + C}{A} = \frac{screenwidth}{x}$$

$$\frac{D + B}{D} = \frac{screenheight}{y}$$

(x, y) will be the final current position of the pen.

5.3 Output Visualization

To see the final results, we have created a special Java application using the Graphics2D component [8]. The application reads the serial data sent from the Raspberry Pi controller that contains the final result and visualises it on screen. The screen of the Java application can then be projected on the whiteboard to create a fully function digital whiteboard that can be written on using the special pen that was designed in previous parts.

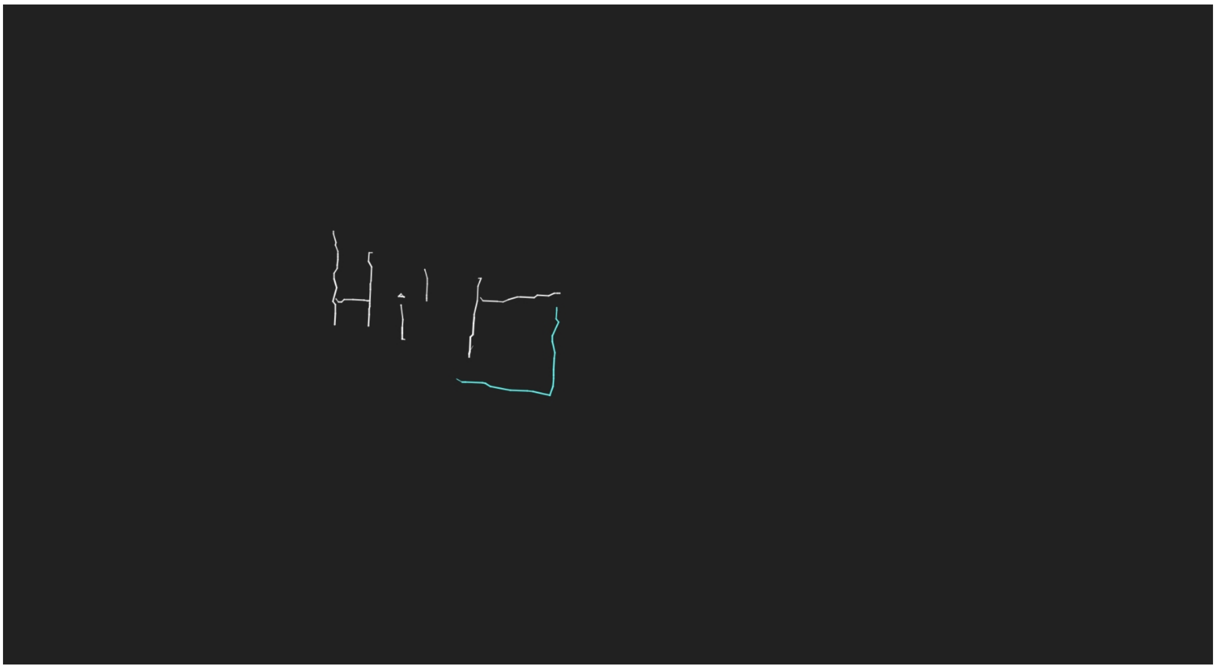

Figure 5.26: Whiteboard Visualization 1

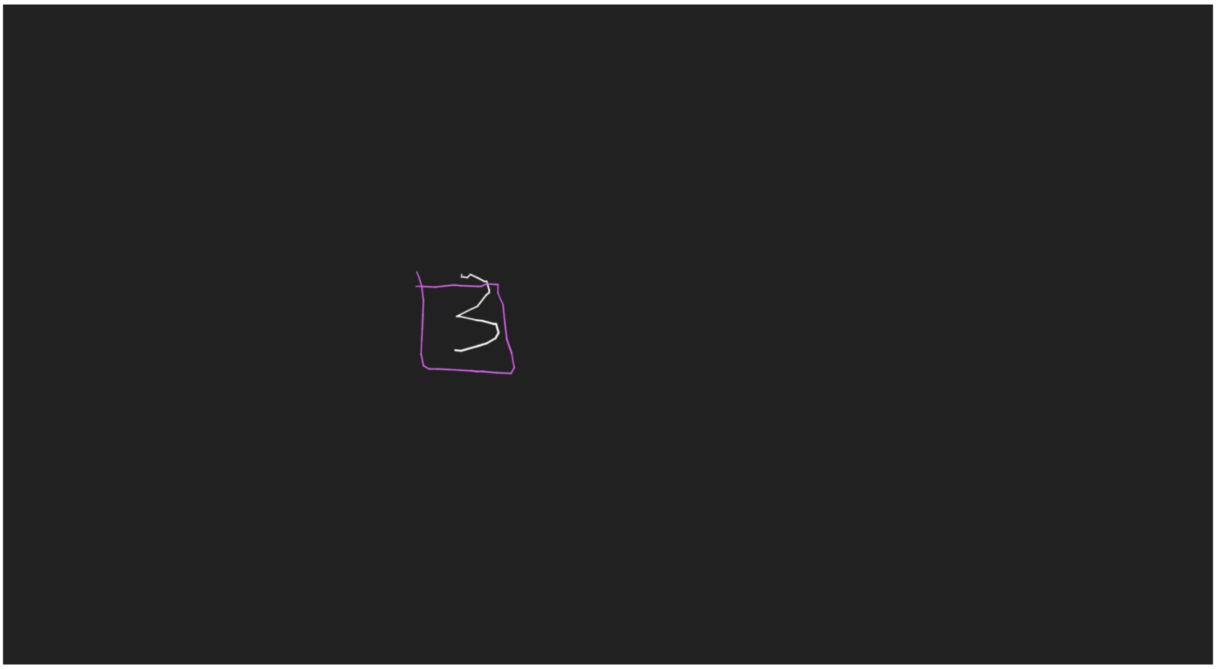

Figure 5.27: Whiteboard Visualization 2

Chapter 6

Results & Discussion

6.1 Final Project

The final outcome of the project is a portable digital pen that's capable of:

1. Tracking the pen with an acceptable accuracy and low latency.
2. Relatively good performance when it comes to drawing.
3. Ability to change the color of the ink used when drawing.
4. The ability to create pages, and navigate between them.
5. The user can remove pages and erase pages simply.
6. The working area is easily configurable and with high accuracy.
7. The ability to save the work created by the user as a portable document.

6.2 Project Outcomes

The project was hopefully able to achieve the purposes it was created for:

1. Enhance the learning experience with a mix of traditional methods and modern technology.
2. Reduce the strain of carrying multiple textbooks and taking notes behind the lecturer/teacher.
3. Effectively employ the limited time for each classroom into education.

Chapter 7

Conclusion & Future Work

7.1 Summary

Annotate was a project that aims to create a portable digital pen that can be used anytime and anywhere. The pen was designed with care to mimic the behaviour of normal pens. The Raspberry Pi controller came with multiple functions that can be executed using the provided keypad, the functions allow the user to change the color of the ink, to create pages and navigate between them, and to save the created work as a portable document.

Annotate was created in the hope of enhancing the educational field with modern technology while taking into consideration the difficulties of transitioning between old technologies and new technologies, while providing only benefits that would convince users to switch.

We hope that Annotate was able to a achieve the purpose it was created for. We tried our best to implement all the features we had in mind in the best way possible while keeping the performance and the accuracy in the acceptable range.

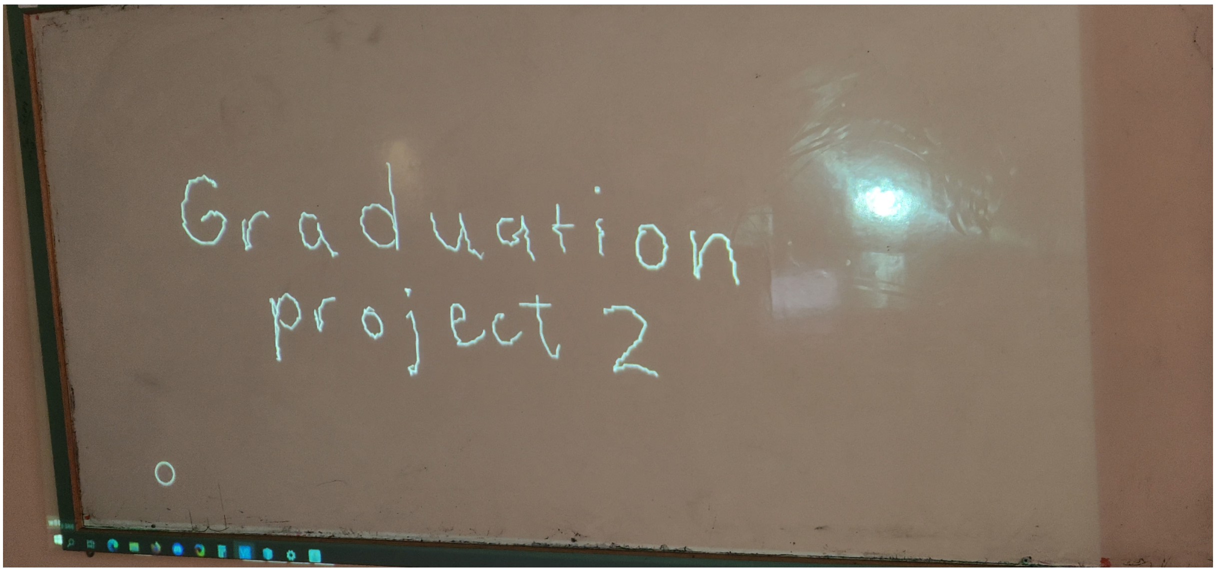

Figure 7.1: Annotate With a Projector

7.2 Future Work

There are some areas that Annotate could be improved in, including:

1. Higher accuracy and performance when determining the working area of the pen. The processing speed of the Raspberry Pi was a bottleneck in that regard.
2. Improving the accuracy of the image processing to be able to detect the pen under well lit areas.
3. Moving the output demonstration to the Raspberry Pi itself rather than an external device, but we were limited due to the capabilities of the Raspberry Pi.
4. Allow the pen to work with any application as a normal input device rather than working using a special software.

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