WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Automatic Board Cleaning Machine

Krushnakant Arjun Karwal [a], Mayuresh Satish Unawane [b], Prof. Shahu A. Zalte [c]

a. Student, Mechanical Department, Sandip Foundation's Sandip Polytechnic, Mahiravani, Nashik-422313, India;krushnakarwal07@gmail.com
b. Student, Mechanical Department, Sandip Foundation's Sandip Polytechnic, Mahiravani, Nashik-422313, India;unawanemayuresh@gmail.com
c. Faculty, Mechanical Department, Sandip Foundation's Sandip Polytechnic, Mahiravani, Nashik-422313, India;shahu.zalate@sandippolytechnic.org

ABSTRACT:

The rapid progression of automation and smart systems across multiple sectors has yielded significant advancements in board cleaning-a task traditionally rooted in manual labour within educational and industrial contexts. Automatic board cleaning machines have emerged as critical innovations, substantially enhancing hygiene, time efficiency, occupational health, and system integration. This literature review explores the full spectrum of these systems, tracing their historical genesis, dissecting diverse mechanical and electronic methodologies, evaluating cleaning techniques, and assessing the transformative impact of IoT and smart integrations. Drawing from academic sources, industry reports, patents, and recent web resources, the review presents an in-depth analysis of design paradigms, components, control architectures, health and environmental considerations, and comparative performance metrics. The study also charts patent and market trends, identifies leading industry actors, evaluates performance in educational settings, and anticipates future directions, all organized around a comprehensive system block diagram. The analysis concludes that ongoing developments in automation, smart technologies, and sustainability will continue to reshape the landscape of board maintenance-from traditional classroom whiteboards and chalkboards to state-of-the-art PCB cleaning in electronics manufacturing.

Keywords: Automatic board cleaning, smart duster, IoT integration, mechanical design, PCB cleaning, Arduino, chalk dust, health and safety, sustainability, block diagram, robotics, environmental impact, industrial automation, educational technology.

Introduction

Classroom and industrial boards-spanning greenboards, blackboards, whiteboards, and printed circuit boards (PCBs)-are fixtures in modern educational, corporate, and manufacturing environments. The fundamental need to maintain board cleanliness for effective visual communication has remained, even as content delivery and board materials have evolved. Traditionally, board cleaning has been labour-intensive, time-consuming, and fraught with health concerns due to dust exposure-most notably in chalkboard contexts, where chalk dust can significantly impair both human health and electronic equipment reliability.

The global push towards automation and smart environments has naturally extended to this domain, prompting the development of various automatic and semi-automatic board cleaning systems. These systems promise to reduce manual effort, minimize downtime, improve hygiene and indoor air quality, and integrate seamlessly with wider smart building and Industry 4.0 paradigms.

Recent years have witnessed the rise of intelligent devices capable of not only cleaning but also monitoring, scheduling, and even adapting cleaning intensity based on sensor feedback. In industrial sectors such as electronics manufacturing, automatic PCB cleaning machines ensure high performance by removing residues that could compromise functionality, reliability, and safety. In educational and corporate environments, automated board cleaners have become essential for health, operational efficiency, and productivity, with increasing integrations of IoT and AI for smart maintenance and reporting.

This review offers an exhaustive examination of the technologies, methodologies, and innovations underpinning automatic board cleaning machines, with a special focus on their design, implementation, performance, and the challenges and opportunities presented by integrating modern automation and sustainability principles. By synthesizing academic studies, patents, manufacturer specifications, and recent professional insights, the report seeks to present a reference framework for researchers, practitioners, and policy makers engaged with smart cleaning solutions.

Methodology

This literature review is grounded in a systematic approach, synthesizing and critically analysing a broad range of academic papers, patents, technical reports, and contemporary web-based sources published between 2015 and 2025. The methodologies applied in the review encompass:

- **Systematic Literature Review:** Identification and scrutiny of peer-reviewed articles, conference proceedings, and industrial white papers focusing on automatic board cleaning technologies, mechanical and control systems, and health/environmental impacts.

- **Patent Analysis:** Examination of recent patent filings and granted patents for board cleaning devices (e.g., CN112428722A), combined with a review of domain-specific patent retrieval platforms.
- **Industrial Survey:** Incorporating product literature and technical data from leading industry actors for both educational and industrial board cleaning systems (e.g., Teknik, nu/clean).
- **Comparative Case Studies:** Side-by-side evaluation of representative cleaning machines and mechanisms based on performance metrics, control strategies, and application context.
- **Block Diagram Synthesis:** Construction of generic and specific block diagrams to represent system architectures and control flows, based on accumulated empirical data and design reports across the reviewed sources.
- **Trend Analysis:** Assessment of the latest trends in IoT, AI, cloud-based management, and sustainable cleaning from current market studies and technology blogs.

The literature was selected with emphasis on recent advances, validated practical deployments, and theoretical underpinnings of cleaning systems in diverse contexts-including educational institutions, electronics manufacturing, and general smart building environments.

Historical Evolution of Board Cleaning Machines

Early Developments

Board cleaning traditionally involved manual effort-using cloths, dusters, or erasers to clear chalkboards and whiteboards. As chalkboards became a classroom staple in the 19th and 20th centuries, so too did the health risks associate with airborne chalk dust[1]. Early mechanical aids, such as rope-and-pulley erasing systems, offered only modest gains in time or ergonomic relief.

In industrial contexts-specifically electronics manufacturing-the growing complexity and density of PCBs in the late 20th century demanded new, highly efficient cleaning protocols. Manual washing proved insufficient for removing tiny contaminants that could cause board failures; thus, the first batch and inline automatic PCB cleaning machines began appearing in the 1980s and 90s.

From Manual to Automated Systems

Recent decades have seen marked evolution:

- **Mechanical Automation:** Early automatic cleaners relied on motorized mechanical systems, using simple tracks and motorized dusters to traverse the board's length and width.
- **Electromechanical Integration:** The use of microcontrollers (e.g., Arduino, Atmega328) enabled programmable motion sequences, directional reversal, and remote or scheduled operation, thus paving the way for more autonomous.
- **Sensor-Driven Control:** Ultrasonic, infrared, and Hall-effect sensors were introduced to detect board edges, dust accumulation, and cleaning completeness.
- **Internet of Things (IoT):** Integration with cloud-based platforms, mobile apps, and building management systems to enable remote monitoring, scheduling, predictive maintenance, and data analytics has amplified in the last five years.
- **Green and Sustainable Design:** Attention has shifted to energy-efficient operation, water-saving mechanisms, and materials selection, particularly in industrial PCB cleaning where eco-friendly aqueous systems have begun to replace solvent-based techniques.

Modern State

As of 2025, automatic board cleaners exist in forms ranging from compact, cost-effective classroom smart dusters to advanced industrial PCB washers, with functionality enhanced by AI-based scheduling, adaptive cleaning intensity, and full integration into smart facilities for energy/resource optimization.

Mechanical Mechanisms and Designs

Key Approaches in Physical Design

Automatic board cleaning machines depend on robust mechanical frameworks for motion control, cleaning efficiency, and component durability. The core designs are classified as follows:

- **Track-and-Wheel Systems:** A duster or cleaning pad is mounted on a mechanical track (aluminium, steel, or plastic) with wheels or rollers, allowing horizontal (and sometimes vertical) movement across the board's surface.

- **Rack-and-Pinion Drives:** The conversion of motor shaft rotation to linear motion is achieved via rack-and-pinion mechanisms, valued for simplicity and cost-effectiveness. This system is commonly seen in microcontroller-based and educational project devices.
- **Lead Screw and Linear Bearing Systems:** For higher precision and load-bearing, some advanced systems utilize lead screw drives and linear bearings, ensuring smooth and consistent movement, especially in larger or heavier setups.
- **Belt or Chain Drives:** Utilized for both cost savings and motion longevity, belts provide low-noise and reliable transmission, though they may be more susceptible to wear and maintenance demands in repetitive-use scenarios.
- **Gantry and Dual-Axis Motion:** Some smart and industrial cleaners implement dual-axis motion (X and Y), allowing the duster or cleaning head to address the entire board area or to focus on specific zones as needed, often under microcontroller or AI direction.
- **Brush and Sponge Attachments:** Cleaning surfaces may be equipped with synthetic brushes (for dry or wet cleaning), sponges, or foam pads, the choice influenced by board type and contamination level.

Mechanical Innovations for Safety and Efficiency

- **Limit Switches and Edge Detection:** To prevent overrun or mechanical collision, physical limit switches, sonar, or IR sensors are deployed to detect board edges and trigger reversing or stopping actions.
- **Pressurization Mechanisms:** The application of moderate and consistent pressure by the duster ensures effective contact with the board; some designs employ spring-loaded or adjustable tension systems to optimize performance and limit wear.
- **Removable and Cleanable Pads:** Many modern systems permit easy removal, cleaning, or replacement of the pad/duster unit, enhancing hygiene and operational continuity.

Application-Specific Mechanical Features

- **PCB Cleaning:** Specialized mechanisms such as contact cleaning rollers, anti-static coating, and vacuum extraction are prevalent in automatic PCB washers, ensuring both efficacy and ESD control.
- **Chalkboard Dusters:** Integrated vacuum or dust collection hoods are sometimes fitted to capture airborne chalk dust at the point of cleaning, thus significantly reducing environmental contamination.
- **Partial Cleaning Modes:** Some systems allow targeted or partial board cleaning, catering to board zoning or multi-section erasing controlled manually or via remote interface.

Summaries from recent research:

SmartDusterProjects:

Implement motor-driven duster rails for linear or reciprocal cleaning cycles, using materials such as aluminium tracks and soft pads for universal blackboard or whiteboard applications. Extensions include integrated water sprinklers for wet cleaning and the use of microcontrollers for programmable logic.

ComparativeHealth Studies:

Multiple studies documented the detrimental health effects of chalk dust exposure-ranging from asthma to dermatitis and eye irritation-affirming the necessity of automated systems to mitigate these risks.

▪ Integrated IoT Board Cleaners: Recent research has explored integrating Wi-Fi modules and mobile apps, allowing users to initiate cleaning cycles remotely or via scheduled commands, and to selectively clean sections of large boards-a feature especially useful in interactive or smart classrooms [.

▪ User-Centric and Adaptive Designs: Academic prototypes have introduced vertical and horizontal cleaning units, limit switches, and safety stoppers to avoid collisions, ensuring user safety and adaptability to various board sizes and mounting situations.

PatentLandscape:

Ongoing patent activity reveals new approaches, such as combined chalk dispensing and cleaning systems, adaptive brush replacement to match contamination, and machine learning integration for optimally scheduling cleaning cycles based on board usage patterns

. 1. These sources collectively establish that modern automatic board cleaning systems are multi-disciplinary, drawing on mechanical, electrical, software, and user experience innovations.

Actuation and Power Systems

Motor Technologies

Actuation in automatic board cleaning systems depends predominantly on reliable electric motors. Common options include:

- **DC Geared Motors:** Widely used for low-cost, moderate-torque requirements, DC motors coupled to gearboxes provide sufficient drive for light-to-medium board cleaner robots and facilitate easy speed and direction control.
- **Stepper Motors and Servos:** For higher precision movement (e.g., writing robots, dual-axis cleaners), stepper motors-often with micro stepping drivers like the A4988-enable programmed positioning for both writing and cleaning modules. Servo motors are favoured for tasks requiring angular control, such as up-down actuation of a cleaning pad.
- **Brushless DC Motors:** Increasingly, BLDC motors with higher efficiency, torque constancy, and durability are being adopted-particularly in PCB cleaners and industrial robotic cleaning arms.
- **Motor Ratings:** DC motor ratings typically span from 80 to 5000 RPM with voltage ranges from 6V to 24V, depending on load, chassis size, and duty cycle requirements.

Power System Architecture

- **Switch Mode Power Supplies (SMPS):** Conversion of standard AC mains power (typically 230V) to low voltage DC (12V or 24V) via SMPS is standard for stationary or plug-in devices, offering efficiency and electrical safety.
- **Rechargeable Battery Packs:** For mobile or portable designs (e.g., classroom robots, remote-operated devices), incorporated battery packs (Li-ion, NiMH) of suitable capacity power the motors and control circuits, with charging managed via built-in or docking stations.
- **Redundancy and Protection:** Overcurrent/overvoltage protection, fusing, and thermal cutoffs enhance system robustness and prevent hardware damage during abnormal operation.

Energy Efficiency Trends

Recent advances target energy economy: low-friction materials, lightweight modular designs, brushless motors, and intelligent triggering (e.g., occupancy sensors to activate cleaning only when the room is vacant) all contribute to minimizing the environmental footprint.

Control Systems and Automation

Microcontroller and Embedded Systems

Central to modern automatic board cleaners are microcontroller-based control systems. Common implementations employ:

- **Arduino UNO/ATmega328:** These open-source controllers are renowned for ease of programming, community support, and sufficient I/O for motor, sensor, and relay management.
- **Other Microcontrollers:** STM32, ESP32, Atmega-128, or specialized industrial controllers are variously used, with more advanced devices providing extended communication and security capabilities.
- **Motor Driver ICs:** L293D, L298N, and custom H-bridge drivers manage direction and speed for up to two or four motors per device, allowing for both unidirectional and bidirectional cleaning paths.

Sensing and Feedback Systems

- **Limit and Proximity Switches:** Used for mechanical end-of-travel detection and collision prevention.
- **Ultrasonic and Infrared Sensors:** Edge detection or spatial navigation, especially in more sophisticated or dual-axis systems.
- **Current and Pressure Sensors:** Sometimes included to monitor cleaning pressure or detect motor stall (indicative of blockages or wear).

Automation and Smart Features

- **Remote and Scheduled Cleaning:** Many designs now support remote activation via IR, Bluetooth, or Wi-Fi (Nedelcu, ESP8266/ESP32), allowing users to schedule cleaning or initiate cycles via smartphone app or wireless remote.

- **IoT and Data Logging:** Integration with cloud platforms enables usage analytics, predictive maintenance, and integration with building management systems for smart facility operations.
- **AI-Based Optimization:** In large-line PCB cleaners or facility-scale systems, AI-based scheduling and adaptive cleaning cycles are being piloted, leveraging occupancy or contamination sensors for resource optimization.

Safety and Error Handling

Modern control systems incorporate fail-safe protocols and interlocks (e.g., stopping all motion upon sensor failure or unexpected obstruction, user alerting, logging error events for diagnosis).

Cleaning Techniques and Attachments

Cleaning Methods and Materials

- **Dry Cleaning:** The most widespread for blackboards and whiteboards, employing felt, foam, microfiber, or synthetic pads to capture and remove chalk/maker.
- **Wet Cleaning:** For stubborn marks, periodic hygiene, or chalkboard whitening, water or diluted cleaning solution is sprayed or dispensed via integrated pumps, with subsequent squeegee or brush action and airflow for drying (particularly where chalk dust caking is problematic).
- **Sprinkler and Blower Integration:** Some advanced classroom systems feature micro-pumps and small fans for enhanced cleaning and drying, allowing for fully automatic wet-and-dry cycles in both chalk and whiteboard contexts.
- **Brush and Roller Mechanisms:** Rotating brushes, sponge rollers, or vibratory pads are commonly employed for either direct board contact or for cleaning other cleaning tools (e.g., in chalk duster cleaning robots).

PCB-Specific Cleaning Techniques

- **Aqueous Cleaning:** Boards are subjected to wash and rinse cycles with specially formulated water-based solutions, often combined with ultrasonic agitation and precision spraying. Inline and batch processing are common, and post-clean drying is critical for PCB reliability.
- **Contact Rollers:** In high-spec PCB assembly, soft anti-static rollers (as in Teknik BC-40) remove debris at micron and nanometre scales before critical soldering steps, maximizing yield while meeting ESD and cleanliness standards[2].
- **Vacuum Extraction:** Dust and solvent residues are extracted under negative pressure to eliminate airborne contamination and ensure compliance with safety standards.

Health and Safety Attachments

- **Vacuum Hooded Dusters:** In environments with problematic dust (e.g., chalkboards, PCB lines), integrated vacuum systems minimize aerosol dispersion and reduce exposure risk.
- **Closed-Loop Cleaning:** For chalk dust, closed-loop systems enclose the cleaning event, collecting and sealing off collected particulates from the ambient air.

Health, Safety, and Dust Management

Human Health Considerations

- **Chalk Dust Hazards:** Prolonged exposure to chalk dust is linked to asthma, allergic reactions, skin irritation, and eye damage. Students and teachers in traditional chalk-based classrooms face significant risks-including those with pre-existing respiratory conditions.
- **Electronic Equipment Damage:** Dust infiltration into electronics (computers, projectors) can cause short-circuiting, overheating, and premature component failure-especially problematic in “chalk-and-talk” classrooms outfitted with electronic aids.

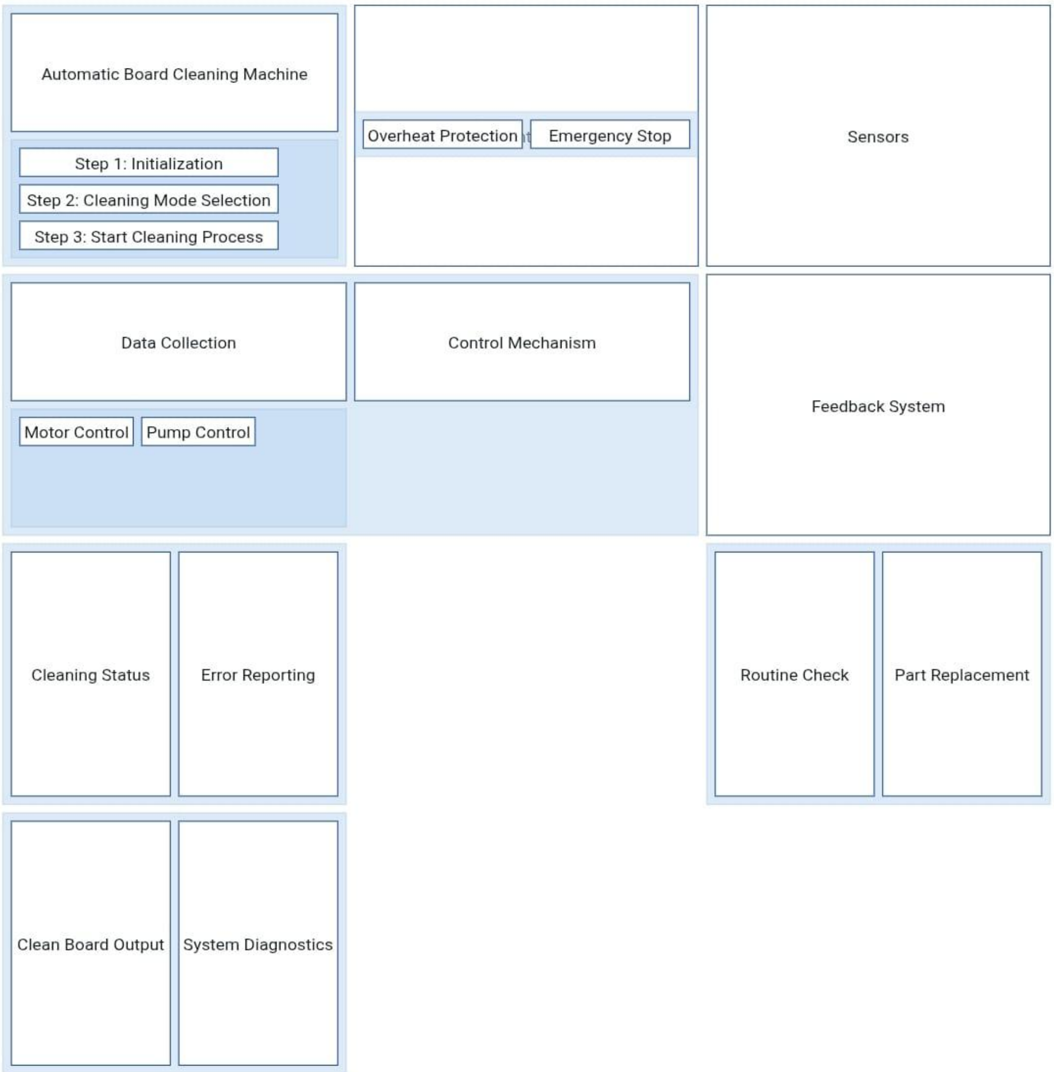
Intelligent Dust Control

- **Integrated Dust Collectors:** Modern systems are increasingly designed to collect chalk dust at source. Filtered vacuum units, often enclosed within the eraser, prevent particle release during cleaning and tool cleaning events.
- **Enclosure and Containment:** Sealed systems, sometimes with HEPA filtration or closed-loop dust recycling, are deployed in high-risk environments and industrial PCB cleaning.

Standards and Best Practices

- **Ergonomics and Accessibility:** Devices are designed for safe operation (remote controls, mobile app integration, obstacle-avoidance), reducing the chance of repetitive strain, accidental contact, or overexertion.
- **Compliance:** PCB cleaners and industrial-grade school equipment adhere to standards such as ANSI/ESD s20.20 and IPC-CFX for electrostatic discharge safety and cleanliness.

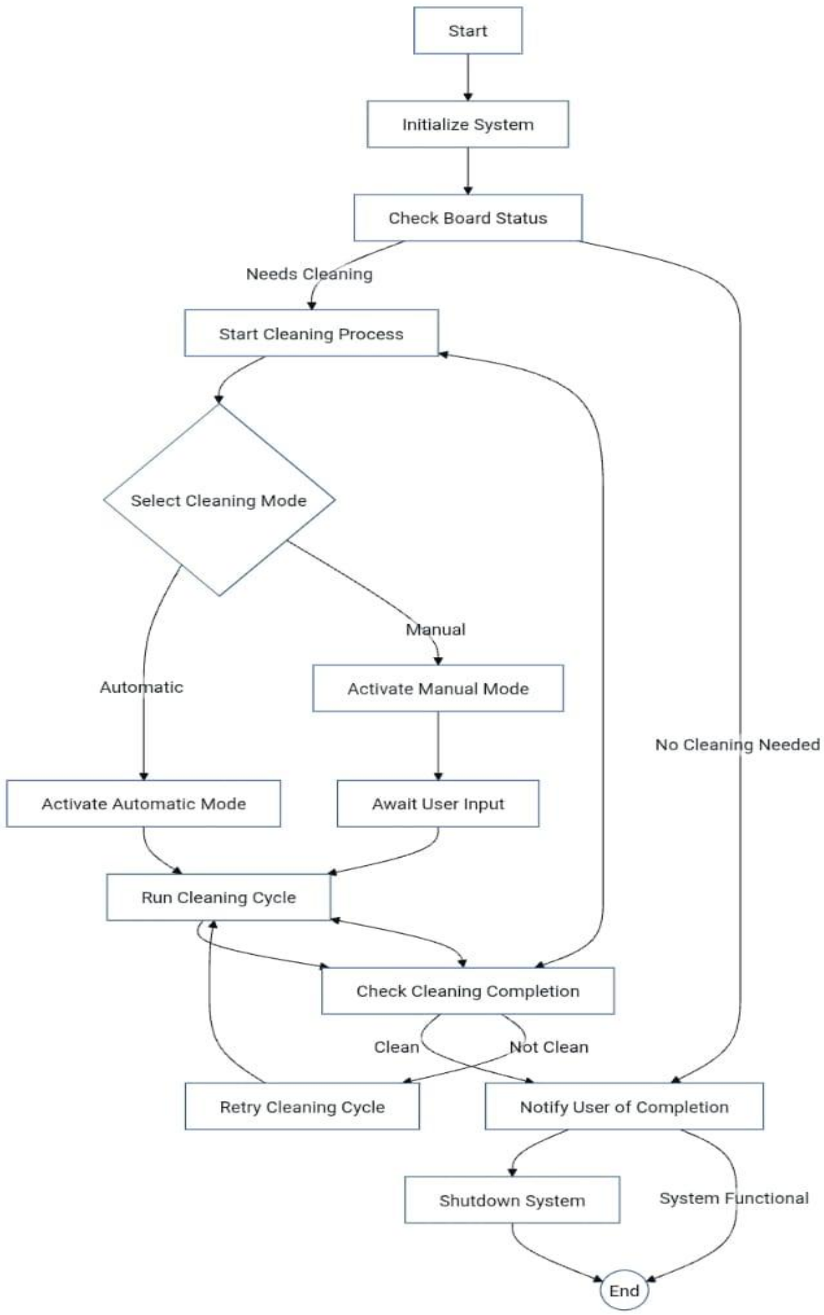
Block Diagram and System Architecture



Block Diagram Components:

- **Power Supply (SMPS/Battery):** Converts AC to required DC.
- **Microcontroller (Arduino/AT mega):** Central logic and control.
- **Motor Drivers (L293D/L298N):** Interface controller with DC/Stepper/Servo motors.
- **Motors (DC/Stepper/Servo):** Provide actuation for sliders, wheels, and cleaning pad.
- **Sensor Array (Limit/Ultrasonic/Infrared):** Detects board boundaries, cleaning completeness, and obstacles.
- **Cleaning Assembly (Pad/Brush):** Removable or fixed, responsible for physical cleaning.
- **User Interface (Switch/Remote/App):** Operation start/stop, (partial) area selection, and diagnostics display.

- **Optional Attachments:** Sprinkler/fan (wet/dry), vacuum extractor (for dust), IoT/Bluetooth/Wi-Fi modules.



Limitations and Challenges

Despite significant progress, automatic board cleaning systems encounter several intrinsic and practical challenges:

▪ Surface Compatibility: Some specialty boards (glass, uneven, or very large installations) may not be compatible with standard cleaning units or require costly customization [15].

▪ Mechanical Warranter: Repeated cycles can increase the risk of track/drive mechanism failures, requiring periodic maintenance and component replacement.

▪ Cleaning Quality for Stubborn Marks: In some cases, residues (permanent marker ink or aged chalk stains) may not be fully removed by standard cleaning passes, necessitating manual intervention [6].

▪ Initial and Maintenance Costs: While component costs have fallen (thanks to off-the-shelf electronics and modular construction), upfront installation and ongoing maintenance may deter widespread adoption, especially in under-resourced settings [18].

▪ Safety Concerns: Moving assemblies pose a risk of pinching, collision, or accidental operation if not properly secured and equipped with safety interlocks and user proximity detection [20].

▪ Partial/Spot Cleaning Complexity: Achieving selective cleaning (without disturbing in-use board sections) raises both hardware and software complexity.

▪ Integration with Non-Standard Smart Systems: Compatibility with existing smart classroom IoT frameworks and protocols may not yet be universal

Materials and Components

Key Materials Used

Component	Typical Materials	Rationale
Track/Frame	Aluminium, mild steel, ABS	Durability, lightness, corrosion resistance
Cleaning Pad	Felt, microfiber, sponge	Gentle friction, dust retention, easy cleaning/replacement
Wheels/Bearings	Nylon, steel, plastic	Smooth motion, corrosion resistance
Drive Rods	Steel, chromed steel	Wear resistance, smooth linear translation
Housing/Chassis	Plastic, aluminium	Weight savings, cost efficiency, robustness
Motors	Steel (casing), magnet	High torque, longevity, thermal tolerance
Electronic Boards	FR4 PCB, copper traces	Electrical insulation, reliability
PCB Cleaner Rollers	Soft synthetic rubber	ESD compliance, efficient particle pickup

Criteria for Material Selection

Materials are chosen for their cost-effectiveness, local availability, machinability, electrical and mechanical properties, and suitability for intended cleaning frequency or industrial sanitation requirements.

Applications

Educational Sector

- **Institutional and Classroom Use:** Automatic board cleaning machines are now common in progressive schools, colleges, and training centres. They:
  - Save instructional time (5-15% per class period).
  - Reduce teacher workload and ergonomic complaints.
  - Foster inclusive, dust-free environments-critical for those with respiratory concerns.
- **Smart Classroom Integration:** Devices are integrated into smart classroom systems for coordinated cleaning schedules and real-time usage logging.

Corporate and Meeting Spaces

- **Conference Room Whiteboards:** Automated cleaning ensures professional appearance between sessions, reducing downtime and manual cleaning labour.
- **Remote Operation:** Integration with scheduling or room management systems enables cleaning to occur after business hours.

Electronics Manufacturing

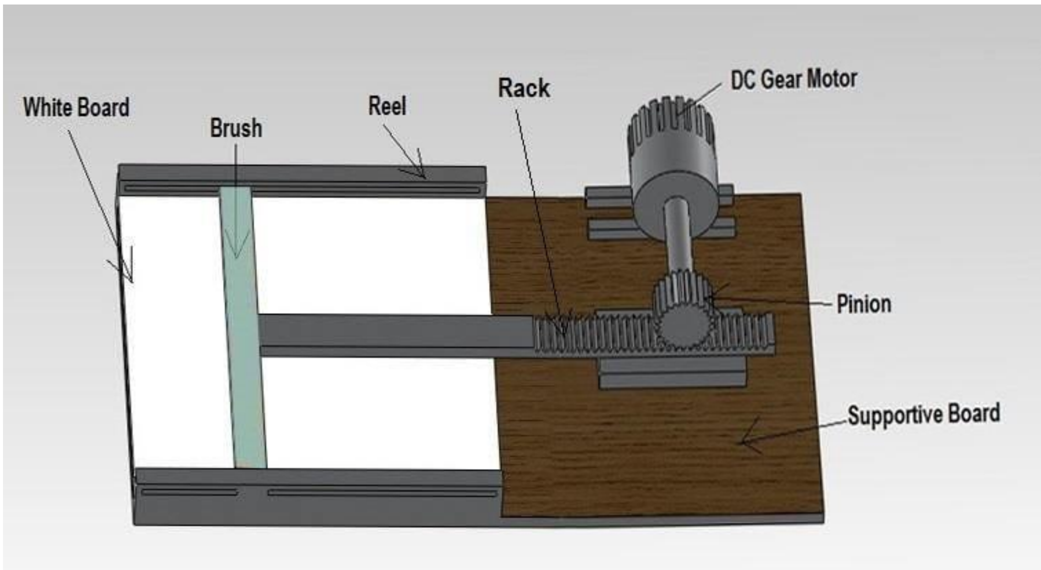
- **PCB Cleaning:** Critical for achieving high reliability in modern electronics, automatic PCB washing and drying solutions are now industrial standards-applicable in telecommunications, aerospace, automotive, and consumer electronics manufacturing.

Healthcare, Labs, and Other Sectors

- **Medical Cleanrooms and Labs:** Automated cleaning of boards and other writing surfaces helps uphold strict hygiene protocols and reduces risks of cross-contamination.

Emerging Applications

- **Robotized General Cleaning:** AI and robotics advances (e.g., Figure 03 humanoid robot, Coenobites L4) are being adapted to multi-surface cleaning, including boards in public and private environments, as part of facility-wide autonomous cleaning solutions.



Performance Metrics and Evaluation

Metrics Used in Academic and Field Studies

Metric	Description	Typical Values
Cleaning Time	Time to clean full or partial board	6-20 seconds (auto), 25+ sec (manual)
Area Coverage	% of board surface effectively cleaned per cycle	>95% (leading designs)
Repeatability	Consistency over repeated cycles (0-10 scale)	≥9/10 (top peer-reviewed)
Residue/Effectiveness	Residual dust or marks after cleaning	<5% of board area (optimal)
Noise Level	Measured in dB during operation	50-60 dB (typical)
User Effort	Manual intervention needed	Minimal to none
Dust Dispersion	Particulate release in ambient air	Zero to minimal (enclosed)
Operation Cost	Maintenance, energy, and consumable replacement	Low to moderate
Health Impact	Measured via environment sampling and user feedback	Strongly positive in auto

Sample Evaluation Results

Studies consistently show a reduction in cleaning time by two-thirds compared to manual cleaning, >90% user satisfaction with fully automatic models, and dramatic improvement in indoor air quality with integrated dust management systems.

Performance trade-offs may appear in systems with lower-end mechanical components, less robust edge detection, or lack of full-surface coverage (e.g., designs lacking dual-axis actuation).

Comparative Analysis of Devices

Classroom Cleaners vs. PCB Washers

Feature	Classroom Board Cleaner	Industrial PCB Washer
Surface Type	Chalkboard, whiteboard	PCBs (rigid, flexible, with components)
Cleaning Medium	Dry pad, optional wet spray	Aqueous wash, ultrasonics, contact rollers
Automation Level	Microcontroller, smart sensors, app remote	PLC/embedded; AI/IoT in advanced units
Dust/Particle Control	Duster, vacuum extractor, filters	HEPA filters, ESD control, vacuum stage
Speed	6-20 seconds per board cycle	6-15 minutes per PCB batch/inline cycle
Area Coverage	Full/partial; user-selectable	100%; real-time sensors
Health Focus	Minimize chalk dust, allergy prevention	Remove solder flux, ensure reliability
Integration	Room automation, app control	SMT line automation, QC feedback
Energy Use	Low (12-24V DC motors)	Moderate to high (industrial equipment)
Sustainability	Reusable pads, low energy	Eco-friendly solvents, water recycling

Key Takeaways

- Educational cleaners focus on ergonomics, health, ease of use, and cost.
- PCB washers emphasize reliability, process integration, fine particle removal, and regulatory compliance.
- Industrial units tend to adopt more advanced control systems, ESD and cleanliness standards, and environmental safeguards.

IoT and Smart Integration

State of the Art

- **IoT-Enabled Devices:** Automatic board cleaners are increasingly IoT-enabled, permitting:
  - Remote configuration, diagnostics, and operation via smartphones or cloud dashboards.
  - Cleaning reports and area usage analytics for facilities management.
  - Predictive maintenance notifications to optimize uptime and longevity of equipment.
- **Smart Scheduling:** Integration with space reservation systems (e.g., meeting rooms, classrooms) enables cleaning schedules that avoid conflicts and maximize board availability.
- **AI and Machine Learning:** Early-stage AI systems analyse sensor data (occupancy, dust/marker detection, cleaning effectiveness) to adapt cycles for maximum effectiveness with minimal resource consumption.

Future Directions

- **Edge Computing:** Processing sensor data locally for real-time optimization and autonomous decision-making (e.g., when to clean specific zones or full surfaces).
- **Cloud-Linked Consumables Management:** Automatic ordering of replacement pads/supplies based on usage analytics and wear sensors.
- **Unified Facility Automation:** Seamless interplay with lighting, HVAC, air purification, and cleaning robots.

Environmental Impact and Sustainability

Key Considerations

- **Material Lifecycle:** Use of recyclable or biodegradable pads, energy-efficient motors, and responsible e-waste handling for electronics.
- **Water and Chemical Use:** PCB cleaners increasingly use closed-loop water systems, eco-friendly aqueous solutions to minimize solvent release and hazardous waste.
- **Dust Recycling:** Some designs collect chalk dust for recycling into new chalk sticks, contributing to circular resource use.

- **Green Certifications:** Products and cleaning protocols may seek Green Seal, Eco Logo, or similar certifications attesting to reduced environmental and health impact.

Market Influence

Sustainability is now a critical factor in procurement decisions by educational institutions, corporations, and manufacturers. As environmental regulations tighten, automatic cleaning systems offering water and energy conservation, low-emission operation, and waste minimization are rapidly gaining market share.

Patent Trends and Key Industry Players

Patent Activity

Recent patent applications reveal growing activity in automated, smart, and eco-friendly board cleaning devices:

- **System Integration:** Mechanisms combining mechanical actuation, dust/spray management, servo-driven precision, and smart controls within unified platforms.
- **Wearable and Modular Attachments:** Interchangeable cleaning heaters, sensors, pads for diverse board types or easy upgrades.
- **Closed-Loop Cleaning:** Multi-stage cleaning blocks and drive frames ensuring no external contamination.
- **Linkage with Writing/Presentation Technology:** Automated cleaning and surface preparation as an extension of digital and interactive board systems.

Leading Industry and Academic Actors

- **Teknik (UK):** Pioneering anti-static contact cleaning for advanced electronics, compliant with ESD and performance certification.
- **Benson Technology (Asia):** Focus on scalable PCB cleaning and contract processing for electronics supply chain.
- **nu/clean (Global):** Advanced PCB washers integrating real-time cleanliness sensors, eco-friendly operation, and modular system integration.
- **Coenobites/Coenobites (CZ/EU):** Developing AI-driven robotic cleaning systems for diverse floor and board maintenance.
- **Academic/Research Groups:** Numerous university projects (e.g., Vidyavaridhi College of Engineering, Kongo Engineering College, RangarajanDr. Sakunthala Engineering College) serve as incubation grounds for innovation in smart duster and whiteboard cleaning design.

Applications in Education

Automatic board cleaners have transformed classroom dynamics and teacher well-being:

- **Time Efficiency:** Teachers save 8-15% of session time otherwise lost to manual cleaning, enabling more extensive learning or shorter lesson turnover.
- **Health Outcomes:** Asthma, eye irritation, and allergic responses attributable to chalk dust are significantly reduced, easing chronic ailments among sensitive populations.
- **Educational Engagement:** Attention and productivity increase when instruction is uninterrupted, and the classroom environment remains physically comfortable.
- **Accessibility:** Smart board cleaners democratize technical maintenance, allowing those with restricted mobility to operate cleaning cycles with ease.

Schools and universities are at the forefront of adopting these technologies, advancing in parallel with broader “smart campus” efforts.

Future Trends in Automatic Board Cleaning

- **Robotics and AI:** Fully autonomous, multi-surface robots are anticipated to handle both board and floor cleaning, adapting to new surface types and contamination profiles as part of holistic smart building or factory ecosystems.
- **Digital-Physical Integration:** Cleaning robots may soon dynamically coordinate with digital whiteboards, scheduling themselves when e-ink or smart glass boards are inactive (or integrating cleaning with digital reset functions).
- **Predictive and Condition-Based Maintenance:** Combining board use analytics and sensor data will enable just-in-time cleaning, reducing both energy and consumable usage while maximizing cleanliness.
- **Zero Waste and Closed-Loop Systems:** Increased regulatory and user demand for zero-emission, closed-loop cleaning and waste handling.

- **Open Source and Customizability:** Growth in open-source hardware/software platforms (e.g., Arduino-based) will spur local innovation in educational, hobbyist, and low-volume industrial contexts, lowering entry barriers for custom solutions.

Results

The literature reveals common consensus:

- Automatic board cleaning machines substantially outpace manual cleaning in speed, coverage, and effectiveness, with typical cycle times reduced by 50-75%.
- Integrated health and dust management systems mitigate environmental contaminants, improving classroom and factory health metrics.
- IoT and AI integration are rapidly increasing, providing measurable operational, environmental, and cost benefits in both education and industry.
- Sustainability, regulatory compliance, and facility-wide integration are now prominent product differentiators, shaping patent and market activity.

Discussion

The **Discussion** integrates technical findings with broader considerations-market trends, user feedback, comparative technology analysis, and future outlook.

A. Comparison with Manual and Other Cleaning Approaches

Automated board cleaning offers significant time, consistency, and ergonomic benefits. Compared with manual duster or mop cleaning, these machines operate faster, provide repeatable quality, and shift the teacher's focus back to instructional delivery. Unlike early fixed or robotic systems that removed segments of the board or required special markers/paper, modern approaches seamlessly retrofit existing surfaces and allow for adaptive, user-triggered operation.

B. Technological Considerations

- *Belt-driven* systems fit cost-sensitive and high-speed requirements, at the expense of some precision.
- *Rack and pinion* and *lead screw* mechanisms are justified for heavier, longer, or highly precise installations.
- *Stepper and servo motor control* enables not just full-board, but partial/localized area cleaning.
- *Sensor integration* (IR, ultrasound, limit switches) and wireless/Bluetooth IoT features open new user interface paradigms.

C. Market and Adoption Trends

The market for board cleaning machines, particularly in education and automation sectors, displays robust growth projections (estimated $2.5-$3 billion in 2025, CAGR ~5-7%) fuelled by industrialization, smart classroom initiatives, and demand from Asia-Pacific due to rapid expansion of schooling infrastructure and electronics manufacturing.

- *Industrial settings* emphasize robust, high-throughput, and double-sided cleaning machines.
- *Educational and office settings* prioritize user safety, minimal maintenance, and ease of integration.
- Modular, miniaturized, IoT-enabled designs are emerging, addressing smaller institutions and flexible workspaces.

D. Sustainability and Maintenance

Modern board cleaners' trend toward eco-friendly materials (biodegradable wipes, dust containment, energy-efficient motors), reduced noise, and user-serviceable parts. The automation shift also lessens dependency on harsh chemical cleaners or disposable materials.

E. Limitations and Future Scope

- Mechanical wear of moving parts (belts, brushes) and duster replacement remain service requirements.
- Complex multi-axis and localized cleaning mechanisms may demand higher investment, limiting adoption in resource-constrained environments.
- Integration with AI (for detection of dirt/marker presence, adaptive cleaning) and cloud-based maintenance analytics is an emerging field ripe for research.

Conclusion

Automatic board cleaning machines-spanning simple classroom devices to industrial-grade PCB washers-represent a convergence of mechanical design, control electronics, smart sensing, and sustainability. Driven by the imperatives of efficiency, health, cost, and regulatory compliance, these devices are setting new standards for maintenance of critical communication and production surfaces. Recent trends, such as integration with IoT, AI, and energy- and water-saving technologies, promise even greater gains in operational intelligence and environmental responsibility.

The evolution of these systems reflects a broader shift towards comprehensive, data-driven automation across sectors. The future is likely to see collaborative, fully autonomous cleaning solutions that are responsive to real-time conditions, seamlessly adapt to heterogeneous infrastructure, and embody best practices in sustainability and health. As adoption accelerates in both educational and industrial arenas, continual cross-fertilization of innovations between these domains is expected-a trend sure to yield further performance enhancements, cost reductions, and societal benefits.

References (27)

1. *STUDY ON EFFECT OF CHALK DUST ON CLASS ROOM ENVIRONMENT AND ON HUMAN ....* https://www.ijamtes.org/gallery/52.%20sept%20ijmte%20-%20cw.pdf

2. *Teknik*. https://www.teknek.com/media/cqnlio43/tek-bc-40-brochure_feb25.pdf

3. *Board cleaning devices patented technology retrieval search results ....* https://eureka.patsnap.com/application-patents-board-cleaning-devices

4. *Sustainable Cleaning Practices 2025.*https://c4maintenance.com/sustainable-cleaning-practices-in-2025-a-guide-to-green-cleaning-and-janitorial-services-for-businesses/

5. *Inline Aqueous PCB Cleaning for Residue-Free Boards.*https://www.surfacemountsolutions.com/services/inline-aqueous-pcb-cleaning

6. *Design & Fabrication of Smart Board Cleaner - IRJET*. https://www.irjet.net/archives/V6/i4/IRJET-V6I4350.pdf

7. *Design and Development of Board Cleaning System - IJARIIT*. https://www.ijariit.com/manuscripts/v4i1/V4I1-1242.pdf?468710&468710

8. *The Future of Eco Cleaning 2025 and Beyond: Innovations and Trends ....* https://ecoflip.org/the-future-of-eco-cleaning-2025-and-beyond-innovations-and-trends-transforming-the-industry/

9. *Design and Fabrication of Automatic Board Erasing Mechanism*. https://www.ijres.org/papers/Volume-9/Issue-6/Ser-7/F09062831.pdf

10. *IJRTI - IJCRT*. https://ijcrt.org/papers/IJCRT24A4843.pdf

11. *Design and Fabrication of Automated Board Cleaner - IJSRSET*. https://ijsrset.com/IJSRSET2310120

12. *SMART CHALK DUST REMOVER - IRJET*. https://www.irjet.net/archives/V9/i8/IRJET-V9I8259.pdf

13. *Automatic White Board Cleaner using Arduino Uno - Pantech.AI*. https://www.pantechsolutions.net/automatic-white-board-cleaner-using-arduino-uno

14. *Johnson Geared Motor 300 RPM 12v dc gear for robotics*. https://www.amazon.in/Robodo-Electronics-Johnson-Geared-Robotics/dp/B00N4O7GU6

15. *Brushless DC Motors & Gear Motors Technical Articles / White Papers*. https://www.orientalmotor.com/brushless-dc-motors-gear-motors/technology/index.html

16. *SMPS Repair in India*. https://dir.indiamart.com/impcat/smps-repair.html

18. *Introducing a cleaning revolution - the autonomous cleaning robot from ....* https://www.cenobots.cz/en/cenobots-l4

19. *Whiteboard Duster - Soni Office Mate*. https://soniofficemate.com/product-category/dusters/

21. *Title: Chalk Dust Extraction and Cleaner: A Health-conscious Solution ....* https://jseepublisher.com/wp-content/uploads/8-JSEE2102.pdf

22. *Automatic White-Board Eraser - IJCRT*. https://ijcrt.org/papers/IJCRT_187756.pdf

24. *Figure AI robot.*https://indianexpress.com/article/technology/tech-news-technology/figure-03-ai-powered-humanoid-robot-10300926/

17. *Automatic Whiteboard Cleaner Design Using Arduino*. https://studylib.net/doc/25850625/ijireeice.2018.696

20. *Mahit Systems Regular Non-Magnetic Perfect Clean for Blackboard ....* https://www.flipkart.com/mahit-systems-regular-non-magnetic-premium-non-magnetic-wooden-white-board-duster-whiteboard-eraser-erasing-marker-chalk-writing-pack-1-dusters/p/itm261d07db886aa?pid=WADG4A7XE5P78FVU

23. *Robotin R2: Autonomous AI Robot Vacuums, Washes, Dries Carpets*. https://newatlas.com/consumer-tech/robotin-r2-robot-cleaner-washes-vacuums/