Board Buddy Project Proposal

University of Illinois Urbana-Champaign

ECE445 - Spring 2025

Team 34

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1. Introduction

1.1 Problem

Teachers too often waste precious class time erasing chalkboards and whiteboards. As any teacher or student can attest, this hiatus in class time hinders the ability to stay engaged and on track. Throughout the team's schooling experience, we have witnessed many teachers and students lose their train of thought during an erasing hiatus. There is a need for an erasing device that can work in parallel with the class, ensuring no moment is wasted in any learning environment.

While researching this project in particular, the team gained valuable insight that solidified our desire to solve this problem. The team had learned that in the Electrical and Computer Engineering Building, and the entire campus, custodians spend hours throughout the night erasing the boards for classes the following day. This not only wastes the time of custodians who have much more important tasks to undertake but also wastes the money of the university as it pays to have someone erase a board.

1.2 Solution

The team has proposed a multi-fold device solution to these problems. Dubbed the Board Buddy, the device will act as an automatic erasing apparatus attachable to any whiteboard or chalkboard in the Electrical and Computer Engineering Building. As the mounting uses a magnetic solution, this erasing device can also be implemented on most educational boards currently made.

The Board Buddy will be integrated into a user-friendly application that will allow the wireless operation of the device. This application will allow remote activation so that the user will only need to be near the room to erase the board. This will save the custodians hours of nightly work. The device will also allow for immediate activation upon user input so that teachers can seamlessly transition from topic to topic on a busy board. This device will go even further to allow for timed board erasing. Being set to erase the board at a certain time, teachers can integrate this device into their schedule so that they enter a classroom with a clean board even if they have a midday class.

1.3 Visual Aid

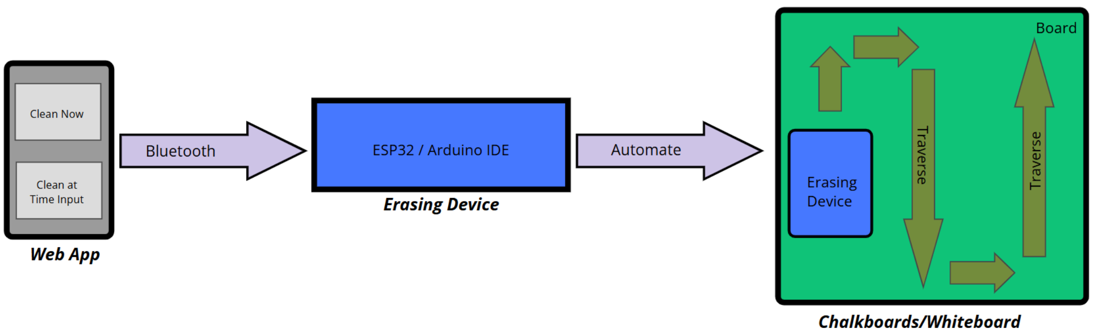

Figure 1

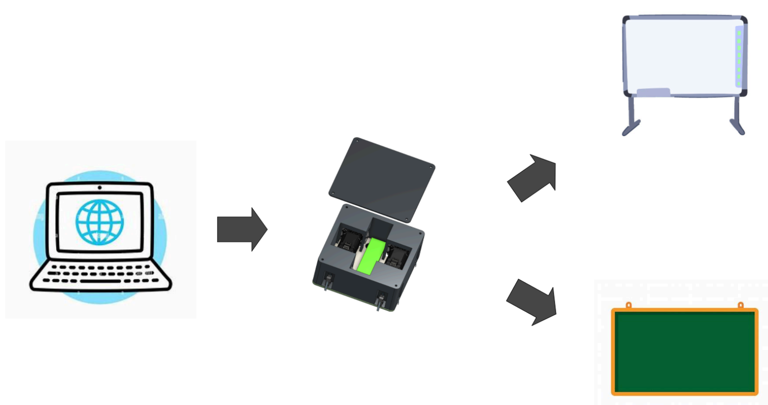

Figure 2

Figure 3

Figure 4

Figure 5

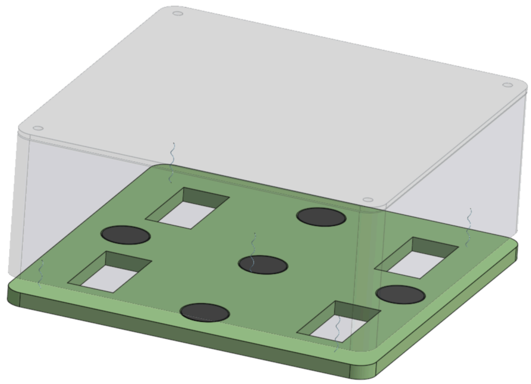

Figure 6

Figure 7

Figure 8

1.4 High-level Requirements List

There are various things that our project must do to operate as planned, but there are three quantitative characteristics in particular that it must exhibit to solve the mentioned problems. These characteristics can be referenced in the bulleted list below:

High-Level Requirements	
1	The most significant characteristic is that this device must erase the majority of the residue in a single pass. This will be tested by drawing filled shapes on the board and measuring the area of residue before and after the passthrough. The device must erase 90% of the residue each time.
2	The next quantitative characteristic is that it must pass through a typical ECEB educational board (4' x 8') in under two minutes. This is to ensure that it truly does not affect class time. An average educational board is four feet by eight feet meaning that we would need to traverse the board at a rate of 4.8 inches per second. If we use 3-inch diameter wheels we would need 0.51 RPS which is around 30.6 RPMs. These calculations will be adjusted based on the final weight of the device along with how many magnets we will end up using inside this device.
3	The final significant characteristic is that it must have app integration. This integration will allow for remote and timed activation. It will have an established connection between a Web app and the ESP-32 module that will have negligible latency (within 10 ms).

Table 1

2. Design

2.1 Block Diagram

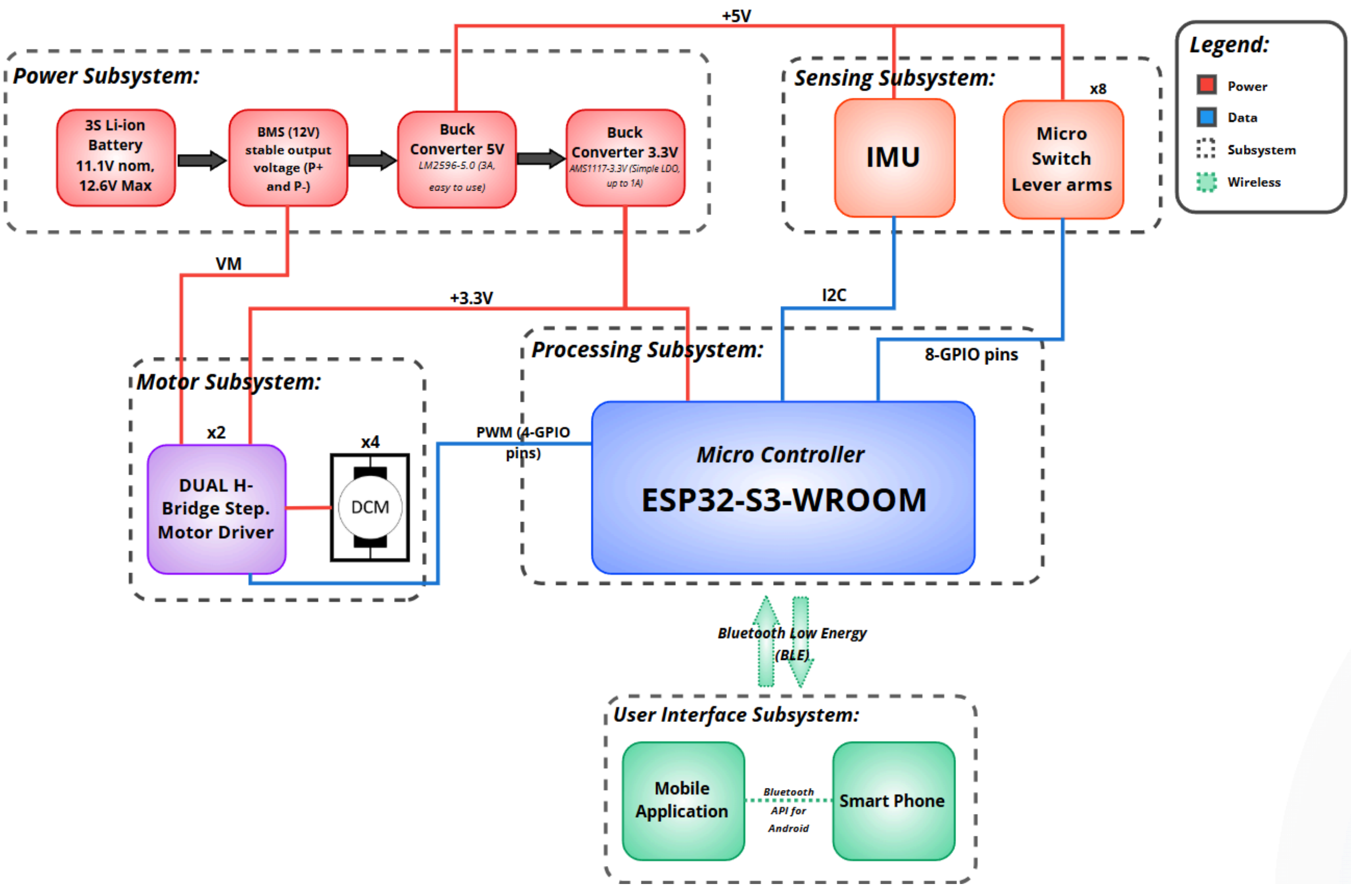

Figure 9

2.2 Subsystem Overview

2.2.1 Power Subsystem:

This subsystem manages the power of the Lithium-Ion battery so that each of our boards/peripherals is powered. The 12V battery input will be stepped down to 5V and 3.3V. The 12V out of the battery management system will be directly fed into both of the motor driver ICs as the motor supply voltage, while the 3.3V and 5V will be the logic-level voltage for our other ICs/sensors.

2.2.2 Sensing Subsystem:

Our sensing subsystem will consist of our accelerometer to provide orientational data in the *x* and *y* coordinate system, and our limit switches will feel out the operational edges of the board. The accelerometer will detect off-axis movement from the device which will then auto-correct to stay on course(drift correction). The limit switches will be utilized in our edge-detecting algorithm where if corners/sides are actuated, we will change directions.

2.2.3 Processing Subsystem:

For this project will be utilizing the ESP32. The ESP32 serves as the central controller, handling sensor data acquisition, actuator control, and motor driving. It communicates with the IMU using the I2C protocol, where GPIO is assigned to SDA and SCL. This allows for real-time orientation and motion data collection, which is essential for system stability and control. In addition to the IMU, the ESP32 interfaces with eight microswitch actuators via dedicated GPIO pins. These microswitches function as limit switches or event triggers, providing feedback on actuator positions. They are configured with pull-up resistors to ensure reliable state detection. For motor control, the ESP32 generates four PWM signals directed to 2, dual H-driver stepper motor ICs. These signals regulate motor speed and direction, ensuring smooth and precise motion control. The PWM signals are managed using the ESP32's hardware timers to achieve efficient and stable performance.

2.2.4 Motor Subsystem:

This subsystem is responsible for the precise movement of the Board Buddy around the board. This system will move the Board Buddy in an S-formation around the board so that every corner is covered. The motors will also receive data from the ESP32 via PWM. This will allow the Board Buddy to autocorrect in off-axis events and limit switch actuation.

2.2.5 User Interface Subsystem:

This subsystem will allow users to schedule erasings when desired and will allow manual use of the Board Buddy device. It will also store a log of all the uses of the Board Buddy and show the device's status. Another key feature we will include notifications to let you know before the board is about to be erased and it will allow the user to cancel the erasing in case a teacher runs past their specified schedule.

2.3 Subsystem Requirements

2.3.1 Power Subsystem:

1. Provide a stable output of 12V +/- 0.1V (1400 mA) (*for motors*)
2. Provide a stable output of 5V +/- 0.1V (3.8 mA) (IMU and limit switch)
3. Provide a stable output of 3.3V +/- 0.1V (740 mA) (Microcontroller and H-Driver ICs)

2.3.2 Sensing Subsystem:

1. The IMU must provide x and y orientation data with an accuracy of ±2°.
2. The system must update orientation estimates at a frequency of at least 50 Hz.
3. The IMU must detect gradual changes in motion (e.g., off-axis drift) and trigger an appropriate response within 200 ms.
4. The IMU data must be processed using a sensor fusion algorithm (e.g., complementary filter, Kalman filter) to reduce drift.
5. Each limit switch must detect contact within 10 ms of impact.
6. The system must stop movement within 50 ms of a limit switch activation.

2.3.3 Processing Subsystem:

1. ESP32 should take in sensor readings/inputs and provide the correct output to motors (within the time restrictions outlined in Section 2.3.2).
2. The UI provided by the configured app should communicate with the ESP32 as outlined in this document with a latency less than 10ms.
    a. The flash storage or shared preferences should store at least 10 scheduled erasing events.

2.3.4 Motor Subsystem:

1. Should be able to adjust speed via ESP32 direction based on actuation of lever arms and IMU data.
2. Needs to be able to support an omnidirectional movement across the board.
3. To avoid disrupting class, the subsystem cannot exceed 40 dB at 1 meter (a whisper is 30 dB).
4. To pass the high-level requirement, the device needs to be able to move at 4.8 inches per second.
    a. If we use 3-inch diameter wheels we would need 0.51 RPS which is around 30.6 RPMs.
        i. This value should be taken as a minimum as we need to further account for magnetic forces and weight.

2.3.5 User Interface Subsystem:

1. Use Flutter as a programming language to make a Chrome, Edge, or Windows app.
2. Must have a user interface that allows for scheduling of erasing of the board. This should store at least 10 scheduled erasing events.
3. Must be able to store a history log of erasings in ESP flash drive or shared preferences.
4. Be able to communicate with the ESP-32 module through Bluetooth.
    a. Must maintain a stable Bluetooth connection within a range of 10 meters.
    b. Must establish a connection within 5 seconds of the prompt.
5. Typical Latency between a local web server and ESP-32 ranges from 1-10ms.
6. Real-Time Status Changes involving battery life or charging status of the device, determining if the device is currently being used which would allow us to turn off the device automatically.

2.4 Tolerance Analysis

Throughout brainstorming possible issues to overcome, a major recurring issue was found: the mounting capabilities of the magnets. The team was challenged to run various tests to ensure the theory behind our design was sound. After researching and buying the ideal neodymium magnets for our design, we acquired an IoLab to run various intricate magnetic tests to ensure their capabilities. First, we measured the magnetic force of two magnets and a typical whiteboard (Figure 10).

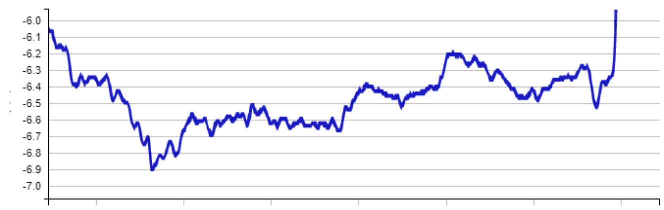

Figure 10

We experimentally received an average of 6.6N between the two magnets and the board, so we implemented Newton's Second Law to determine the mass the magnets can withhold.

$$F = m * a$$

$$m = \frac{6.6N}{9.81 \frac{m}{s^2}} = 672.8 \text{ g}$$

The team was pleased to learn that the design is feasible despite this significant mass, but we still worried that it may not be enough. Therefore, the team procured a third magnet to see if the force would scale linearly with the number of magnets used. The following figure (Figure 11) shows this experiment.

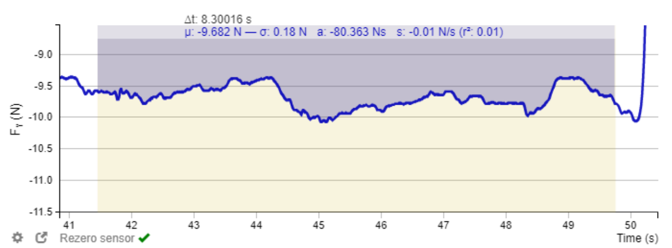

Figure 11

After experimentally receiving an average of 9.6N between the two magnets and the board, we once again applied Newton's Second Law to determine the mass the magnets can withhold.

$$F = m * a$$

$$m = \frac{9.6N}{9.81\,\frac{m}{s^2}} = 978.6 \text{ g}$$

Seeing that not only the force scales linearly with the amount of magnets used but also that it only takes three magnets to nearly hold a kilogram, the team was pleased with the theory behind our design (10 magnets total).

$$Total\ Mass\ (10\ magnets) = 3{,}364 \text{ g} = 7.42 \text{ pounds}$$

Another subsystem we are potentially risky is our power subsystem. Our design will employ the use of three different voltage levels: 12V, 5V, and 3.3V with the potential for a lot of power consumed. Ensuring that we can supply the needed current/voltages for the components requiring these power plains is crucial.

Voltage Distribution		
3.3V	**5V**	**12V**
• ESP 32 (240-740 mA) • Dual H bridge Driver(30 µA) x2	• IMU *MPU 6050* (3.8 mA at full pwr) • Microswitch Lever arm (**N/A**)	• Stepper motor x4 (350 mA)

Table 2

$$I_{3.3_{Max}} = 740\ mA\ (2) + 30\ \mu A \cong 740mA$$

$$I_{5_{Max}} = 3.8\ mA$$

$$I_{12_{Max}} = 350(4)\ mA \cong 1400\ mA$$

$$I_{TOT} \cong 2143.8 \text{ mA}$$

We also would need a battery that provides us with both longevity and weight savings. We believe a battery of this size will fit our needs just fine:

$$12V * 2.1438A = 25.7256\ W$$

Calculating Battery Capacity:

Battery Considerations		
Power Requirement	**Voltage**	**Runtime**
25.7256 W	12 V	30 minutes

Table 3

To determine the required battery capacity for the device, we need to get two key capacity values, Watt-Hours and Amp-Hours.

$$\text{Battery Capacity (in watt-hours, Wh)} = \text{Power (W)} \times \text{Time (h)}$$

$$= 25.7256\ W \times 0.5\ h = 12.8628\ Wh$$

$$\text{Battery Capacity (Ah)} = \text{Battery Capacity (Wh)} \div \text{Voltage (V)}$$

$$= 12.8628\ Wh \div 12\ V \approx 1.0719\ Ah$$

Considering Battery Discharge Limits:

To prolong battery life and prevent deep discharge, it's advisable to use only 50% of the battery's capacity. Therefore, the recommended battery capacity should be:

$$\textit{Recommended Battery Capacity} = 1.0719\ Ah \div 0.5 \approx 2.1438\ Ah$$

In conclusion, choosing parts that exceed our criteria for voltages/currents is paramount for our design as we are utilizing many high/low power devices.

Final Determinations Following Tolerance Analysis			
Magnetic Consideration	**Weight Consideration**	**Battery Capacity**	**Runtime**
10 magnets 33 Newtons	7.42 pounds 3,364 grams	2.1438 Amp-Hours 25.7256 Watt-Hours	30 minutes

Table 4

3. Ethics and Safety

IEEE Code of Ethics (IEEE Code of Ethics, 2025)

[I.1] In regards to IEEE Code I.1, the team must ensure the safety and privacy of the public. To do this, we must take into account the privacy of the device application so we do not release sensitive information. Furthermore, regarding the safety of the public, we must take into account the magnetic aspect of the project. We must ensure that the magnet is not strong enough to damage electronics, especially medical electronics. On the other hand, we must ensure that the magnet is strong enough to hold the device so as to not fall and injure anyone.

[I.5] Pertaining to the IEEE Code I.5, we must be diligent in seeking and accepting honest criticism of our work. Moreover, we must ensure that we state realistic claims of our device's capability while properly crediting the work of others. To do this, we will reach out to the course assistance networks as often as we need while recording honest data to be published with our work. In publishing this work, we will ensure that references are always given to any party that assisted.

ACM Code of Ethics (ACM Code of Ethics, 2025)

[1.6] A particular ACM Code of Ethics, Code 1.6, will be of significant importance in this project. As this device will have Bluetooth capabilities, we must ensure that the application connection respects the privacy of the user. We must be sure to only use the minimum amount of personal information to have the application work as desired.

University of Illinois at Urbana-Champaign Student Code of Ethics (Student Code, 2025)

[1.4] Article 1 Part 4, Academic Integrity, is a code that the team strives to uphold. In this project, the same as many projects before, we must uphold academic integrity. We must ensure that we accredit any affiliated parties or released works that have assisted us.

4. References

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