AutoErasing

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***Abstract*—Our project designed and implemented a system, consisting of a web application, a Raspberry Pi, a non-captive stepper motor spinning on a screw rod, an IP camera, and a projector, which aims to provide unlimited "virtual board" space to instructors and automates the process of board erasing. Instructors can command the system to erase the board, take pictures of the board, and project the pictures back to the board as well as continue writing over the projected content; and students can view class images taken before.**

***Index Terms*—Automation, Classroom Tool, IP Camera, Projector, Raspberry Pi, Stepper Motor, Virtual Board, Web Application**

1 INTRODUCTION

In classroom scenarios, a frequent obstacle encountered by instructors is the insufficient availability of classroom board space for writing. Oftentimes, instructors find themselves compelled to erase the board multiple times within a single lecture, which makes it difficult for them to reference specific notes from previously erased material. Simultaneously, it presents a challenge for students who strive to maintain the pace of note-taking on content that is subject to erasure. In order to address this problem, our team created a "virtual board" system that could provide unlimited virtual board space by allowing the instructors to complete a sequence of automated actions within a single click on the "erase board" button on the website, including taking pictures of the board, erasing the board, and uploading the picture to a website that is accessible to instructors and students enrolled by instructors. The instructors can also project the erased content captured previously using the projector whenever they wish to refer to the content discussed earlier. With the functionality discussed above, our system not only provides instructors and students with access to unlimited virtual board space on the website but also saves their effort by eliminating the need for manual erasures on classroom boards and the capturing of board content.

Compared to other existing automatic board erasers, one of the greatest strengths of our system is that it also automates the process of taking images and uploading images to the website for future reference to provide unlimited board space. Although the use of tablets also addresses the issue of limited board space, it requires the instructors to bring their own tablets and be familiar with crafting notes on tablets, which is not straightforward to accomplish for all instructors, especially for those who are more used to conventional physical classroom boards. Our system, built as an attachment to the boards in classrooms, doesn't have any prerequisite in the use of and familiarity with technology, which would be more accessible to more diverse groups of instructors.

While the main goal of our project is to provide instructors and students with the convenience of referring back to erased lecture content, our project also saves instructors' effort in repetitively erasing the board during lectures and prevents instructors' lectures from being impeded by the need of erasing boards. It's worth noticing that since our design report, we have pivoted our primary goal from allowing instructors to customize the board into different sections to automate the erasing process to providing virtual board space. Therefore, we eliminated the definition of sections and the use of solenoid, but included a projector that allows instructors to project content back to boards to better align with our use case.

2 USE-CASE REQUIREMENTS

Based on the application or problem we have described in the Introduction (Section 1), we have identified the following use case requirements considering the needs of instructors and students in classes in terms of latency, user experience, functionality, accessibility, power consumption, and scalability.

- For users to have seamless experiences using the system, the board erasing and image uploading should have no significant latency. This indicates that the time taken to erase the board should not exceed the time taken for manual erasing. While the time of manual erasing depends on the density of text ink spread over an area of the board and is not as constant as system erasing, we have filled out the entire area our system erases (30" × 15") to measure the worst-case latency of manual erasing, which turned out to be 45 seconds, so our system needs to finish erasing within 45 seconds. Similarly, the images of erased content should be uploaded to the website within 3 seconds after clicking the "erase board button", since this is the average time taken for a website on a standard internet connection to load.

- Our system and user interface are designed to be intuitively navigable for a diverse user base. Our objective is to enable users to learn how to use all functionalities within 1 minute, which indicates that they can locate and activate their desired features without hesitation. In addition, our system should effectively clean the board so that the board is ready for the next iteration of writing without further erasing, and upload captured images of board content that are readable without any glares. We expect 67% of users of our system to agree that our system has achieved their expectations.

- To guarantee the accessibility and affordability of our system for classrooms across various institutions, the cost of the physical attachment, excluding the board and erasers, should not exceed $200, which aligns with the average cost of a typical classroom board. To minimize the power consumption of our system and mitigate associated electricity costs, we expect the peak power of the entire system to not exceed 70W, which is the average power of a laptop in use.
- Our system should be adaptable to classroom boards of different dimensions. The web application should enable instructors to select the board used and configure the actual size of the board. The erased area controlled by the Raspberry Pi should align with the board dimension settings stored in the database of the web application.

3 ARCHITECTURE AND/OR PRINCIPLE OF OPERATION

As depicted in the diagrams, our physical system consists of some attachments to the whiteboard, an IP camera, and a projector. A web application serves as the major interface for users to interact with the rest of the system.

The function of the attachment is to erase the whiteboard. A non-captive stepper motor is employed to drive the horizontal movement of the erasers. For non-captive motors, the screw rod remains static, and the motor spins along the screw rod.

3.1 Physical System

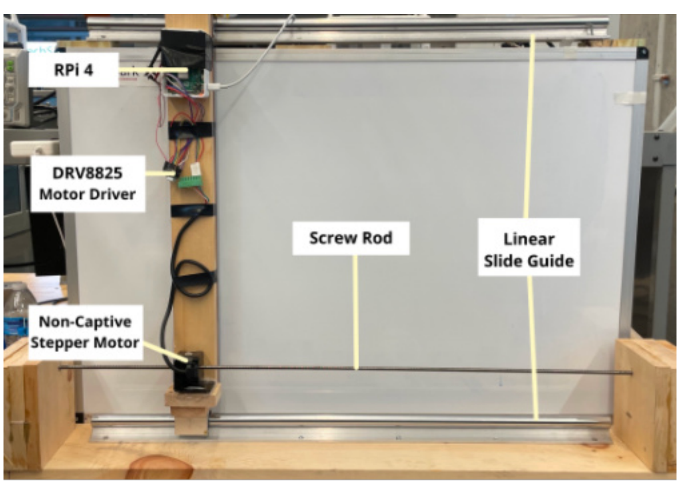

Figure 2: Front view of physical design

The motor is glued to a series of erasers, which are pushed tightly into the board. To keep the stability and smoothness of the movement, we include two linear sliders at the top and bottom of the whiteboard to guide the movement of the erasers.

Note that the above design is different from the previous design report, where we planned to use wheels attached to the motor shaft to move the erasers. The non-captive stepper motor can provide more stable horizontal movements, reducing the risk of the mechanical system falling apart, at the cost of speed.

3.2 Hardware

We use a Raspberry Pi (RPi) and a DRV8825 motor driver to send appropriate output signals to drive the stepper motor. RPi can control the speed and direction of the motor movement by changing the signal to STEP and DIR input on the motor driver. In the actual operation of our project, the speed is set to the optimal value obtained from testing results. The direction is changed after every erasing operation.

Compared with the design report, we deleted the solenoid from our design, due to changes in the use case. We are no longer focusing on erasing sections of the board but instead pivoting to the idea of providing virtual space. Since we are now erasing the entire board, there is no need to pull erasers away from the board. Thus, we simplified our design and removed the solenoid.

3.3 Camera and projector

The IP camera and the projectors are placed in front of the whiteboard to take pictures of the whiteboard content and project content onto the whiteboard. We carefully adjust height and distance to ensure the clearness of the pictures. Note this picture does not reflect the optimal height and distance.

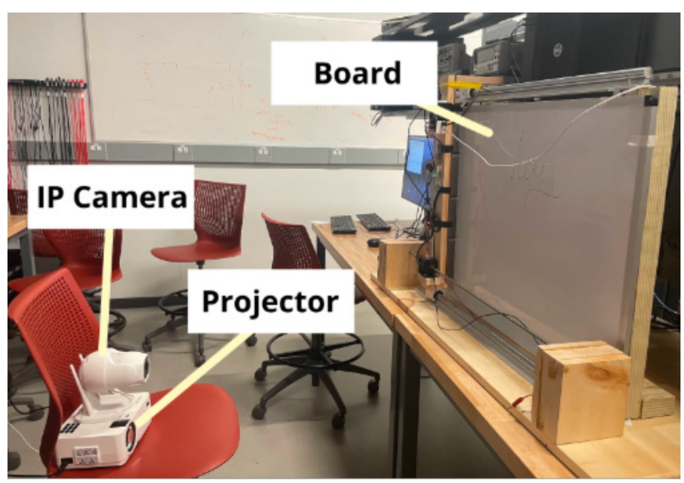

Figure 3: Side view of physical design with camera and projector

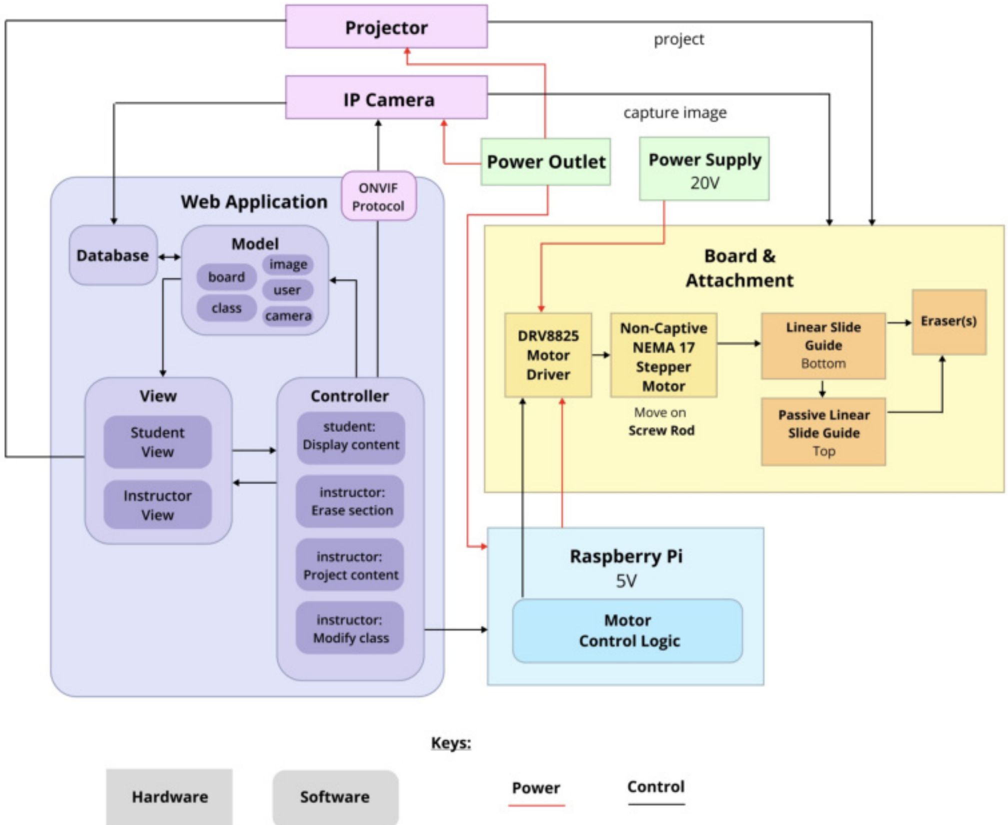

Figure 1: Block Diagram of Entire Design

The wireless IP camera is used to capture the content of the whiteboard right before erasing happens. The web application will be able to access real-time image streaming at the designated IP address over a network in the backend and upload the content to the website on both student view for them to review and take notes and instructor view for them to refer back using the projector.

In the design report, we identified the projection feature as post-MVP. We have successfully implemented this feature, allowing instructors to simply select the pictures from the web application and project them back to the board. While the content is being projected, the instructors are still able to use erasing and image capture features from the web application.

3.4 Software

The web application integrates and communicates with all other components. It can communicate with RPi by sending an erasing command along with board width to RPi's IP address. It communicates with the IP camera through the ONVIF protocol and obtains the images. Projectors are used in similar ways as a regular projector in classrooms.

The web application also serves as an interface for users. It consists of both the instructor's view and the student's view. To address privacy concerns, users will need to use Google OAuth to log in before they can access content on the web application. In the instructor view, users will be able to create classes and edit class information, such as student ID and board width. They will also be able to click "erasing board", to get a picture of the content on the board and erase the entire board. The pictures will be uploaded to the web application, and instructors can select them and project them back onto the board at any time. In the student's view, they will be able to view all pictures to help them take notes.

4 DESIGN REQUIREMENTS

According to the previous discussion on use case requirements (Section 2), we have listed the following design requirements.

- To ensure we meet the use case requirement of having at most 45 seconds of erasing time, our RPi should be able to send signals through the motor driver to the non-captive stepper motor and instruct it to rotate at a speed of at least 2666 steps/second. The speed of the motor moving along the screw rod is calculated by dividing the 30-inch width by 45 seconds of expected completion time. We then convert this speed to steps per second by multiplying the speed of a motor moving horizontally on the screw rod by

4000 steps of rotations per inch of horizontal movement, where the value 4000 steps/inch is obtained from the datasheet of the non-captive stepper motor. This gives the equation

$$\frac{30in}{45seconds} * \frac{4000steps}{1in} = 2666steps/second \quad (1)$$

- To achieve a maximum of 3-second latency on the image-capturing feature, we require the time it takes between clicking on the "erase board" button and the time the new image shows up on the website to be less than 3 seconds. The image-capturing feature includes the web application sending client requests to the backend, the backend communicating with the IP camera to obtain the captured image, and the backend sending the image back to the frontend. Since it may be inaccurate to measure individual time intervals for each step, and assuming the web application network connection is stable, we only measure the roundtrip time it takes for the instruction to be completed at the frontend and require the time to be less than 3 seconds.

- The use case requirements expect the total peak power consumption of the system to be fewer than 70W. The breakdown of such power consumption includes power usage of IP camera, RPi, and motor movement. Based on the specifications we could obtain, the power consumption of the IP camera is capped at 24W, and that of the RPi is 7W. Now this gives us

$$70W - 24W - 7W = 39W \quad (2)$$

as the peak power consumption expected for the motor movement. We are capable of measuring data on voltage(V) and current(I), so when calculating the power consumption (P) of motor movement, we will use the equation

$$P = V * I \quad (3)$$

- According to the datasheets, the rated current of the non-captive stepper motor is 1.5A, and the rated voltage of the motor driver input is 45V. Based on (3), we calculate the maximum voltage we can supply to the motor to meet the power consumption requirements under safe operating conditions.

$$\frac{39W}{1.5A} = 26V \quad (4)$$

This is smaller than the rated voltage of the motor driver, so we take the minimum of the two voltage and set the voltage limit to the motor to be around 26V.

5 DESIGN TRADE STUDIES

In the following subsections, we will discuss 4 design trade studies, mostly focusing on the physical board system and motor control.

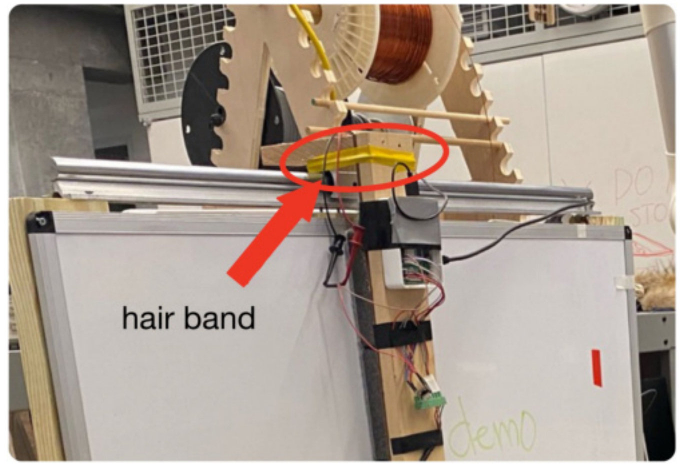

Figure 4: Hair Band on Eraser System

5.1 Erasing Cleanness VS. Motor Speed

The physical attachment of the eraser system should apply pressure on the whiteboard to achieve effective erasing of the board. During the semester, our team has made various attempts to apply different pressures to the board to observe the erasing cleanness. While it's difficult to measure the exact pressure applied on the board and ensure the pressure is constant on the entire eraser, our team has decided to use hair bands to bond the top slider block to the large erase so the tension on the hair band could help to enforce pressure between the eraser and the whiteboard. Looking at Figure 2, note this is possible because the bottom slider block is kept stationary by screwing the slider rail to the wood piece underneath the physical whiteboard system. We also chose to use a thick wood piece to hold the erasers to avoid bending of the erasers.

We experimented with multiple numbers of hair bands to represent different pressures. The result shows that more than 1 hair band could usually lead to the motor spinning without moving forward horizontally for a short period. Without any hair band, we tested another approach by gluing the slider block very tightly to the top bar of the wood piece holding the eraser. However, this doesn't have enough force to ensure the cleanness of the board. In order to prioritize the cleanness of the board while maintaining a relatively high speed of motor movement, we have decided to use 1 hair band to apply enough but not too much pressure between the eraser and the whiteboard.

5.2 Erasing Latency VS. Power

While it's easy to see the latency of motor movement and power consumption are related because the current supply affects the speed the motor can achieve, we were initially not certain about the motor's behavior given various current and voltage values.

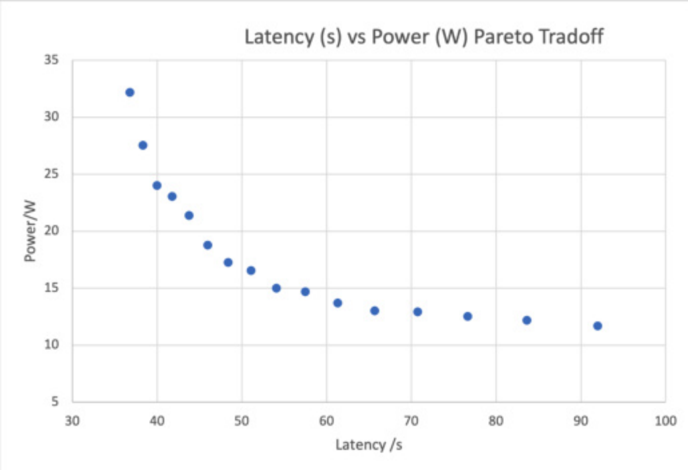

Figure 5: Power Consumption VS. Latency

As a result, we have decided to conduct experiments on the relationship between power consumption calculated by (3) and the latency obtained through running RPi code and measuring the time elapsed to erase the entire board with a width of approximately 30 inches. The Pareto graph is included above, and all data is obtained under the condition that the board is erased clean.

As indicated in the design requirements, we would like to keep the power consumption of the motor movement under 39W, so data points are only measured if they meet the requirement. While the optimal speed we could achieve is slightly under 40 seconds, we do notice that the power consumption increases very fast with the latency being smaller. If the motor does not receive enough current supply at a specified running speed, we usually observe the motor spin without moving horizontally for a short time. This scenario also causes the motor driver to heat up quickly, and the eraser will not be able to move exactly 30 inches at a specified time interval. To avoid such instability, we decided to choose a latency of approximately 45 seconds that meets the use case requirement but doesn't cause a risk of breaking the system down.

According to (3), we set the power supply to be 20V, and thus the current limiting is approximately

$$\frac{20W}{20V} = 1A \tag{5}$$

Note that the control of both voltage and current is achieved because the motor driver contains a current-limiting resistor, allowing us to modify its resistance.

5.3 A4988 VS. DRV8825 Motor Driver

To send instructions from RPi to the non-captive stepper motor, we require the transition of signals through a motor driver. There are various choices of motor drivers that provide very similar functionality with slight changes in the pin settings. Originally, our team researched online and found a relatively cheap and commonly used motor driver, A4988. Since there are many existing examples of using A4988 as a motor driver for the NEMA 17 motor, we decided to start with A4988. After experimenting with the effect of A4988, we observed significant difficulties in achieving satisfactory latency in erasing. To meet the expected latency, our design requirement has specified that the rotation speed of the motor should be approximately 2600 steps/second. However, when supplied with the calculated voltage and current, the motor can achieve a maximum speed of around 1000 steps/second.

We did more research on various types of motor drivers and decided to use DRV8825. The voltage limiting for A4988 is approximately 35V, whereas that of DRV8825 is 45V. This means DRV8825 has more potential to provide higher power if we eventually make the design choice to exceed the power consumption limit by a small amount. In our case, we did not use this advantage due to the previous discussion on power consumption choice. In addition, testing results show that DRV8825 helps to double the maximum speed the same non-captive stepper motor could achieve under the same voltage and current supply. The reason is unknown since such information cannot be obtained from the datasheet, but this indicates to us that choosing DV8825 could help us boost the performance of erasing latency significantly, with a slight increase in expense.

5.4 Motor Movement Mechanism

Motor movement is one of the most crucial components of our project because it directly affects the functionality of erasers. To lower the potential risk, our highest priority in designing the motor movement mechanism is to avoid the instability of the system. After deciding to use a stepper motor, which could provide us the accurate precision of movement to compensate for the absence of a sensor, we explored two approaches to moving the motor.

The first approach is to use a regular stepper motor and attach it to a wheel, which rotates on a slider rail to move the eraser system attached to the stepper motor. However, since the erasers need to be pushed on the board to apply some pressure, such a mechanism does not work as intended because the force pushing back from the whiteboard is likely to cause the wheel and motor to bend outward from the whiteboard. This also leads to potential friction between the wheel and the slider rail, so it may further prevent the motor from moving as expected.

Therefore, we've chosen the second approach, which is to use a non-captive stepper motor moving along a screw rod, as described in system architecture. Pivoting from the wheel movement to the current design leads to a substantial decrease in speed since the non-captive stepper motor needs to rotate 20 revolutions to move 1 inch horizontally. Despite this difficulty, the non-captive stepper motor moving along the screw rod does not face the risk of falling off the slider rail. In addition, we've added linear slide guides as described previously. With such a design, the pressure applied between erasers and the whiteboard no longer affects the movement of the motor.

6 SYSTEM IMPLEMENTATION

In the following subsections, we will discuss in detail the implementations of each subsystem, including physical attachment, hardware components, image capturing and projection, as well as web application. In addition, we also discuss about integration choices between web application and RPi.

6.1 Physical Attachment

Our physical attachment to the whiteboard includes RPi, motor driver, non-captive stepper motor, screw rods, and linear slider guide. To connect these components, we decided to use wood and nails because they create stable connections.

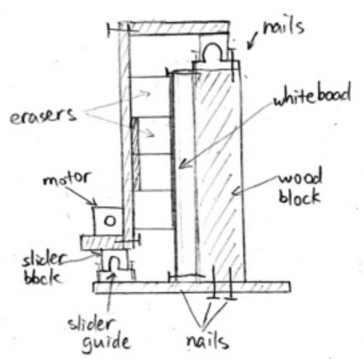

Figure 6: Side view of design

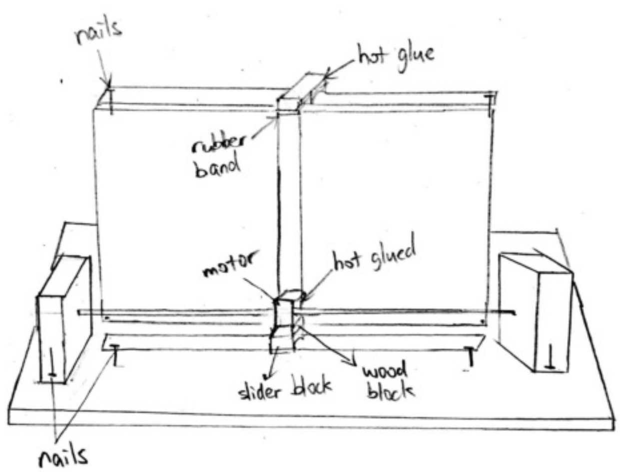

Figure 7: Front view of design

In our design, we used three large wood blocks on the back of the whiteboard to hold the whiteboard vertically in place and to support the weight of the heavy slider guide on top. The lower slider guide is nailed to the bottom wood sheet. We assembled a Z-shaped wood piece, where the upper and lower horizontal wood pieces connect to the slider blocks and the erasers are hot glued to the vertical wood piece.

In reality, we realized that the nails work well on larger blocks of wood, such as the big pieces that hold the whiteboard. However, on smaller blocks of the wood, such as the ones connecting erasers and the motor, nails would create cracks, and eventually break the wood. Thus, we switched to wood glue for connecting small pieces of wood to wood, and hot glue for connecting small pieces of wood to metal.

When we connected the erasers, we observed that the performance of erasing was worse in the middle of the board compared with the upper and lower parts of the board. To fix this issue, we put one sheet of thin wood between the middle erasers and the supporting wood block, so that the erasers are more compressed to the board. To find a balance between the pressure on two sides and the middle of the board, we carefully tested and adjusted the thickness of the wood sheet and decided that 3mm had the best erasing performance.

6.2 Hardware Components

The DRV8825 motor driver has 12 pins. It requires a low signal on the ENABLE pin, a high signal on the SLEEP and RESET pin, a PWM wave on the STEP pin, and a voltage supply on the VMOT pin to generate output on the 4 motor pins that would drive the motor. The direction of the stepper motor depends on the signal on the DIR pin and the speed depends on the frequency of the PWM wave.

We initially used an A4988 motor driver in our design, which has very similar pin layouts. However, we realized that its performance was unstable for speeds larger than 1500 steps per second, possibly because it only has a current rating of 1 A and could not support the high current requirement for high speed. Thus, we turned to DRV8825, which has similar functionality but can support a higher voltage supply and has a higher current rating of 1.5A.

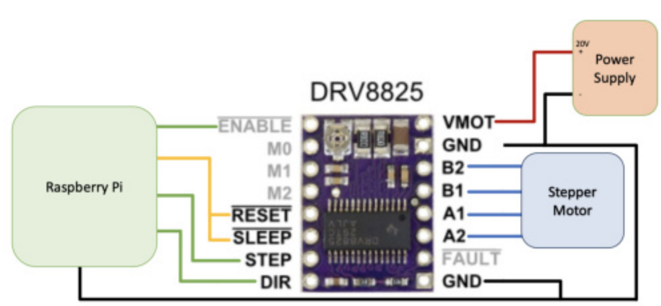

Figure 8: Layout of motor driver

We implemented two ways of driving the motor to the desired speed. The first function simply sets the speed to the desired value and runs for a certain time to reach the distance specified. The second function would start at a relatively lower initial speed and gradually accelerate to the desired speed, stay at that speed for some time, and decelerate to the initial speed before stopping.

Compared with the accelerate method, the constant speed method has smaller latency given the same maximum speed. However, it becomes unstable under high speed, due to the sudden large change in current. The accelerate method is in general more stable but is slower because it takes time to accelerate and decelerate to the desired speed. As explained in detail in Section 5, we performed multiple tests and determined the optimal speed to be 2600 with the constant speed method.

6.3 Image Capturing and Projection

A camera module is incorporated into our design to capture the content of the board before it is erased. Following the image capturing, it sends the image immediately to the web application, allowing it to be stored in the database. We have decided to use an IP camera, which has an IP address making it accessible over the Internet. With the camera model we've chosen, the built-in pan and tilt functionalities can help to adjust to the angle facing the specified sections upon receiving the corresponding command from the web application. While commanding the Raspberry Pi to erase the content on board, the web application requests a new image from the IP camera right before the erasing takes place. Note that for security and privacy reasons, no real-time video is captured from the camera.

Through the ONVIF IP camera API, the backend can easily access the real-time captured image and read the image stream to store it in the database in various image formats. Such images, if deployed to AWS, will be stored in a static folder in the Apache server based on a unique name. Whenever needed, the web application can directly fetch from its static folder database to obtain the images and display them to users including instructors and students.

Any captured image can be projected back by displaying a single image on the website and showing the browser tab in the projector.

6.4 Web Application

Serving as the interface for users to interact with different functionalities and the center of communication, our web application has frontend and backend components. The website frontend uses HTML to build the skeleton of the pages and specify elements on different pages, and CSS to format the way different elements appear on the page to make it more user-friendly. For the backend, we have chosen to set up the website using the Django framework and program the functionalities in Python.

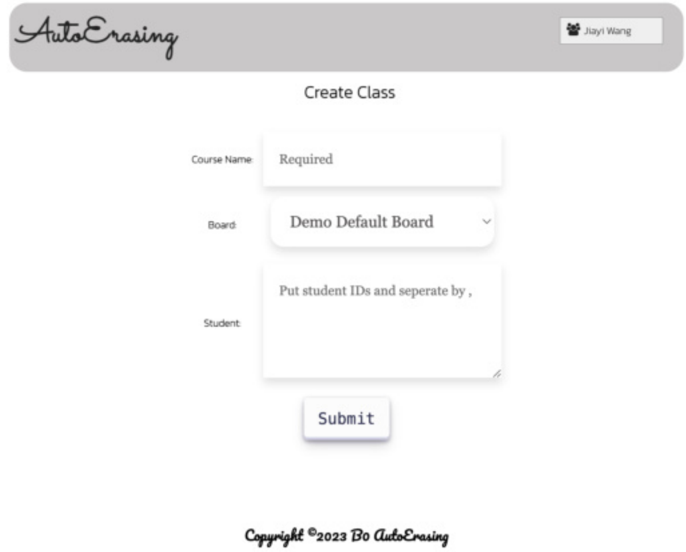

Figure 9: Instructor View of Create Class Page

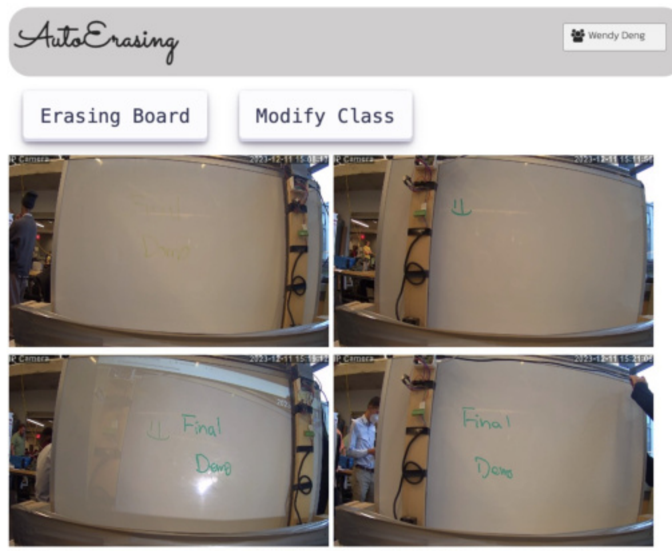

Figure 10: Instructor View of Erasing Board Page

The instructors will need to create a class, add students, and configure the board setting and camera positioning before accessing other system functionalities. Once the instructor clicks on "Erasing board", the backend will refer to the board setting stored in the database configured by the instructor when creating the class to obtain relevant information such as the board's width, and send it to Raspberry Pi. Such information is then used by RPi to further calculate motor movement instructions. At the same time, it takes images of content to be erased through the image-capturing mechanism discussed in the previous subsection. We use the ONVIF protocol to control the pan and tilt of the camera and save a picture to the database. Each time the class page is fetched, the Django framework retrieves the image files from the database and displays them to the users. In addition to the instructor view, our web application also supports student view, where an enrolled student can also access the captured images but does not have the capability of controlling the board erasing functionality.

6.5 Integration

The web application communicates with RPi by connecting them to the same network and sending requests to RPi's IP address. We initially planned to have RPi send a response back to the web application after erasing was completed. However, we realized that waiting for erasing to finish would block the picture uploading process. Thus, to reduce latency in image-capturing functionality, we decided not to let RPi send back the response indicating that it has finished erasing. Rather, the web application calculates on its end the time it takes for the eraser system to move across the board and blocks new "Erasing board" attempts.

7 TEST & VALIDATION

In response to the quantitative and qualitative use case requirements discussed in Section 2, we have completed a set of tests to ensure our system meets the users' needs. To develop a more comprehensive testing strategy, we adhered to test-driven development principles that ensure the performance of each subsystem to identify potential bottlenecks. As a result, we performed unit tests on the latency of the erasing functionality and the image capturing functionality, the power consumption, and the web application interface, as well as an overall system test on the functionality of the entire system.

7.1 Results for Latency Test

To ensure the users have seamless experiences using the system, the latency of erasing board and uploading images should be minimal. Therefore, we measured the latency of those subsystems to test if our implementation meets the low latency requirements of the users.

For the erasing subsystem, we programmed the motor to complete board erasing 5 times and calculated the average erasing time. Due to the space occupied by our mechanical components at the board's edges, the effective dimension of the board our system erases is 30" × 15", and we expect the erasing to be finished in less than 45 seconds as discussed in the Use-Case Requirements (section 2). The average erasing time we measured with the speed we decided to use was 50 seconds. However, as discussed in the Design Trade Studies (section 5), the power consumption of the motor increases as its speed increases, which might cause the motor to idle and stuck in a position for a few seconds over a certain threshold. Therefore, the speed we use is the most optimal we can achieve while prioritizing the stability of the system and the cleanliness of the board. Consequently, we made a deliberate decision to maintain the erasing latency at 50 seconds, slightly exceeding the metrics we set in Use-Case Requirements.

For the image-capturing subsystem, our test involves using JavaScript to record the elapsed time between clicking the 'erasing board' button and the image being posted on the website. Similarly, we repeated this process 5 times to calculate the average latency. Our calculations show an average time of 1.3 seconds, meeting the metrics of less than 3 seconds we established based on the average time taken for loading a page. This ensures that users do not experience any noticeable latency when accessing captured images.

7.2 Results for Power Consumption

To make sure our system doesn't use too much power in classroom settings, we tested and calculated the average power consumption of each subsystem, including the motor, the RPi, and the IP camera. Since the projector is not consistently powered on and activated solely with the instructor's intention, it was excluded from our power consumption calculations. We manually measured the maximum average power calculated from the voltage and current supplied to the motor during the 5 times we erased the entire board, and the average power of the erasing system is 19.65 Watts based on our calculations. For RPi 4 we are using, the maximum power it can achieve is 7 Watts. While it's hard to measure the power consumed by the IP camera and it's not specified in its datasheet, we decided to include the maximum power its power supply adapter can supply in the calculation, which is 24 Watts. The total power added up to 50.65 Watts. It's noteworthy that most IP cameras only consume up to 6 Watts, but in either case, the overall power of our system used meets the metrics of 70 Watts we set. This means our system would consume less power than a laptop if used in the same durations, suggesting its suitability for classroom use without causing disruptions.

7.3 Results for Website User Experience

Regarding the user experience, we have also developed a unit test for the website interface before integrating it with the stepper motor and RPi to ensure our user interface is intuitive and easy to navigate for users from both groups. Therefore, we conducted a usability test following the think-aloud protocol on 1 student and 1 professor to gain insights from both perspectives. We recorded their feedback and time used to perform a series of tasks including creating a class, adding students, modifying the class, erasing the board and opening captured images for the instructor; and navigating to the class page and viewing captured images for students. It takes 45 seconds for instructors and 7 seconds for students to complete all the required actions, which meets our metrics of 1 minute completion time. This suggests that the use of our web application could be mastered by users from both groups within a relatively short period of time, and both users provided positive feedback on the simplicity of the design. Since we have also received feedback on adding more instructions on the home page and making the navigation bar clearer following the information hierarchy, we have implemented those changes in our second iteration of the design to improve the performance of our interface even further.

7.4 Results for Overall System Test

In addition to the unit tests discussed in the previous sections, we also performed an overall system test to evaluate the performance of the entire system integrated from the subsystems with 3 instructors and 3 students. The overall system test consists of two parts. In the first part, the users were asked to perform a set of tasks in our system, and in the second part, they needed to answer some follow-up questions.

For users from the instructor group, they needed to complete the following actions:

- Create a class
- Add students with ID X, Y, Z to the class
- Erase the board
- Access the captured image of the first section
- Project the image back to the board

Then, for users from the student group, they needed to:

- Navigate to the class page for class X
- Access the captured image taken at time xx:xx

After completing those tasks, we collected feedback from the participants by asking them a series of questions. To carry out a comprehensive test on the functionality of the system, we broke down the system's functionality into the following aspects: overall latency, board cleanliness, image readability, user experience, and usefulness.

- Latency:
  - "Did you feel any noticeable lag in erasing or image capturing?"
- Board Cleanliness:
  - "Did you notice any ink marks remained on the board that prevents you from directly using the board for the next iteration of writing?"
- Image Readability:
  - "Can you read the content on the image without any difficulties?"
- User Experience:
  - "Is the website intuitive to use?"
  - "Could you locate the right place to click on for each task?"

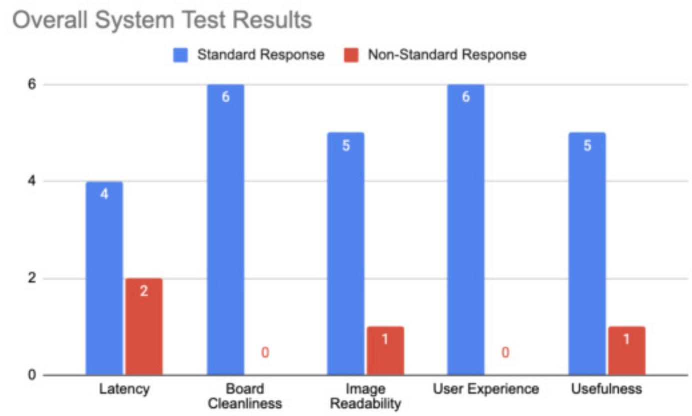

Figure 11: Answers Collected For Overall System Test

- Usefulness:
  - "Would you prefer using this system or manually erasing?"

By asking those questions, we were able to understand the usability of our system from the users' perspective. We expected to receive a standard response of "No" for latency and board cleanliness and "Yes" for image readability, user experience, and usefulness, with at most 2 non-standard responses for each section. With the results collected shown in the graph below, we have achieved the metric of at least 67% of the standard responses.

8 PROJECT MANAGEMENT

8.1 Schedule

The schedule in Fig. 14. demonstrates the process of building up the system. The arrows indicate that a previous task needs to be completed before a subsequent task. The schedule has been modified since the design report to account for shipment delays, and technical challenges faced during the process such as the mechanical setup of the system.

8.2 Team Member Responsibilities

The software and hardware parts of the system were divided into tasks based on the strengths of the group members, while group members also helped each other and collaboratively worked on the integration and testing of the system and mechanical setup.

8.2.1 Jiayi Wang

- Back-end development of the web application
- Initial motor movement design and testing (with Xiaoyu)
- Erasing latency tests (with Xiaoyu)

- Part of integration of IP camera communication with web application (with Wendy)
- Integration of RPi communication with web application
- Mechanical setup and integration of the system

8.2.2 Wendy Deng

- Front-end development of the web application
- Parts of back-end development of the web application including OAuth login and incorporation of the IP camera module
- Camera latency test and website user experience test
- Mechanical setup and integration of the system (with other team members)

8.2.3 Xiaoyu Chai

- RPi code controlling movement of motor
- Erasing latency tests and power consumption tests
- Integration of RPi with web application (with Jiayi)
- Mechanical setup and integration of the system (with other team members)

8.3 Bill of Materials and Budget

Most of the budget is spent on the purchases of hardware components such as the stepper motor, the screw rod, and the motor driver as well as the physical parts such as the board and the wood. To see the full Bill of Materials, please refer to Table 1. Among the purchases we made, those not used due to design shifts are labeled with * in the table. After the design report, we have shifted our design from two stepper motors spinning on wheels to one stepper motor rotating along the screw rod. Moreover, we have switched to a DRV8825 motor driver to achieve a higher speed. Therefore, we purchased several new motors, screw rods, and new motor drivers to account for those design changes. We have also purchased wood and nails to assemble our system.

8.4 AWS Usage

Since our team figured out a way to establish the communication between RPi and the web application without deploying the website, we decided to not request the AWS credits and ran the server locally. However, to scale the system to a wider application across different institutions in the future, the deployment of the website would be considered.

8.5 Risk Management

During the development process, we have encountered a lot of technical challenges. We were able to handle them promptly and overcome them successfully by attempting different approaches and coming up with backup plans on time.

8.5.1 Mechanical Setup and Woodwork

In our team, none of us has prior experience with mechanical engineering and woodwork including but not limited to wood cutting, screwing the rods into wood, and designing a stable wood structure. To ensure we could successfully set up the mechanical part of our design and physically connect our hardware components together, we have reached out to Techspark staff for help. We measured the dimensions of the required blocks so they could help with cutting. Moreover, we talked to one friend in mechanical engineering major and discussed which direction of screwing has the minimal risk of cracking the wood. In addition to that, we have identified a different approach in that we applied wood glues for joining thinner wood sheets that crack if we screw into them.

8.5.2 Motor Movement

Prior to the project, no one in our team had experience with robotics. Therefore, in the first iteration of our design, we proposed to use a stepper motor spinning on wheels to control the movement of erasers to achieve the functionality of the erasing board. However, as our professor pointed out, this design neglects the effect of the counteractive force of the force pressing erasers to the board and friction, which has a high chance of failing. Therefore, we discussed with a professor about alternative approaches furthermore and decided to modify our design to use a noncaptive stepper motor rotating along a screw rod instead of on wheels. Eventually, we managed to use this setup to move the eraser to erase the content on the board as we expected.

8.5.3 Performance of Motor Driver

While testing the speed of the stepper motor with various voltage and current combinations, we figured out that higher voltage and current could support our motor to move faster. However, due to the voltage constraint of the A4988 motor driver we initially used, we could not achieve the highest potential speed of our NEMA 17 stepper motor. After realizing that, we researched different options of motor drivers and decided to use a DRV8825 motor driver which can take larger voltage. With the new motor driver, we achieved a higher moving speed of the motor and decreased the latency of board erasing.

Table 1: Bill of materials

Description	Model #	Manufacturer	Quantity	Cost @	Total
Stepper Motor*	1207	Pololu	2	$18.95	$37.90
A4988 Motor Driver*	1182	Pololu	2	$13.95	$27.90
A4988 Motor Driver 10 pieces*	Photect-DriverModule-09	Photect	1	$13.49	$13.49
DRV8825 Motor Driver	2133	Pololu	2	$15.95	$15.95
Stepper Motor brackets*	2257	Pololu	2	$3.95	$7.90
Solenoid*	FLT20190821M-0051	Fielect	1	$14.99	$14.99
Raspberry Pi	RPi 4 8GB	Raspberry Pi	1	$0	$0
Projector	DH856	Vivetek	1	$0	$0
IP Camera	AT-200DW	Alptop	1	$39.99	$39.99
Wheel*	1424	Pololu	1	$5.75	$5.75
Mounting Hub*	1203	Pololu	1	$8.95	$8.95
Motor Brackets*	2257	Pololu	1	$3.95	$7.90
Whiteboard	WB3624L	Zhengzhou Aucs Co.,Ltd.	1	$31.79	$31.79
Erasers	SAN81505-8	Newell Rubbermaid Office	1	$20.99	$20.99
Battery*	DURMN21B4PK	Duracell Distributing, Inc	5	$6.48	$32.40
Battery Case*	A23	LAMPVPATH	1	$6.49	$6.49
NEMA 17 Stepper Motor	17N13S1504FF5-200RS	Stepper Online	1	$33.84	$33.84
NEMA 23 Stepper Motor*	23N22S3004HG5-250RS	Stepper Online	1	$54.58	$54.58
1/4”-20 Thread Screw Rod	99030A985	McMaster-Carr	1	$48.36	$48.36
3/8”-5 Thread Screw Rod*	99030A100	McMaster-Carr	1	$46.42	$46.42
Linear Slide Guides	SBR20	Vevor	1	$43.99	$43.99
Wood Boards	100322335	Home Depot	4	$13.47	$53.88
Screws	PTN2S1	Grip-Rite	1	$9.97	$9.97
Wood Glue	1414	Titebond	1	$9.98	$9.98
					$573.41

8.5.4 IP Camera Control

Since no one knows the use of IP cameras, another challenge we encountered was the difficulty of connecting it to the school network and controlling it through the ONVIF protocol. While the instruction only explains how to connect a camera to a network through ethernet, we reached out to the supplier of the camera and followed the steps they provided. Moreover, Wendy researched how to set up ONVIF protocol to store the image captured by the IP camera and was able to complete the image-capturing functionality of the system after attempting with different port numbers.

8.5.5 RPi Communication

Prior to this project, all of the team members had experience working with a Raspberry Pi and setting up communication between a web application and RPi. Therefore, Jiayi and Xiaoyu researched this area, and after figuring out the IP address of RPi, the server of the web application connecting to the same network with RPi could send information to RPi. However, a consequent challenge we faced was that we could not figure out a way to connect the RPi to the school network due to its required authentication, but in order to communicate with the IP camera, the server of the web application needed to connect to the school network. To address this issue, we searched for how students from other institutions overcame the same issues and managed to connect the RPi to the school network with the employment of a monitor.

9 ETHICAL ISSUES

Throughout the project, we have identified several ethical considerations we have to address and proposed solutions to address each of the issues.

One of the issues related to the safety consideration is the potential risk introduced by the hardware components of the system. Our system as an external attachment to a board might impede instructors' movement and hurt them since it extends out from the board and moves the motor along the screw rod. If the instructor is walking while lecturing, there is a high chance that they accidentally touch the rod and get hit by the motor, or bump into the attachment and cause the attachment to fall apart. To prevent this type of accident, we have screwed three wood blocks at the same height as the board behind the board to support the system and screwed all the mechanical parts tightly to minimize the risk of components falling apart. In addition to that, we added a protection layer outside of the motor and screw rod as demonstrated in the figure below, which effectively prevents users from accidentally touching the rod and the motor.

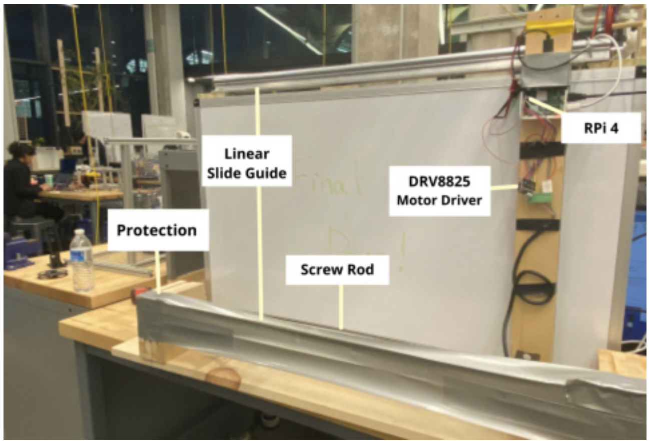

Figure 12: Implementation With Protection Layer Covering Rod and Motor

Another consideration in the aspect of privacy and security would be the risk of disclosure of class images. Since the images captured by the IP camera are stored in the database of the web application, if our website is prone to hackers' attacks, unauthorized individuals would be able to access the class information, violating the copyright of the institutions. To address the issue, we decided to better secure our web application by sanitizing users' input and rejecting any input with symbols other than dash and comma to prevent injection attacks, and adding a CSRF token to our form to prevent cross-site request forgery.

Moreover, one of the common issues related to the public welfare aspect is that technologies are typically less accessible to individuals or groups with lower incomes. With the use of motors, cameras, and projectors, the accessibility of our system might be limited to a certain range of educational institutions, which might contribute to economic inequality. To address this issue, we will select subparts with lower cost and self-assemble the attachment instead of relying on high-cost existing technologies such as robotic arms to minimize the total cost of the systems to be less than $200. In this way, we can make the system more accessible to a wider range of the public while maintaining most of the functionalities we desire to have.

10 RELATED WORK

There are existing automatic board erasers designed with a wide range of mechanical approaches such as using DC gear motor controlled by Arduino in the design of Muthusamy et al. (2018) and using an actuator to drive the pinions to erase a certain section of the board as demonstrated in the design by Martinez et al. (2018). In contrast to conventional automatic board erasers, our product introduces the functionality of image capturing, accessing, and projection, allowing for future reference of the erased content via the website, while the incorporation of the website also makes the interaction between users and the system more intuitive.

11 SUMMARY

Overall, we are confident that our virtual board system has achieved the MVP and will bring convenience to both instructors and students in a classroom setting with the ability to reference erased board content and automate the board erasing process, aligning with our envisioned goals.

11.1 Future work

Potential extensions of the project involve transitioning to a screw rod with a larger pitch size to optimize the erasing speed and deploy the website for public use. However, since we have successfully developed a fully functioning prototype, future work can easily progress once the compatible components are identified.

11.2 Lessons Learned

One of the most important lessons our team learned during the project is to always prepare for the changes and have backup plans. Since the proposal, we have pivoted the vision of our project 3 times, leading to a series of use cases and design changes. Moreover, the unexpected damage to the hardware components also slowed us down while building the system. With the ability to adapt to change more promptly, we could potentially overcome those technical challenges faster and incorporate more features as post-MVP.

Glossary of Acronyms

- MVP - Minimum Viable Product
- ONVIF – Open Network Video Interface Forum
- PWM - Pulse Width Modulation
- RPi – Raspberry Pi
- IP - Internet Protocol
- API - Application Programming Interface
- HTML - Hypertext Markup Language
- CSS - Cascading Style Sheets

References

1. Martinez, D. (2018). Automatic dry eraser: Report. UT Austin Wikis. https://wikis.utexas.edu/x/ig5cCw
2. Muthusamy, Suresh Meenakumari, R Raghavendran, P.s.Raghavendran Gowrishankar, V Karthikeyan, P Vadivel, Surendar Jagan, C Prashant, N. (2018). Design and Development of Automatic Whiteboard Cleaner for Effective Cleaning Mechanism using Arduino. IJIREEICE. 6. 30-33. 10.17148/IJIREEICE.2018.696.

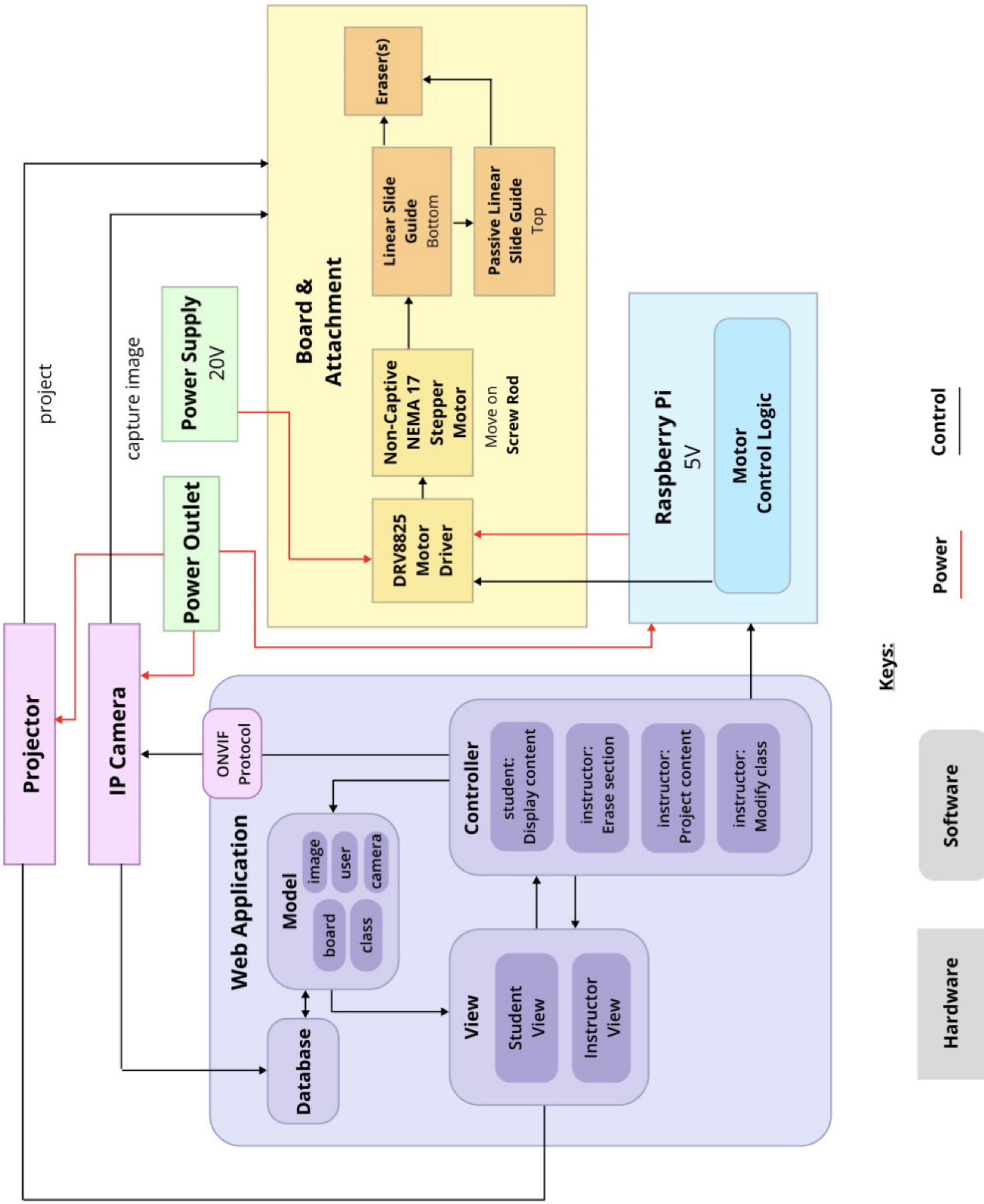

Figure 13: A full-page version of the same system block diagram as depicted earlier.

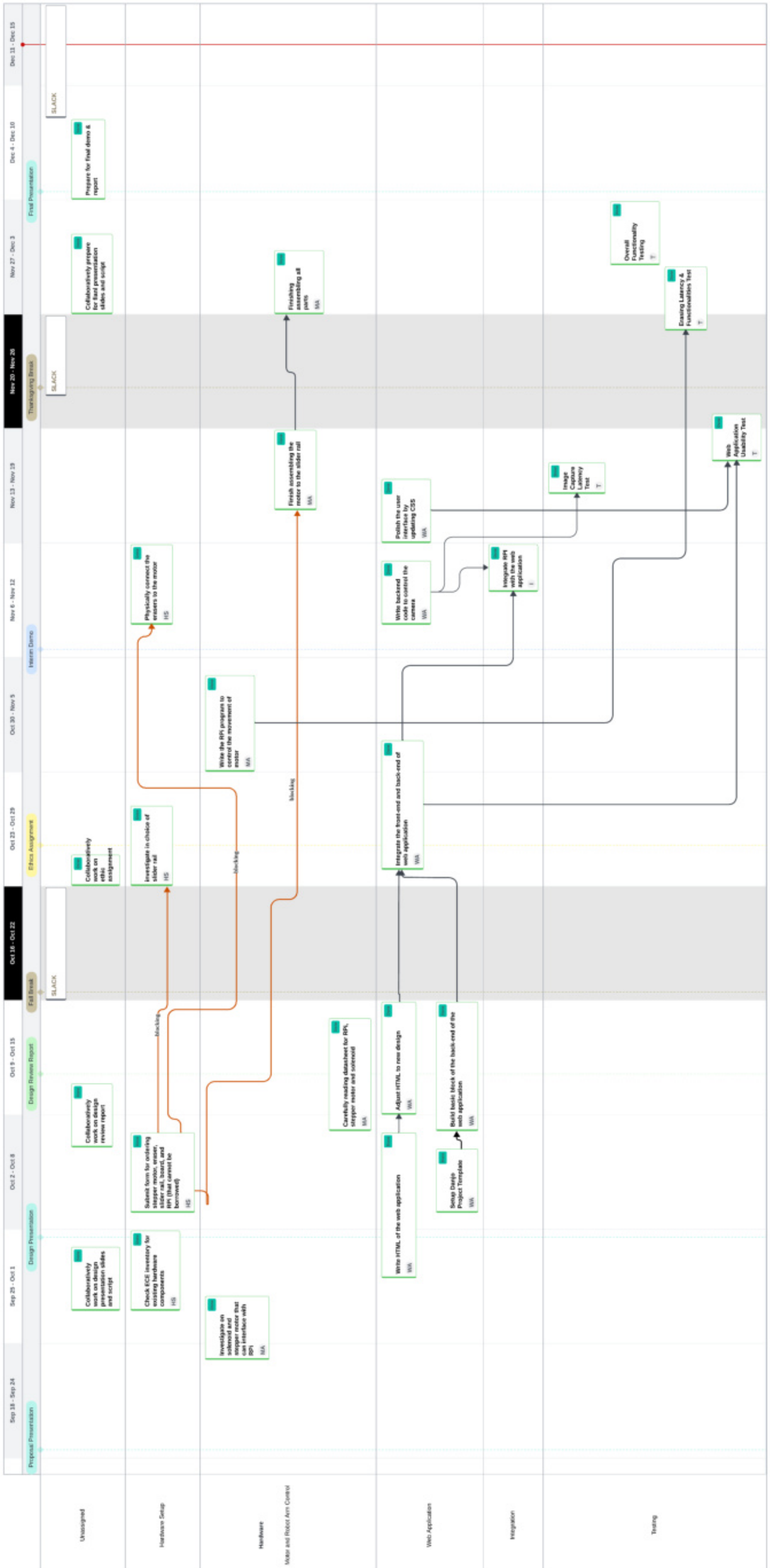

Figure 14: Gantt Chart