

**ERASERBOT V3.0: OPTIMIZATION OF AN AUTOMATED BLACKBOARD ERASER**

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**ABSTRACT**

In educational settings, upholding cleanliness and guaranteeing effective classroom management is vital for successful teaching and learning. Conventional blackboard erasing requires considerable effort, takes a lot of time, and can expose educators to chalk dust, potentially leading to health issues over time. This research introduces the creation and assessment of EraserBot V3.0, an automated blackboard eraser aimed at enhancing erasing capability, efficiency, and dependability via automation. The design employs two Nema 17 stepper motors linked to GT2 timing belts for coordinated horizontal motion and a DC motor connected to paint rollers for the erasing function. An IR receiver paired with a remote control enables the system to function in one full cycle, with a vacuum cleaner subsequently turned on to gather chalk dust. An Arduino Uno R3 acts as the primary controller, complemented by stepper motor drivers and a toggle switch for controlling the main power. The blackboard is made of plywood and is held up by a tubular steel frame measuring 2"x1". The system underwent testing against manual erasing and earlier versions of EraserBot over four trials. In every trial, the blackboard was completely wiped clean within a 20-second interval. Findings validated the notable enhancement in performance and dependability of EraserBot V3.0 compared to previous techniques. The research effectively created a working prototype that automates the cleaning process, contributing to safer and tidier classroom settings.

*Keywords:* Automation, blackboard eraser, stepper motor, vacuum system, Arduino, chalk dust collection

**INTRODUCTION**

Blackboards are still a key tool in many classrooms despite the rise of digital alternatives. They are easy to use and allow teachers to present lessons interactively. However, erasing the board manually is a time-consuming task that interrupts the flow of teaching and exposes educators to chalk dust, which could lead to health issues like respiratory problems over time.

In today's classrooms, there's a growing push to incorporate technology to make things more efficient and comfortable for both teachers and students. One area that could benefit from automation is the process of erasing blackboards. By automating this simple but repetitive task, teachers could save time and reduce their exposure to chalk dust, creating a healthier learning environment. Furthermore, chalk dust is bad for both humans and machinery. Projectors and other classroom equipment are prone to dust accumulation from chalk dust, which is not particularly dense. One of the causes of the equipment's heat output is this: if it produces a lot of heat, it may wear out before the actual life is up. Classrooms can be more modern and avoid the issues mentioned above by using the automated blackboard eraser.

This research focused on improving the previous study, EraserBot v2.0. EraserBot v2.0 represents a significant improvement in automated blackboard cleaning technology compared to its predecessor, EraserBot v1.0. The study aimed to increase the working capability of the previous project, lessen the work for the instructors from erasing the board, which is causing disturbances during the discussion, and give them more time to finish their topic. It is also an eco-friendly erasing machine because the covers on each side of the erasing mechanism trap the dust. EraserBot v2.0 used two motors for a more precise erasing mechanism, a confined space with covers on each side of the erasing mechanism to lessen the scattered dust from the chalk,

changing the chalkboard eraser with a rotary duster eraser, and made the design better, having the compartment for the eraser to use the whole surface area of the blackboard. The system was equipped with a toggle switch that served as the main power switch for the entire system. Three push buttons were installed in the system: button 1 (start button), button 2 (stop button), and button 3 (reset button). The system powers up when the toggle switch is turned on. When the start button is pressed, the eraser will erase the board from left to right, and vice versa. When the stop button is pressed, the eraser will stop erasing as the motor stops rotating. When the reset button is pressed, the eraser will return to its home base position, which is on the left side of the blackboard. The system used two motors: one for vertical motion and the other for horizontal motion. To move the eraser horizontally, a Nema17 motor with a DRV8825 Breakout Board was employed to control its left and right movement. It was designed to have a duration of eight seconds for the initial cycle and four seconds for the subsequent cycle. A Nema23 motor paired with a TB6600 Stepper Motor Driver was used for the eraser's vertical rotational motion.

The goal was to design a device that thoroughly and quickly erases blackboards. This equipment aimed to improve the teaching process by allowing educators to spend more time focusing on education without interruptions from manual erasing.

This project improves classroom practices by utilizing technology to handle repetitive cleaning. The ultimate result should be an improved classroom experience, making it more efficient and user-friendly for both teachers and students.

## Objectives of the Study

### General Objectives:

To enhance the design, functionality, and efficiency of the EraserBot v2.0 by optimizing its automated blackboard erasing capabilities and integrating a dust-collection system.

### Specific Objectives:

- To minimize airborne particles in the classroom by integrating a more effective vacuum system that efficiently collects chalk dust during the erasing process.
- To improve the efficiency of blackboard cleaning, ensuring that the system erases the board thoroughly.

These objectives aimed at creating a practical, innovative solution that benefits educators and enhances the overall classroom experience.

## Significance of the Study

This study on the optimization of an automated blackboard eraser is significant for various stakeholders in educational environments. By automating the task of erasing blackboards, this project aimed to deliver practical, efficiency-based benefits to teachers, students, and educational institutions.

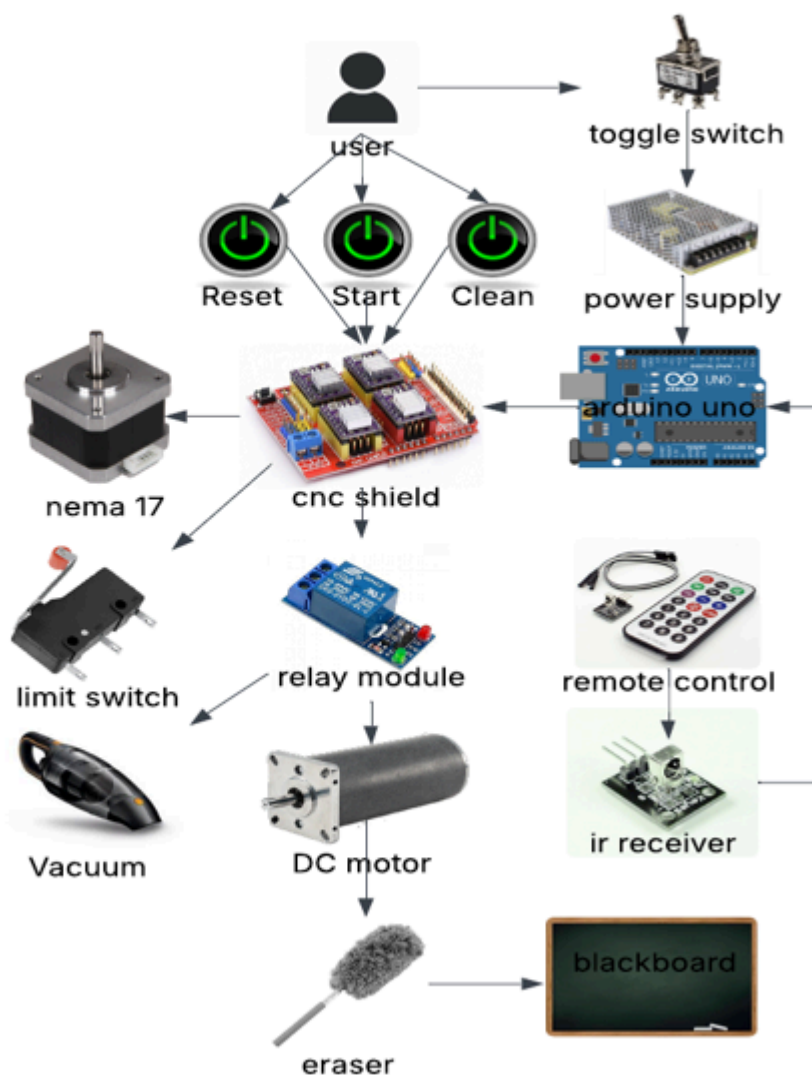
- **For Teachers** - The automated blackboard eraser saves valuable time during lessons by eliminating the need for manual board cleaning. Teachers will be able to focus more on teaching and engaging with students without interruptions.
- **For Students** - A more streamlined and efficient classroom environment means fewer disruptions during lessons. This contributes to a smoother flow of instruction, allowing students to stay focused and engaged.
- **For Educational Institutions** - Schools and universities that adopt this automated system will benefit from enhanced classroom management. The device could reduce

wear and tear on traditional blackboards and eliminate the need for frequent maintenance or cleaning services.

- **For Future Research** - The findings and developments of this study can serve as a reference for future innovations in classroom technology. This study can inspire further research into improving automated systems in educational settings, contributing to the ongoing modernization of learning environments.

**Discussion of Framework**

**Figure 1**  
*Diagram Interconnection of the Proposed Project*



A microcontroller-based automated blackboard cleaning system, EraserBot v3.0 is made to be effective, accurate, and user-friendly in classrooms and present settings. The Arduino Uno, which serves as the main control unit coordinating several physical components, is at the center of the system. A panel with reset, start, and clean buttons allows the user to start system operations. An extra toggle switch manages the primary power source. These user inputs make both manual and semi-autonomous operations possible.

A Nema17 stepper motor coupled to a CNC shield powers the cleaning mechanism's linear axis, allowing the eraser to move horizontally under control. If future upgrades are considered, the CNC shield increases the system's capability for coordinated multi-axis control and streamlines stepper motor connections. To avoid over-travel and enable accurate repositioning after resets, a limit switch defines a reference home position.

A DC motor pushes the eraser head up against the blackboard surface to wipe vertically. A relay module controls this motor, and a vacuum machine removes chalk dust. The Arduino can securely and effectively switch high-power devices thanks to the relay. Wireless capability is enabled by an infrared receiver and remote control, improving usability by allowing teachers to initiate operations remotely.

Overall, EraserBot v3.0 offers a dependable automated cleaning solution through the careful integration of control electronics, mechanical drive systems, and user interface elements. Future iterations integrating sensors, wireless connection, or AI-driven behavior will have a solid foundation thanks to it.

### Scope

The scope of this study is on the design, development, and optimization of an automated blackboard eraser system. The primary goal was to create a device that efficiently erases blackboards, thereby improving classroom efficiency and reducing exposure to chalk dust for teachers and students. The study covered the following areas:

- **Design and Development:** The project involved creating a functional prototype that integrates both erasing and dust-collection mechanisms. This included selecting materials, developing the mechanical and electronic components, and ensuring the system operates smoothly in classroom settings.
- **Functionality Testing:** The study tested the eraser's ability to clean various blackboard surfaces and collect dust effectively.
- **Improving the Design and Features of EraserBot V2.0:** Enhancement in mechanical design, integrating remote control and vacuum system to collect chalk dust.

### Delimitation

The study was limited to the following:

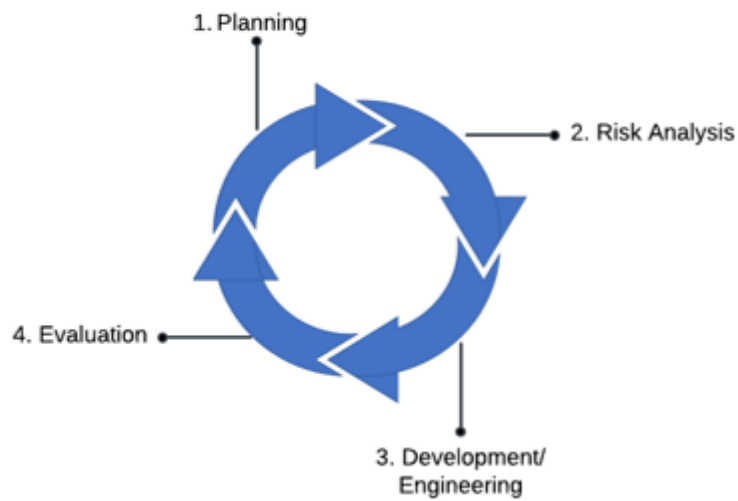
- **Limited to Traditional Blackboards:** The study focused only on traditional blackboards that use chalk. Whiteboards, digital boards, or other writing surfaces were not included in the scope of this project.
- **Classroom Setting:** Testing of the automated blackboard eraser primarily took place in a controlled classroom environment. Variations in environmental factors such as humidity or chalk quality may affect performance. Still, they were not be the main focus of this research.
- **Cost and Energy Efficiency:** While efforts were made to use affordable and energy-efficient components, the study did not focus on comprehensive cost analysis or energy consumption beyond the prototype stage.

## METHODOLOGY

### Research Design

The study's research design followed the spiral methodology. This method outlines the phases of creating a hardware device, from planning to deployment.

**Figure 2**  
*Spiral Methodology*



With the spiral methodology, EraserBot v3.0 developed through iterative cycles of continuous refinement, enabling the team to address risks and enhance the system gradually. During the planning phase, the team recognized the drawbacks and health hazards of manually erasing blackboards, particularly exposure to chalk dust. The main goals were to create an automated system that could accurately detect boundaries, quickly erase them, and efficiently collect chalk dust using a built-in vacuum. The team collected feedback from teachers and students to ensure the system met classroom needs while remaining easy to use and safe.

Specific requirements were listed, emphasizing user preferences such as user-friendliness and security, while also taking into account input from teachers and students.

During the risk analysis stage, the team identified potential issues such as motor failures, imprecise boundary identification, ineffective dust collection, and difficulties with software merging. Mitigation plans involved obtaining dependable components, developing secondary hardware designs, and conducting preliminary subsystem testing. This stage also included determining if the suggested elements were practical and examining different methods to reach the intended results.

Incremental implementation of hardware and software took place during the development phase. The team assembled the motorized eraser mechanism, incorporated boundary-sensing sensors, and coded the Arduino microcontroller to coordinate the hardware with user commands. Refinements were made in each development cycle based on test results. As an example, modifications were made to the vacuum system to enhance dust collection effectiveness and to the motor calibration for more seamless erasing movements.

The assessment stage focused on thorough testing and user input. The system's speed, precision, and dust-collection performance were measured against manual erasing and the previous model, EraserBot v2.0. Continuous improvements were made to the design through iterative feedback cycles. Utilizing the spiral methodology, the team effectively created a refined prototype that tackles risks and guarantees dependability, effectiveness, and usefulness in actual classroom settings.

**Figure 3**  
*Flowchart of the System*

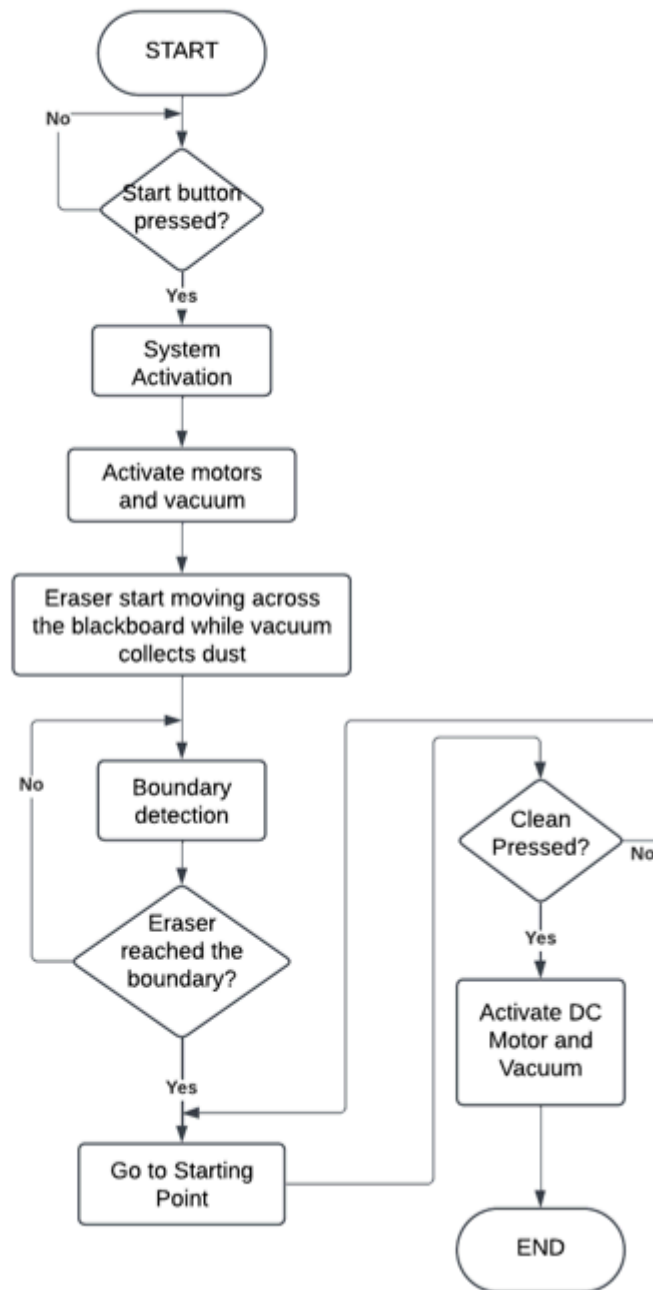


Figure 3 shows the operational steps of an automated system for erasing and cleaning blackboards, specifically EraserBot v3.0. It highlights the logic for activating the system, managing motor functions, and executing cleaning procedures through user input and sensor feedback.

The process starts with a START node, signifying that the system is idle. It then verifies whether the start button has been pressed. If the button remains unpressed, the system

continues to loop, persistently checking for user interaction. Once the button is pressed, the system moves to the system activation state, booting up the required components.

After system activation, the flow moves to activate motors and vacuum, which energizes the stepper motors that control the eraser's movement and activates the vacuum for dust collection. Next, the eraser begins its operation: "Eraser starts moving across the blackboard while vacuum collects dust," indicating that the eraser glides over the board's surface while simultaneously cleaning and vacuuming.

The system then performs boundary detection with sensors or limit switches. If the eraser has not yet reached the boundary, it loops back to continue its movement and cleaning. Once the eraser hits the boundary, the flow shifts to go to starting point, guiding the eraser to return to its original position, getting ready for another cycle, or awaiting further commands.

### **Research Locale**

The research took place at Saint Mary's University, particularly in classrooms that have traditional chalkboards. This location was selected because it typifies where the EraserBot v3.0 will be used. The establishment provides a controlled environment to test and assess the system's functionality in real-world scenarios, ensuring the relevance and usefulness of the results.

### **Research Participants**

Teachers and students who will primarily use the EraserBot v3.0 were the participants in this research. Teachers engaged with the system in class, using the automated blackboard eraser to wipe the board without having to do it by hand. Students, in contrast, offered input on how effective the system was in terms of user experience. In a typical classroom setting, both teachers and students will assess the system's usability, convenience, and overall performance. Their input will play a key role in determining whether EraserBot v3.0 meets the classroom's practical requirements and provides a smooth solution for erasing blackboards and collecting dust.

### **Research Instrument and Tools**

The main tool for this research was the fully developed version of EraserBot v3.0. The main elements included the Arduino Uno microcontroller, stepper motors, a vacuum dust collection system, and safety limit switches. The model was developed and trialed to automate the cleaning of blackboards and the collection of chalk dust. Information collected while in use, like how well it cleans and the rate at which it collects dust, were documented and assessed to determine how well the prototype was working. Software tools such as Microsoft Excel were used to document results and support analysis and validation of the system's functionality.

### **Data Gathering Procedure**

The researchers used a systematic approach to gather and examine data to assess the effectiveness of EraserBot v3.0. Initially, the preparation stage included finding a chalkboard with dimensions comparable to those in the Engineering Building classrooms (1.16 meters by 2.38 meters). The researchers ensured that all components of EraserBot v3.0, including the eraser, vacuum system, and control mechanisms, functioned properly. Tables already created, such as Tables 1, 2, 3, and 4, were used to record performance metrics such as speed, accuracy, and cleanliness.

In the engagement phase, four individuals were selected to manually erase the blackboard. Each person cleared the board, and the time taken was noted in four attempts. EraserBot v3.0 performed identical tasks in controlled settings, evaluating its speed and cleanliness in each trial, conducted five times to maintain consistency. Furthermore, EraserBot

v3.0 was compared to v2.0 and v1 in comparative trials. In the final stage, the collected data was analyzed by averaging the recorded times and examining the results to compare manual erasing with automated methods and to evaluate enhancements from previous versions. The efficiency of the vacuum system was evaluated by checking the blackboard and the surrounding area for any remaining chalk dust. The data were systematically entered into the tables and then analyzed to find ways to improve the prototype in line with the project's goals.

**Table 1**  
*Significance of Time*

Type	Time (seconds)				
	Trial 1	Trial 2	Trial 3	Trial 4	Average
Manual Erasing					
EraserBot v3.0					

Based on Table 1, proponents can observe a notable discrepancy in time between manually erasing and using the EraserBot v3.0. To start, the researchers had to find out how long it took each person to clean the board. Because everyone is unique, four people were selected to erase the blackboard using the traditional method. Once the researchers had timed the process, they evaluated (1) manual erasing versus EraserBot v3.0 and (2) EraserBot v3.0 versus EraserBot and EraserBot v2.0.

**Table 2**  
*Significance of Time (EraserBot v2.0 VS EraserBot v3.0)*

Type	Time (seconds)				
	Trial 1	Trial 2	Trial 3	Trial 4	Average
EraserBot v2.0	24	24	24	24	24
EraserBot v3.0					

The outcome of Table 2 determined the necessity of making changes to the prototype. Once the researchers collected data from Table 3, they tested the two methods four times. Using four trials, the researchers were able to achieve consistency in comparing the manual erasing with EraserBot v3.0, as well as comparing EraserBot v3.0 with both EraserBot and EraserBot v2.0.

**Table 3**  
*Significance of Precision*

Type	Attempts				Average
	Trial 1	Trial 2	Trial 3	Trial 4	
Manual Erasing (Input Average time)					
EraserBot v3.0 (Average time)					

**Table 4**  
*Significance of Precision (EraserBot v2.0 versus EraserBot v3.0)*

Type	Attempts				Average
	Trial 1	Trial 2	Trial 3	Trial 4	
EraserBot v2.0 (Average time)	24.0 (Cleaned)	24.0 (Cleaned)	24.0 (Cleaned)	24.0 (Cleaned)	<b>24.0 (Cleaned)</b>
EraserBot v3.0					

After waiting for the average time, the researchers manually checked if the board has been completely erased. Data were encoded into the table by marking it as either "Cleaned" or "Not Cleaned."

Just like collecting data, erasing manually was done similarly. The participants operated the EraserBot v3.0 for a typical duration, monitoring whether the board's output indicated it is "Cleaned" or "Not Cleaned."

**Treatment of Data**

The researchers collected data through timed trials to evaluate the effectiveness of manual erasing, EraserBot v2.0, and EraserBot v3.0. Every technique underwent five tests to guarantee reliability and consider potential fluctuations in performance or external conditions. The duration of cleaning the blackboard was timed with a stopwatch, and the findings were recorded in Tables 4 and 5. Table 4 concentrated on comparing manual erasing with every iteration of the EraserBot V3.0. In contrast, Table 5 focused on assessing the enhancements across the different versions of the EraserBot.

The average time taken for each method was be determined by analyzing the data from all five trials using this formula:

$$Average\ Time = \frac{Trial\ 1 + Trial\ 2 + Trial\ 3 + Trial\ 4}{4}$$

This average will be entered in the "Average" column of the charts

**RESULTS AND DISCUSSION**

The content focuses on the advancement of the EraserBot project, specifically highlighting improvements from version 2.0 to 3.0. It includes a breakdown of the hardware components, the system configuration, the testing approach, and the performance evaluation. Through these comparisons, the data emphasizes the increased accuracy, reliability, and overall

efficiency introduced in the latest version, reflecting the ongoing refinement of the design and functionality.

**Table 5**  
*Data Gathered in Significance of Time (Manual Erase and EraserBot v3.0)*

Type	Time (seconds)				
	Trial 1	Trial 2	Trial 3	Trial 4	Average
<b>Manual Erasing</b>	41.10	45.05	55.51	29.82	<b>33.00</b>
<b>EraserBot v3.0</b>	20.0	20.0	20.0	20.0	<b>20.0</b>

As shown in Table 5, EraserBot v3.0 completed blackboard cleaning tasks significantly faster than the manual method. The timing data for manual erasing were recorded before the development of EraserBot v2.0 and served as a baseline for evaluating improvements. On average, the manual process took 33.00 seconds to clean the board. In comparison, EraserBot v3.0 consistently completed the task in exactly 20.0 seconds across all trials, following precise, pre-programmed instructions. This 13-second difference demonstrates a clear improvement in operational efficiency and task consistency enabled by automation. Unlike manual erasing, which can vary depending on the individual and conditions, EraserBot v3.0 maintained uniform performance. These results highlight the advantages of using an automated system, especially in terms of speed, reliability, and repeatability. Overall, EraserBot v3.0 offers a more effective, time-saving alternative, making it a valuable tool for educational environments that require frequent blackboard maintenance.

**Table 6**  
*Significance of Time (EraserBot v2.0 VS EraserBot v3.0)*

Type	Time (seconds)				
	Trial 1	Trial 2	Trial 3	Trial 4	Average
<b>EraserBot v2.0</b>	24	24	24	24	<b>24</b>
<b>EraserBot v3.0</b>	20.0	20.0	20.0	20.0	<b>20</b>

Table 6 provides a detailed comparison between EraserBot v2.0 and the upgraded EraserBot v3.0, emphasizing improvements in performance, precision, and consistency. The data collected for v2.0 during earlier development phases served as a benchmark to evaluate the improvements incorporated into the newer model. EraserBot v3.0 consistently completed the blackboard cleaning process in 20 seconds per trial, with the task evenly split between left-to-right and right-to-left motions according to pre-programmed instructions. This uniform performance highlights the enhanced motion control and operational stability of the latest version. A significant factor contributing to this improvement is the transition from a standard DC motor, used in v2.0, to a stepper motor in v3.0, supported by a dedicated driver module. This setup allows for precise step-based movements, resulting in improved coverage and repeatability. In contrast, EraserBot v2.0 exhibited less consistency due to limited control capabilities. Overall, the design upgrades in v3.0 delivered greater efficiency, accuracy, and dependability in automated blackboard cleaning applications.

**Table 7**  
*Significance of Precision (Manual Erasing and EraserBot v3.0)*

Type	Attempts				
	Trial 1	Trial 2	Trial 3	Trial 4	Average
<b>Manual Erasing (Input Average time)</b>	41.10 (Cleaned)	45.05 (Cleaned)	55.51 (Cleaned)	29.82 (Cleaned)	<b>33.0</b> <b>(Cleaned)</b>
<b>EraserBot v3.0 (Average time)</b>	20.0 (Cleaned)	20.0 (Cleaned)	20.0 (Cleaned)	20.0 (Cleaned)	<b>20.0</b> <b>(Cleaned)</b>

Table 7 compares manual chalkboard erasing with EraserBot v3.0, with particular emphasis on reliability and precision. The manual erasing data collected during the testing phase of EraserBot v2.0 was used as a baseline for assessing the improvements introduced in the newer version. Results from the trials showed that manual erasing was less consistent, with notable variability in performance. In one case, a participant experienced an allergic reaction to chalk dust, which affected the quality of the cleaning and highlighted a common drawback of manual methods: their vulnerability to environmental conditions, such as airborne particles.

By contrast, EraserBot v3.0 demonstrated uniform performance throughout all tests. Each trial was completed in exactly 20 seconds, with full and consistent cleaning achieved every time. The prototype operated independently of external factors, maintaining steady functionality regardless of dust or other environmental influences. These results confirm that EraserBot v3.0 not only improves the speed and thoroughness of cleaning tasks but also provides a more dependable and health-conscious alternative to traditional manual erasing, particularly in settings where dust sensitivity may pose a problem.

**Table 8**  
*Significance of Precision (EraserBot v2.0 versus EraserBot v3.0)*

Type	Attempts				
	Trial 1	Trial 2	Trial 3	Trial 4	Average
<b>EraserBot v2.0 (Average time)</b>	24.0 (Cleaned)	24.0 (Cleaned)	24.0 (Cleaned)	24.0 (Cleaned)	<b>24.0</b> <b>(Cleaned)</b>
<b>EraserBot v3.0 (Average time)</b>	20.0 (Cleaned)	20.0 (Cleaned)	20.0 (Cleaned)	20.0 (Cleaned)	<b>20.0</b> <b>(Cleaned)</b>

Table 8 reinforces the findings in Table 3 by highlighting the improvements in precision and consistency achieved with EraserBot v3.0 compared to its immediate predecessor. These improvements were largely due to the transition from a traditional DC motor, used in the earlier version, to a stepper motor in EraserBot v3.0. The stepper motor provided greater control over movement through small, defined steps, enhancing the prototype's ability to maintain accurate positioning during the cleaning process. As a result, EraserBot v3.0 delivered more consistent and reliable cleaning results across repeated trials. The increased motion accuracy reduced the likelihood of missed areas. It improved surface coverage, ultimately making the device more efficient and reliable. This technical enhancement marks a significant step forward in the system's development, supporting the goal of automating blackboard cleaning with high performance and minimal variability.

## CONCLUSION AND RECOMMENDATIONS

### Summary

The project titled "EraserBot V3.0: Optimization of an Automated Blackboard Eraser" was initiated to develop a more efficient, consistent, and sanitary method for cleaning blackboards in classroom settings. Manual erasing can be time-intensive and physically demanding and can contribute to chalk dust exposure, which can affect respiratory health. Earlier models of EraserBot offered basic automation but were unreliable and lacked smooth operation.

The third iteration, EraserBot V3.0, presented a significantly enhanced version designed to address these shortcomings. It features two NEMA 17 stepper motors paired with GT2 timing belts for horizontal traversal across the blackboard. Initially using a NEMA 23 motor (later replaced by a DC motor), the system operates five paint rollers that serve as erasers. An Arduino Uno R3 handles system control, while motor drivers ensure coordinated and precise movement. An IR remote allows users to trigger the erasing function, making manual operations more convenient. A key improvement is the inclusion of a vacuum cleaner that activates automatically after each cycle and upon returning to its home position—effectively managing residual chalk dust.

Performance-wise, the EraserBot was evaluated across three chalk intensity levels: light, medium, and heavy. In four trials per level, both light and medium writings were erased in a single 20-second pass. Heavily applied markings required up to three cycles to achieve full erasure. Despite this, the device successfully erased all chalk levels, reflecting major improvements over manual cleaning and previous versions.

### Conclusion

Following thorough development, prototyping, and testing, the researchers accomplished the objectives established for EraserBot V3.0. The initiative sought to enhance the design and functionality of the earlier version by emphasizing cleaner performance and improved erasing efficiency. By conducting methodical experiments and assessing performance, the subsequent conclusions are reached:

- The incorporation of a more efficient vacuum system in EraserBot V3.0 greatly decreased the existence of airborne chalk particles while in use. The dust-collection system engages automatically following each erasing cycle. It operates consistently, enhancing air quality in the classroom and reducing exposure to chalk dust for students and teachers alike.
- The system showed enhanced effectiveness in cleaning blackboards. Light and medium chalk intensities were eliminated in just one 20-second cycle, whereas hard chalk marks needed as many as three cycles for complete removal. This result represents a significant improvement compared to manual cleaning and previous iterations of the EraserBot, achieving the goal of developing a more comprehensive and efficient erasing system.

In general, EraserBot V3.0 effectively accomplished its defined goals. It not only increased cleanliness and ease of use in classroom environments but also boosted user safety and enhanced effectiveness — establishing it as a vital asset in contemporary educational contexts.

### Recommendations

In light of the development, testing, and analysis of EraserBot V3.0, the researchers present the following recommendations for future improvements to enhance the system's performance, usability, and adaptability in real-world classroom settings:

1. Integrate RFID Technology in Place of the Remote Control - Replacing the current infrared remote-control system with an RFID-based triggering mechanism is highly recommended. The remote control, being a detachable and portable device, poses the risk of being misplaced or lost. On the other hand, an RFID system can be programmed to respond only to authorized tags—such as a teacher's ID card—offering better access control, durability, and ease of use. This modification would eliminate reliance on external controllers while also enhancing system security and classroom convenience.
2. Install a Screw-Based Tensioner for Adjustable Pressure - To improve the erasing efficiency across various chalk intensities, a screw tensioner mechanism could be added. This would allow users to manually adjust the downward force or tension between the rotating paint roller spindle and the blackboard surface. Fine-tuning the pressure ensures optimal contact regardless of chalk density, board texture, or roller wear, thereby improving erasing consistency and minimizing the number of required cycles.
3. Implement a Reverse Polarity Feature for the DC Motor - Introducing a reverse polarity control to the DC motor used in rotating the erasing rollers would enable bi-directional rotation. This functionality can prevent wear on a single roller side, extend the system's lifespan, and potentially improve erasing performance by alternating directions during cleaning cycles, allowing a more thorough sweep of chalk residue.
4. Incorporate a Mechanical or Electronic Braking System - A braking mechanism—either passive or active—should be integrated to enhance the system's positional accuracy and safety. This is especially useful for preventing the system from overshooting or continuing movement due to momentum when the motor is powered off. A braking system will ensure that the eraser halts precisely at its intended position, preserving alignment and preventing mechanical stress.
5. Add a Drag Chain for Organized Cable Management - Installing a drag chain (cable carrier) would provide better protection and routing for electrical wires and cables moving along with the gantry or eraser head. This would reduce the risk of tangling, snagging, or cable damage during operation. A drag chain also improves the overall professional appearance of the prototype. It increases durability by minimizing stress on moving wires.
6. Restrict Cleaning Operation to the HOME Position - To avoid misalignment and ensure accurate erasing performance, the cleaning process should only be initiated when the system is at the designated HOME position. This not only prevents potential mechanical issues and reduces strain on components but also helps minimize operational noise—especially when the vacuum is activated—by ensuring all elements are properly aligned before cleaning begins.

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