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Need for Design and Development of Mechatronic System for Automatic Blackboard Cleaning: A Review

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Abstract. The conventional method of cleaning blackboards is time-consuming and often produces considerable chalk dust, which can affect classroom cleanliness and the health of students and teachers. This project presents the design and development of a mechatronic system for automatic blackboard cleaning that integrates mechanical, electrical, and control components to automate the cleaning process. The proposed system consists of a motordriven cleaning mechanism, suitable wiping material, guide rails, sensors, and a microcontroller-based control unit. When activated, the system moves the cleaning mechanism systematically across the blackboard surface to remove chalk marks with minimum human effort. The design aims to provide uniform cleaning, reduce dust generation, improve operational efficiency, and minimize cleaning time. The developed prototype is evaluated based on cleaning effectiveness, operating time, power consumption, and reliability. The proposed system offers a simple, economical, and user-friendly solution for educational institutions and demonstrates the practical application of mechatronics and automation in classroom environments.

Keywords: Mechatronics, Automatic Blackboard Cleaning, Automation, Motorized Cleaning Mechanism, Microcontroller, Sensors, Chalk Dust, Mechanical Design, Control System, Smart Classroom.

I. Introduction

Blackboards and whiteboards are commonly used as teaching aids in schools, colleges, and other educational institutions. However, repeated manual cleaning of the board requires physical effort and consumes valuable teaching time. The problem becomes more significant when large boards have to be cleaned frequently during lectures. Therefore, researchers have proposed automated board-cleaning systems to reduce human effort and improve cleaning efficiency [1], [2]. In the case of blackboards, manual erasing also produces chalk dust. The accumulation and dispersion of chalk dust can affect classroom cleanliness and may cause discomfort to people who are repeatedly exposed to it. Automatic cleaning systems with dust-collection or suction arrangements have therefore been investigated to reduce direct exposure to chalk dust [3], [4]. Different mechanical mechanisms have been developed to automate the movement of the cleaning element. These include chain-drive, rack-andpinion, rope-and-pulley, sliding-door, lead-screw and six-bar mechanisms. These mechanisms convert the rotary motion of a motor into linear, reciprocating, or guided motion of the duster over the board surface [5]–[10]. Microcontrollers have also become an important part of automatic board-cleaning systems.

Arduino, PIC and ATmega-based controllers can be used to control motor speed and direction. Motor drivers such as the L293D allow the motor to rotate in both clockwise and anticlockwise directions, while limit switches and sensors can be used to detect the end positions of the cleaning mechanism [8], [11]. Several studies have demonstrated that automated cleaning can reduce the time required compared with manual cleaning. One performance study reported an average automatic cleaning time of approximately 13 seconds compared with 27 seconds for manual cleaning for the tested board area [12]. Recent work has further combined motorized wiping mechanisms with dust collection and electronic control to improve classroom convenience and reduce physical effort [13].

Thus, an automatic board cleaner can be developed by integrating a suitable mechanical wiping mechanism, DC geared motor, motor driver, microcontroller and position sensors. Such a system can provide automatic and uniform board cleaning while reducing manual effort, cleaning time and exposure to chalk dust.

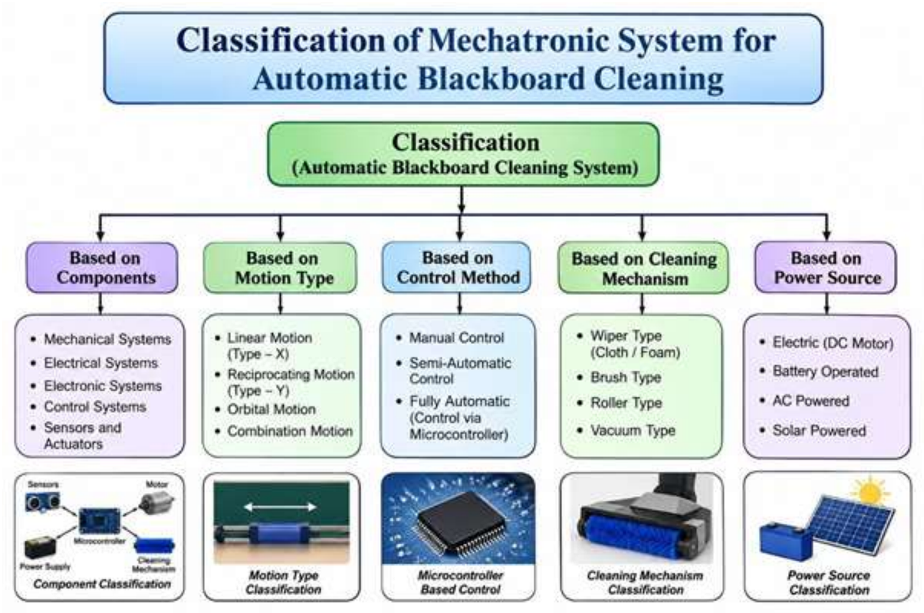

Figure 1. Classification Automatic Blackboard Cleaning

II. Literature Review

The development of automatic blackboard and whiteboard cleaning systems has progressed from simple motorized mechanisms to microcontroller-based and sensor-assisted systems. The literature mainly focuses on reducing manual effort, minimizing cleaning time, improving cleaning uniformity, and reducing exposure to chalk dust. Different mechanical mechanisms and control strategies have been investigated to achieve reliable movement of a cleaning element across the board surface. Ferdous and Elahi [1] presented an automatic board-cleaning system using a microcontroller, establishing an early approach toward electronically controlled board cleaning. Dhanjal and Pratihar [2] developed a board-cleaning serial manipulator, demonstrating the use of robotic manipulation concepts for automated board cleaning. Saraswat and Tyagi [3] proposed a new automatic blackboard-cleaning design aimed at reducing the effort and time associated with conventional manual cleaning.

Santhosh et al. [4] developed an automatic blackboard cleaner using a motorized mechanical arrangement. Their work demonstrated the feasibility of converting motor rotation into the required movement of the cleaning mechanism. Poornachandra et al. [5] proposed an automated board duster, further investigating the use of mechanical and electrical components for automatic wiping. In 2018, Suresh et al. [6] developed an Arduino-based automatic whiteboard cleaner, showing the increasing application of microcontrollers for controlling the cleaning mechanism. Singh et al. [7] investigated an automated whiteboard duster using polyester film and rollers, while Ajimkha et al. [8] proposed a rope-and-pulley-based smart duster for automated board cleaning.

Chavan et al. [9] developed an automatic whiteboard cleaner intended to improve the effectiveness and convenience of board cleaning. Alias et al. [10] presented a smart whiteboard cleaner for classroom applications, emphasizing automation for educational environments. Manihalla et al. [11] developed an electromechanical blackboard-cleaning system using a controlled mechanical arrangement, demonstrating the application of electromechanical conversion for automatic board movement.

Several studies published in 2021 further expanded the range of mechanisms used for automatic cleaning. Kannadhasan et al. [12] investigated an automatic blackboard dust remover, incorporating dust-removal considerations in addition to mechanical cleaning. Alias et al. [13] proposed a smart whiteboard cleaner, while Gangurde et al. [14] investigated an automatic blackboard cleaner based on a rack-and-pinion mechanism. Abinesh et al. [15] presented a blackboard-cleaning system using a mechanical wiping arrangement. A separate performance-evaluation study [16] investigated repeatability, cleaning effectiveness, and cleaning time, providing a basis for evaluating automatic cleaning performance. Akhter et al. [17] developed a microcontroller-based automatic whiteboard cleaner using Arduino, a DC gear motor, rack-and-pinion mechanism, and a sonar sensor, demonstrating the integration of sensing and automatic position control.

More recent research has focused on improving usability and practical performance. Khairullah and Kunchi Mon [18] developed the Easy-Erase whiteboard prototype, continuing the development of automated or assisted whiteboard-cleaning technology. Kafui and Bani [19] investigated the design, development and performance evaluation of an automatic whiteboard cleaning system, indicating increased emphasis on experimental performance assessment. Thombare et al. [20] developed a blackboard-cleaning robot, representing a further step toward robotic board-cleaning applications. Overall, the literature shows a clear progression from basic motorized cleaning mechanisms to microcontroller-based, sensor-assisted and robotic systems.

The reviewed studies employ different mechanisms, including serial manipulators, pulley and rope systems, rollers, rack-and-pinion arrangements and other guided wiping mechanisms. Although these approaches demonstrate the feasibility of automatic board cleaning, several issues remain, including incomplete cleaning, mechanical alignment, sensor reliability, dust management, component wear, power consumption and system complexity. Therefore, further research is required to develop a compact, economical, reliable and efficient automatic board cleaner capable of providing complete and uniform board coverage with minimum maintenance.

III. Mechatronic Technologies for Automatic Blackboard Cleaning

The Design and Development of Mechatronic System for Automatic Blackboard Cleaning combines mechanical, electrical, electronic, sensing, and control technologies to automate the blackboard-cleaning process. The major technologies used in the proposed system are described below.

1. Mechanical Motion Technology: A mechanical motion system is used to move the cleaning unit across the blackboard surface. Guide rails, sliders, rollers, lead screws, belts, chains, or rack-and-pinion mechanisms can be used to convert rotary motor motion into controlled linear movement. The mechanism should provide smooth movement and sufficient cleaning pressure.

2. Motor and Actuation Technology: An electric motor acts as the main actuator of the system. A DC geared motor can be used because it provides suitable torque and controllable speed. Stepper or servo motors can also be considered where accurate positioning is required. The motor drives the cleaning mechanism through a suitable transmission system.

3. Microcontroller Technology: A microcontroller such as Arduino Uno, ESP32, or similar controllers can be used as the central control unit. It receives signals from sensors and controls the motor according to the programmed sequence. The controller can automatically start, stop, reverse, and regulate the cleaning operation.

4. Sensor Technology: Sensors are used to determine the position and operating condition of the cleaning mechanism. Limit switches can detect the end positions of the cleaner and initiate motor reversal. Proximity or position sensors can also be incorporated for more precise movement and obstacle detection.

5. Motor Driver Technology: A motor-driver circuit is required between the microcontroller and motor because the controller cannot directly supply the current required by the motor. Driver modules such as an L298N or other suitable H-bridge driver can provide motor direction and speed control.

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6. Cleaning Technology: The cleaning unit may use a sponge, microfiber cloth, brush, felt, or rubber wiper depending on the blackboard surface. The cleaning material should remove chalk marks effectively without scratching or damaging the board. A replaceable cleaning pad can make maintenance easier.

7. Power Supply Technology: The system requires a suitable DC power source for the controller, sensors, and motor. A rechargeable battery can make the system portable, while an AC-to-DC adapter can be used for stationary operation. Voltage regulators can provide the required voltage levels for electronic components.

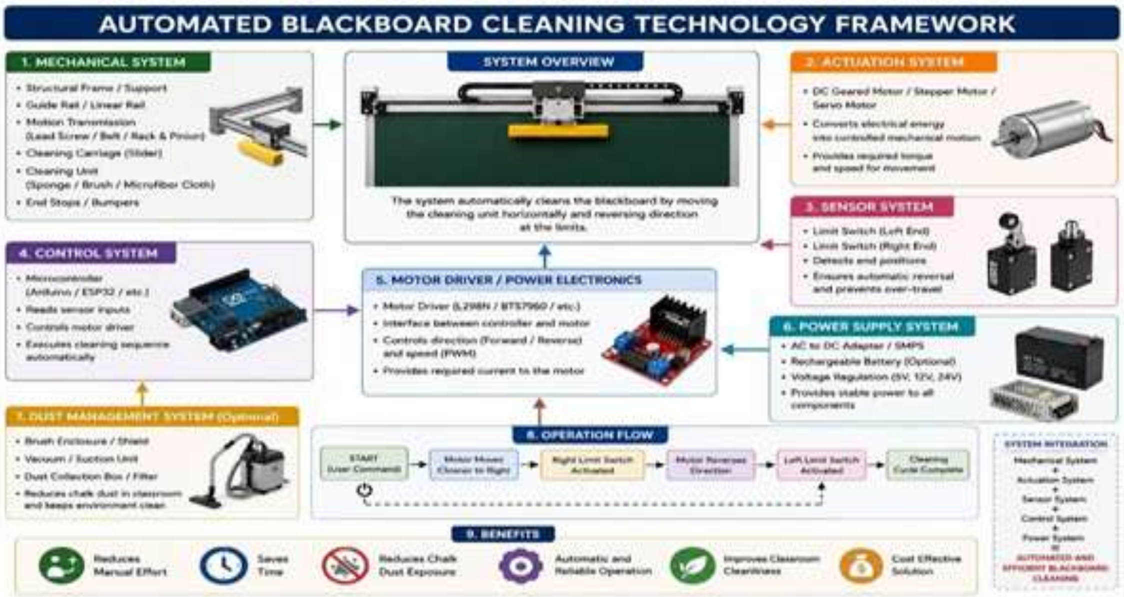

Figure 2. Automated Blackboard Cleaning Technology Framework

IV. Value Creation Opportunities

The proposed Automated Blackboard Cleaning Technology creates value by replacing a repetitive manual activity with a controlled mechatronic system. The integration of mechanical components, electric motors, sensors, microcontrollers, and cleaning mechanisms provides several technical, economic, environmental, and operational benefits.

1. **Reduction in Manual Effort:** Conventional blackboard cleaning requires a teacher or other person to manually move the duster across the entire board. This operation has to be repeated several times during a teaching session, especially when different topics are written on the board. The proposed automated system eliminates most of this repetitive physical activity by using a motor-driven cleaning mechanism. Once the cleaning command is given, the system can automatically move the cleaning unit across the board. This reduces the physical workload on teachers and support staff and allows them to concentrate on teaching and other classroom activities. The system is particularly beneficial for large blackboards, where manual cleaning requires greater effort.

2. **Time Saving:** Manual cleaning can interrupt the teaching process and consume valuable classroom time. An automated cleaning system can perform the cleaning operation according to a predefined movement sequence. The motor moves the cleaning unit along the required path, reaches the end position, reverses its direction, and completes the cleaning cycle automatically. The cleaning speed can be selected according to the board size and required cleaning quality. By reducing the time required for repeated cleaning operations, the system can improve the overall efficiency of classroom activities. Faster cleaning can also be useful in lecture halls and coaching centres where the board is frequently reused.

3. **Reduction in Chalk-Dust Exposure:** One of the important value-creation opportunities is the reduction of direct exposure to chalk dust. During conventional cleaning, the person cleaning the board is positioned close to the board while wiping the chalk marks. The movement of the duster can cause chalk particles to become airborne. The automated system allows the cleaning process to be performed without requiring a person to stand directly in front of the board. In addition, a dust shield, enclosed cleaning head, or optional suction mechanism can be incorporated into the design. These features can help control the dispersion of chalk particles and contribute to a cleaner classroom environment.

4. **Improved Cleaning Efficiency:** Manual cleaning depends on the user's wiping technique, applied pressure, movement speed, and attention. As a result, some portions of the blackboard may remain partially uncleaned. The proposed system provides controlled and systematic movement of the cleaning unit. The cleaning pad can be designed to maintain appropriate contact with the board surface while travelling across it. Multiple passes can also be programmed when necessary. This provides more consistent cleaning and improves the overall quality of the cleaning operation. Proper selection of cleaning material, motor speed, contact pressure, and movement pattern can further increase cleaning efficiency.

5. **Smart Classroom Integration:** The proposed system can be developed beyond a simple automatic machine by integrating it with smart classroom technologies. A microcontroller can act as the main control unit, while wireless communication modules such as Wi-Fi or Bluetooth can provide remote operation. An instructor could initiate the cleaning process using a control panel, mobile application, or classroom automation system. Sensors can provide information about the position and operating condition of the cleaning mechanism. Future systems could also incorporate scheduled cleaning, remote monitoring, and automatic fault detection. Therefore, the project provides a foundation for integrating traditional blackboards into modern smart-classroom environments.

6. **Low-Cost Manufacturing:** The proposed system can be designed using commercially available and relatively inexpensive components. DC geared motors, guide rails, limit switches, Arduino-compatible microcontrollers, motor drivers, belts, lead screws, rollers, and cleaning materials are readily available for prototype development. The structural frame can be manufactured using aluminium profiles, mild steel, or other suitable materials. Local manufacturing and standard components can reduce fabrication costs. A modular design can also make individual components easier to replace. Consequently, the system has the potential to become a cost-effective alternative to more complex automated cleaning equipment.

7. **Energy Efficiency:** Energy consumption is an important consideration in an electrically operated mechatronic system. The proposed cleaner does not need to operate continuously because the motor is activated only when a cleaning cycle is required. A suitable geared motor can provide the required torque at relatively low speed, reducing unnecessary power requirements. The microcontroller and sensors consume comparatively small amounts of electrical energy. Automatic stopping at the end of the cleaning cycle prevents the motor from operating unnecessarily. A rechargeable battery can also be used where portable operation is required. Proper motor selection and optimization of the cleaning path can further improve energy efficiency.

8. **Improved Classroom Cleanliness:** Repeated manual cleaning can cause chalk particles and residue to accumulate around the blackboard and on nearby surfaces. An automated cleaning mechanism can be designed to collect or contain a portion of this residue. A brush enclosure or dust-collection arrangement can be added around the cleaning unit. The cleaning pad can also be made removable so that it can be cleaned or replaced periodically. These features can reduce the accumulation of chalk residue and help maintain better classroom cleanliness. The benefit becomes more significant in classrooms where blackboards are used and cleaned many times throughout the day.

9. **Reliability and Repeatability:** A major advantage of automation is the ability to perform the same operation repeatedly according to a predefined sequence. In manual cleaning, the result can vary depending on the person performing the operation. In the proposed system, the movement of the cleaner is controlled by the programmed logic of the microcontroller. Limit switches or position sensors can detect the end positions and initiate automatic reversal. This prevents the cleaning mechanism from unnecessarily travelling beyond the board. The same movement pattern can be repeated during every cleaning cycle, improving operational consistency and reliability.

10. **Improved Safety:** Safety can be incorporated into the design through sensors, controlled motor operation, and appropriate mechanical protection. Limit switches can prevent excessive movement of the cleaning carriage. The motor can be stopped automatically when the cleaning cycle is completed. Mechanical covers can protect moving components such as belts, gears, chains, or lead screws from accidental contact. Emergency-stop functionality can also be incorporated into an advanced version. These features can reduce the possibility of mechanical damage and improve the safety of users and the equipment.

Table 1: Comparative analysis of the research papers

Ref.	Author/Paper	Board Type	Cleaning Mechanism	Control System	Main Components	Main Advantage	Major Limitation
1	T.U.Santhosh et al.	Blackboard	Gear, wheel & guideway	Switch / motor control	DC geared motor, gearbox, wheels, guideways, duster	Simple and low-cost construction	Mainly suitable for linear movement
2	S. B. Alias et al.	Whiteboard	Motor-driven wiping	DPDT switch	12-V DC motor, switch, duster	Simple operation and reduced cleaning time	Limited automation and control
3	V.Kannadhasan et al.	Blackboard	Mechanical wiping + suction	Electrical control	Vacuum pump, dust collector, duster	Reduces chalk-dust dispersion	Additional suction system increases complexity
4	V. S. Kumar et al.	Blackboard	Suction-based robotic movement	ATmega328P-U + Bluetooth	Suction fan, motor driver, battery, controller	Can move on a vertical board without a fixed frame	Suction depends on surface condition and robot weight
5	G. Gangurde et al.	Blackboard	Rack-andpinion	Sensor-based control	DC motor, rack, pinion, sensor	Accurate linear movement	Requires proper alignment of rack and pinion
6	M. I. Ajimkha et al.	Blackboard/Whiteboard	Rope-andpulley	Electronic control + limit	Motor, rope, pulley, limit	Suitable for long boards	Rope/pulley requires maintenance

				switches	switches, duster		and tension adjustment
7	Saraswat and Tyagi	Blackboard	Sliding-door mechanism	Microprocessor / programmed control	DC motor, relay, sliding mechanism	Simple wiping action with less manual effort	Movement is mainly restricted to the designed path
8	Automatic Board Cleaner, ICMIEE	Blackboard	Cord-andpulley	Arduino UNO + L293D	4 DCmotors, pulleys, cords, SS pipes, aluminium bar, cloth, foam	Automatic bidirectional wiping	Multiple motors increase wiring and synchronization requirements
9	P. P. Manihalla et al.	Blackboard	Lead-screw mechanism	Microcontroller + limit switches	Lead screw, motor, slider, guideway, sponge	Controlled and precise linear motion	Lead screw can increase mechanical complexity
10	V. A. Abinesh et al.	Blackboard	Six-bar linkage	Motor-driven	Links, crank, bearings, felt	Reciprocating motion similar to a wiper	Mechanical linkage requires accurate fabrication

V. Challenges

The reviewed literature on automatic blackboard and whiteboard cleaning systems identifies several challenges that influence the overall performance, reliability, and practical implementation of these systems. One of the major challenges is achieving complete and uniform cleaning over the entire board surface. The cleaning element must maintain proper contact with the board while moving across its surface; otherwise, residual chalk or marker marks may remain in some areas. Differences in board size, surface condition, and cleaning-material properties can further affect cleaning effectiveness. Another important challenge is mechanical movement and alignment. Systems using rack-and-pinion, rope-and-pulley, rollers, lead-screw, sliding and other mechanisms require accurate alignment for smooth operation. Misalignment can produce vibration, friction, uneven movement, or mechanical obstruction. Continuous operation can also lead to wear of gears, ropes, pulleys, rollers, guideways, and other moving components, increasing maintenance requirements.

Motor control and synchronization are additional challenges, particularly in systems using multiple motors. The motors must operate at appropriate speeds and directions to ensure that the cleaning mechanism moves uniformly across the board. Improper synchronization can cause tilting, jamming, or incomplete coverage. Therefore, suitable motor drivers and control algorithms are required for reliable operation. Position detection and boundary control are also important for automatic operation. Sensors and limit switches must accurately detect the end positions of the board so that the cleaning mechanism can stop or reverse at the appropriate point. Sensor positioning, detection accuracy, and reliability can directly affect system performance. In sensor-based systems, variations in board conditions and environmental factors may also influence detection accuracy.

Dust management remains a significant challenge, especially for blackboard-cleaning applications. Mechanical wiping can disperse chalk particles into the surrounding environment. Although some systems incorporate vacuum pumps, suction fans, or dust collectors, these additional components can increase the weight, size, power consumption, cost, and complexity of the overall system. Therefore, an effective dust-collection arrangement must be developed without compromising the simplicity of the cleaner. Another challenge is power consumption and energy management. Motorized cleaning mechanisms require sufficient electrical power for repeated operation, and systems using multiple motors or additional suction units may consume more energy. Maintaining adequate power while keeping the system compact and economical is therefore an important design consideration.

Finally, cost, system complexity, and maintenance remain important practical limitations. Increasing the number of motors, sensors, controllers, and mechanical components can improve automation but also increases manufacturing cost and maintenance requirements. The literature therefore indicates a need for a balanced design that provides reliable automatic cleaning while maintaining simple construction, low power consumption, low maintenance, and affordable cost. Addressing these challenges is essential for developing an efficient and practically deployable automatic board-cleaning system.

Future scope

The future development of automatic blackboard and whiteboard cleaning systems can focus on improving cleaning efficiency, reliability, automation, and user convenience. Based on the reviewed literature, future systems can be designed to achieve complete and uniform cleaning of the board by improving the contact pressure, cleaning material, and movement mechanism. Different mechanical arrangements can be further optimized to provide smoother motion, reduced friction, lower wear, and better coverage of the complete board surface. Further research can focus on the integration of advanced sensors and intelligent control systems. Microcontrollers can be used to coordinate motors, position sensors, and the cleaning sequence, while improved sensing techniques can provide accurate boundary detection and automatic stopping or reversing of the cleaner. Future systems may also incorporate horizontal and vertical movement to provide systematic cleaning of large boards and reduce the possibility of uncleaned regions. Another important area of future development is dust management. Compact vacuum or dust-collection systems can be integrated with the cleaning mechanism to reduce the dispersion of chalk particles during blackboard cleaning. The dust-collection arrangement should be lightweight and energy-efficient so that it does not significantly increase the size, cost, or power consumption of the system. Future automatic cleaners can also incorporate wireless and smart-control features.

Bluetooth, Wi-Fi, or mobile-based interfaces could allow users to start, stop, and monitor the cleaning operation remotely. Intelligent control could further enable automatic adjustment of motor speed and cleaning cycles according to board size and operating conditions. Finally, future research should emphasize the development of compact, lightweight, economical, and low-maintenance systems. Long-term experimental testing should be carried out for different board sizes, surface conditions, cleaning materials, operating speeds, and repeated cleaning cycles. Performance can be evaluated in terms of cleaning time, cleaning completeness, power consumption, dust-collection efficiency, mechanical durability, and reliability. Overall, the future scope lies in integrating efficient mechanical movement, accurate sensing, microcontroller-based automation, effective dust management, and economical construction into a single reliable system suitable for widespread use in schools, colleges, and other educational institutions. Overall, the future scope of automatic board-cleaning technology lies in integrating efficient mechanical movement, accurate sensors, microcontroller-based automation, effective dust collection, wireless control and improved cleaning materials into a single reliable system.

The objective should be to achieve complete board coverage, shorter cleaning time, reduced human effort and minimum maintenance while keeping the system simple, lightweight and affordable. The reviewed literature supports the need for improved autonomous movement, uniform coverage and better integration of mechanical and electronic control technologies.

VI. Conclusions

The comprehensive review of 20 research papers [1]–[20] demonstrates that automatic blackboard and white-board cleaning systems are a promising alternative to conventional manual cleaning methods. The reviewed studies show that automated cleaning can reduce human effort, cleaning time, and direct exposure to chalk dust, while improving the convenience of board maintenance. Various mechanical approaches, including rack-and-pinion, rope-and-pulley, rollers, sliding mechanisms, lead-screw arrangements, serial manipulators, and robotic systems, have been investigated for achieving automatic movement of the cleaning mechanism across the board surface. The comparative review indicates that each mechanism provides specific advantages but also has certain limitations. Simple motorized and pulley-based systems offer relatively easy fabrication and low-cost implementation, while rack-and-pinion and lead-screw mechanisms provide controlled movement. Microcontroller-based systems using Arduino, motor drivers, sensors, and limit switches provide improved automation, position detection, and automatic direction control. However, challenges such as incomplete cleaning, mechanical alignment, sensor reliability, component wear, dust generation, power consumption, and system complexity remain important considerations in the development of reliable automatic board cleaners.

The literature also indicates that effective board cleaning depends on maintaining proper contact between the cleaning material and the board surface while ensuring smooth and uniform movement. Dust-collection systems can improve the cleanliness of the surrounding environment, particularly for blackboard applications, but they may increase the size, weight, cost, and power requirements of the system. Therefore, an effective automatic board cleaner should achieve a suitable balance between cleaning performance, mechanical simplicity, automation, reliability, and cost. Overall, the reviewed research provides a strong foundation for the development of a compact, economical, reliable, and efficient automatic board-cleaning system. Future improvements in mechanical design, sensing, microcontroller-based control, cleaning materials, and dust management can further enhance system performance and durability. The continued development of such systems can reduce repetitive manual work and provide a convenient, safe, and efficient solution for blackboard and whiteboard cleaning in schools, colleges, and other educational institutions.

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