Smart Robotic Arm-Based Broom with Dust Detection Using IoT and Computer Vision

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ABSTRACT

The demand for cleaner, more efficient, and self-sufficient indoor spaces is rapidly increasing. Traditional manual cleaning methods are inconsistent and time-consuming, while most commercial robotic vacuum cleaners follow rigid, pre-set routes and lack intelligent dirt detection. However, advancements at the intersection of robotics, IoT, and computer vision are paving the way for unsupervised cleaning systems capable of sensing and responding to dirt in real time. This survey focuses on the development of a smart robotic arm equipped with a broom and integrated IoT-based computer vision for dust detection. We comprehensively review dust-cleaning robotic arms, computer vision techniques for dirt detection, remote monitoring via IoT, and autonomous indoor navigation. The evolution of cleaning robotic arms is traced from basic mechanical designs to sophisticated, vision-based systems that can identify dirt, utilize advanced algorithms for path optimization, and target cleaning with intelligent sweeping mechanisms. Research highlights the effectiveness of computer vision in recognizing dirt patterns, while IoT technologies enable real-time remote control and monitoring. Path-planning algorithms like A* further enhance navigation in complex environments. Although challenges such as lighting conditions, reflective surfaces, and mechanical constraints persist, the integration of these technologies holds significant promise for achieving truly autonomous and efficient indoor cleaning.

This survey synthesizes key research trends and technological innovations that directly inform the design and implementation of the advanced automated floor-cleaning system developed for the capstone project.

INTRODUCTION

Keeping offices, homes, and industries clean and hygienic is always necessary, but manual cleaning is always inconsistent, tedious, and very time-consuming. While it's possible to purchase commercial robotic vacuum cleaners, they operate under the same programmed movements, are incapable of understanding whether or not the floor is dirty, and clean the area in the same inefficient manner. These inefficient methods lead to high energy cost. Fortunately, the cleaning industry is advancing with the help of embedded systems, the internet of things, and computer vision. Contemporary research is attempting to achieve the integration of remote cloud systems, smart navigation, computer vision for dirt detection, and robotic systems that perform selective cleaning. In dirt detection, vision-based systems rely on contrast variations of the target dirt within the captured image, and in selective cleaning, dust dirty areas are addressed with the use of robotic arms that perform efficient sweeping. This document attempts to survey the body of knowledge in the following domains:

- Autonomous cleaning robots
- Vision-based dirt detection
- Smart home clearing systems through IoT
- Cleaning robotic arms
- Indoor robotics navigation algorithms.

The objective is to present insights concerning the research directions and trends to assist in the development of a dust detecting, computer vision, IoT integrated smart robotic arm broom.

LITERATURE SURVEY

Year	Name	Author	Methodology	Advantages	Disadvantages	Remarks
2022	Dirt Detection Using OpenCV for Autonomous Service Robots	1.Chaturvedi. N 2. Rao. H	• Developed an innovative solution for detecting dust using an image processing technique which applied grayscale conversion, adaptive thresholding, morphological filtering, as well as texture analysis. • Assessed dirt patches with different lighting and background conditions.	• Contains accurate results when detecting unclear dust particles • The analysis done is low in terms of computational power. • Resolves issues with low-level interaction.	• Low-light performance decreases. • Glossy surfaces create reflection noise.	• This is highly relevant to our project's dust detection module.
2022	Obstacle Detection and Avoidance in Vision-Based Robots	1.Davis. R, 2. Lee. J.	• Implemented a monocular camera-based obstacle detection using edge maps, depth cues, and bounding region estimation. • Integrated feedback control for real-time avoidance.	• Static obstacle detection that is dependable. • Accurate computation of edge and depth • Operates in settings that are somewhat dynamic	• Has trouble with transparent objects • Needs a steady frame rate	• Beneficial for enhancing cleaning robot navigation and safety.
2022	A Comparative	Flores. R.	• For indoor	• A clear comparison	• SLAM requires a lot	• Offers information

	Analysis of Indoor Robot Localization Techniques.		mobile robots, SLAM, Visual Odometry, RFID, and ultrasonic localization techniques were compared. • Examined complexity, cost, and accuracy.	of various localization schemes. • Assists in selecting appropriate indoor positioning techniques.	of processing power. • Infrastructure is required for RFID localization.	for upcoming improvements to indoor navigation.
2021	IoT-Enabled Smart Home Cleaning System with Remote Monitoring	1.Ahmed. T. 2.Robinson.L.	• A cleaning robot was controlled remotely via Wi-Fi and cloud-based dashboards. • Made it possible to monitor performance logs, batteries, and cleaning cycles.	• Strong integration with IoT. • Live monitoring is supported. • Easy management with smartphones.	• Network latency problems. • Lacks smart dirt detection.	• It's very useful for your project's IoT dashboard.
2021	Vision-Guided *A* Navigation for Indoor Mobile Robots	1. Martinez. G. 2.Hu.D.	• Combined A* path planning with camera-based environment feedback. • Used real-time vision correction for improving indoor navigation accuracy.	• Path generation efficiently • High precision of navigation. • Works in semi-dynamic environments.	• Requires good lighting. • Slower in cluttered scenes	• Supports your A* algorithm for your robot's navigation
2021	IoT Integration Techniques for Home	Chen.B.	• IoT Ecosystem for Smart Appliances using MQTT	• Tight/very low communication delay	• Requires stable internet access.	• Useful for enhancing your IoT connectivity framework.

	Automation Robotics		and REST APIs. • Proven low-latency communication capabilities for robotics modules	• Supports automation rules • Secure data flow	• Limited offline capability.	
2021	MQTT Communication for Real-Time Robotics Monitoring	1.Wu. T. & 2.Zhang. Q	• Proposed MQTT-based publish–subscribe communication for robot telemetry, real-time messages, and control signals.	• Lightweight protocol. • Best suited for IoT robots. • Real-time bi-directional data.	• Performance depends on broker load. • Not ideal for high-bandwidth media.	• Helps justify your MQTT communication in IoT module.
2021	Smart Cleaning Robots for Commercial Spaces.	1.Hernandez. L., & 2. Ortiz. S.	• Reviews industrial-grade cleaning robots used in malls and offices; reviews about mapping, scheduling, and semi-autonomous operation.	• Handles large areas. • Strong cleaning hardware. • Long operational life.	• Very expensive. • Complex maintenance.	• It also illustrates the difference between commercial robots and domestic smart robots.
2021	Role of Machine Perception in Next-Generation Robotics	1.Sharma. A. 2.Kumar. V.	• This paper reviewed the changing face of machine perception, with an emphasis on how future autonomous robots rely upon multi-sensor data fusion rather than single-sensor feedback.	• Solid theoretical layout for perception systems. • Helps designers to choose appropriate sensors. • Covers workflows of multi-modal perception. • Highlights challenges	• Not related to cleaning robots. • Lacks implementation-level details for embedded systems	• Useful for designing your robot's perception module; it supports the choice of vision as the principal modality with the option for future sensor fusion

				and future opportunities.		
2020	Computer Vision Challenges in Indoor Automation	1.Morgan.P. 2.Steele.W.	• Assessed challenges that exist within indoor CV systems such as: • Glare and Specular Reflection • Non-un • Texture similarities between dust and floor • Occlusion due to • Sensor noise and camera calibration problems. • The article also introduced solutions like adaptive brightness normalization, histogram equalization, shadow removal, and edge-preserving smoothing filters.	• Explains practical CV difficulties. • Offers mitigation techniques. • Enhances accuracy rates for detection.	• No implementation on cleaning robots. • More conceptual and diagnostic.	• Absolutely essential for enhancing your own dust removal system.
2020	Computer Vision Techniques for Indoor Surface Dirt Classification	1.Singh, A. 2.Iyer, R.	• Texture extraction: GLCM (Gray-Level Co-occurrence Matrix) • HSV segmentation, to differentiate	• Accurately classifies dust, stains, cracks. • Works on a wide variety of floor textures. • Helps robots	• Needs stable light conditions. • Computationally expensive for small microcontrollers • Requires tuning of	• data cable - Supports future improvements in your project by possibly introducing multi-class categorization of dust.

			stains and dust • Density estimation by thresholding • K-means clustering to cluster dirt types • Morphological operations for refining detection	prioritize cleaning intensity.	the parameters with respect to different floor types.	
2020	Energy-Efficient Design of Autonomous Cleaning Systems	Kumar. S	• • Glare and specular reflections • Illumination non uniform. • Contact of dust and floor due to texture similarities • Occlusion by furniture • Motion blur due to the speed of the robot. • Sensor noise and camera calibration	• Explains practical difficulties for a CV. • It furnishes mitigation techniques.	• No implementation on cleaning robots. • Conceptual and diagnostic in the most part	• A must-have reference in enhancing the robustness of your dust detection system.
2020	Vision-Based Autonomous Cleaning Robot for Indoor Environments	1.Kulkarni. R., 2.Mehta, S. & 3.Nair. P.	• RGB-to-grayscale conversion • Smoothing using a Gaussian distribution • Texture analysis for dust differentiation • It is capable of	• Efficient cleaning precisely at the target. • Minimizes mechanical wear and battery use. • Upon implementation, it provides effective dust detection on	• Cannot detect transparent spills-water, oil. • Highly sensitive to shadows and light variations • Struggles with dark or highly	• Provides a solid grounding for your vision-based dust detection module by confirming that OpenCV may be applied.

			performing most tasks dealing with image processing, including the following: Edge and contour extraction • Region-of-interest detection • Motion planning toward dirty areas	regular surfaces. • Works in real-time on the embedded hardware.	reflective floors	
2019	Autonomous Cleaning Robot Using Ultrasonic Navigation	1.Sudheer. K., 2.Prakash. A. 3.Menon. V.	• Developed a robot cleaner that employed ultrasonic sensors for distance measurement and obstacle avoidance. Obstacle avoidance using ultrasonic sensors included: • A predefined zig-zag movement pattern • Real-time wall following • Proximity • Simple sweeping system • The Arduino microcontroller controlled	• Hardware costs were very low. • Effective obstacle detection even in normal conditions • Able to be implemented on simple robots.	• No dust detection capabilities. • Obstacles involving fabric or fuzzy • Cleaning is uniform, not selective	• Highlights the limitations of sensor-only techniques – helping my argument for vision-based intelligent cleaning.

			sensor data and motor activation.			
2019	Robotic Arm-Based Sweeping Mechanism Using Servo Motor Control	1.Tanaka.M. 2.Hiroshi. Y.	• Developed a servo-driven robotic arm for sweeping applications, with 3–5 degrees of freedom; the system used • Metal gear-servos for durability • Angle dynamic adjustment for different sweep patterns • Forward–backward cleaning cycles • Torque analysis for brush handling • Servo calibration routines • Exercise through repetitive motions to chart precision, stroke length, and coverage area.	• High accuracy sweeping motion. • Excellent for cleaning targeted in specific small areas. • Customizable movement sequences	• Servos overheat under heavy load • Requires periodic recalibration.	• Mechanical joints that wear down over time · Very close to the mechanical cleaning arm concept used in your project
2019	Servo-Based Robotic Arm Control for Domestic Automation	1.Patel. M. 2.Shah.K	• Designing a servo-controlled robotic arm in this paper is based on:	• Smooth, controlled servo motion • High repeatability and stability.	• Limited payload capacity. • No perception, no CV involved.	• Applies to motion control, stability and calibration of your robotic arm

			• PID feedback loops • PWM signal-based servo control • Trajectory mapping • Forward and inverse kinematic modeling • The arm has been tested for picking, placing, sweeping motions, and as a help in household matters.	• Safe and easy integration with Arduino/ESP systems.	• Limited mobility	
2019	Embedded Control Strategies for Service Robots	1.Rao. P. 2.Deshpande. N	• Real-time motor control • Efficient sensor data sampling • Multi-thread • Interrupt-driven control loops • Sensors such as IR, ultrasonic, and encoders • Decision-making logic embedded	• More useful for embedded programming. • Enhances system response • Enables scalable architectures for controlling robots	• No references on computer vision. • General, not specific to cleaning	• Helps with efficient ESP32/Arduino logic
2019	Autonomous Cleaning Robot Using Ultrasonic Navigation	1.Sudheer. K., 2.Prakash. A. 3.Menon. V.	• Designed a cleaning robot that employed ultrasonic sensors to calculate distance as well as avoid	• The cost of the • Observable obstacle detection even under normal conditions	• Lack of ability to detect dust • Fabric/ fuzzy obstacles • Cleaning is uniform, not selective	• Illustrates the weaknesses of sensor-only solutions – helping to support your vision-based intelligent

			obstacles. The navigation system used: • A predefined zig-zag trajectory • Real-time wall following • Based on • Simple sweeping mechanism • The Arduino microcontroller managed the coordination of sensor inputs with the movement of the motors.	• Easy to implement on simple robots.		cleaning solution.
2018	Hybrid Cleaning Robots for Multi-Surface Environments	1.Barrett. L. 2.Wilson, H.	Created a hybrid cleaning robot integrating: •Side brushes •Central roller brushes •Suction mechanism •Basic IR-Based Navigation It has been tested with dust, hair, crumbs, and sand on different floor types.	• Able to process heavy debris. • The mechanical cleaning is effective. • Supports carpets, tiles, wood floor cleaning.	• High power consumption. • Cleans everything evenly • No intelligent behavior.	• Supports your message that your intelligent, vision-driven strategy is the best
2018	Path-Planning Algorithms for Autonomous Mobile Robots in	1.Verma. S. 2.Gupta. A.	• Compared A*, Dijkstra, and RRT in indoor cleaning robot	• A* offers the shortest and optimal path. • Lower time	• RRT yields paths that are irregular. • Dijkstra is slow.	• Conclusively, justifies that your project chose to use the A* algorithm for navigation.

	Cleaning Applications		navigation. Path length, time, and robustness in obstacle-rich environments have been evaluated.	complexity than Dijkstra. • efficiency in node expansion,	• A* requires good heuristic design.	
2018	Hybrid Cleaning Robots for Multi-Surface Environments	1.Barrett. L. 2.Wilson, H.	Developed a hybrid cleaning robot that incorporates: •Side brushes • Central Roller Brushes •Suction mechanism •Basic IR-based navigation The robot was tested on dust, hair, crumbs, and sand on different floor types.	• Capable of handling heavy debris. • The result of good mechanical cleaning is • Theoretically, it can work on carpets, tiles, wood	• No intelligent behavior. • High power use. • Cleans everything evenly	• Aids in explaining why your intelligent, vision-centric approach is better.

SUMMARY

From the previous studies, modern innovations are robotics, computer vision, IoT, and autonomous navigation that synergistically provide a solid base for the smart cleaning system. The use of computer vision studies demonstrates that different methods for detecting dirt, such as grayscale, thresholding, and texture analysis, are useful to determine even the dust on some surfaces indoors and these methods are implemented on OpenCV, but these methods are only useful on certain lighting conditions. In studies of robotic arms, the advantage of servo systems in sweeping actions is reiterated, for they provide localized cleaning and are superior in performance to uniform cleaning and more traditional methods. The studies demonstrated that A* and other pathfinding algorithms together with navigation systems are able to provide a user better, more efficient, and reliable system to get to places where dirt is located and these systems also consume less energy. The integrated system composed of computer vision and robotic arm actuation and with IoT communication, accompanied by efficient pathfinding algorithms and autonomous navigation represents a more effective and available solution for cleaning numerous modern places, these systems exemplified in the Smart Robotic Arm–Based Broom with Dust Detection Using Iot and Computer Vision.

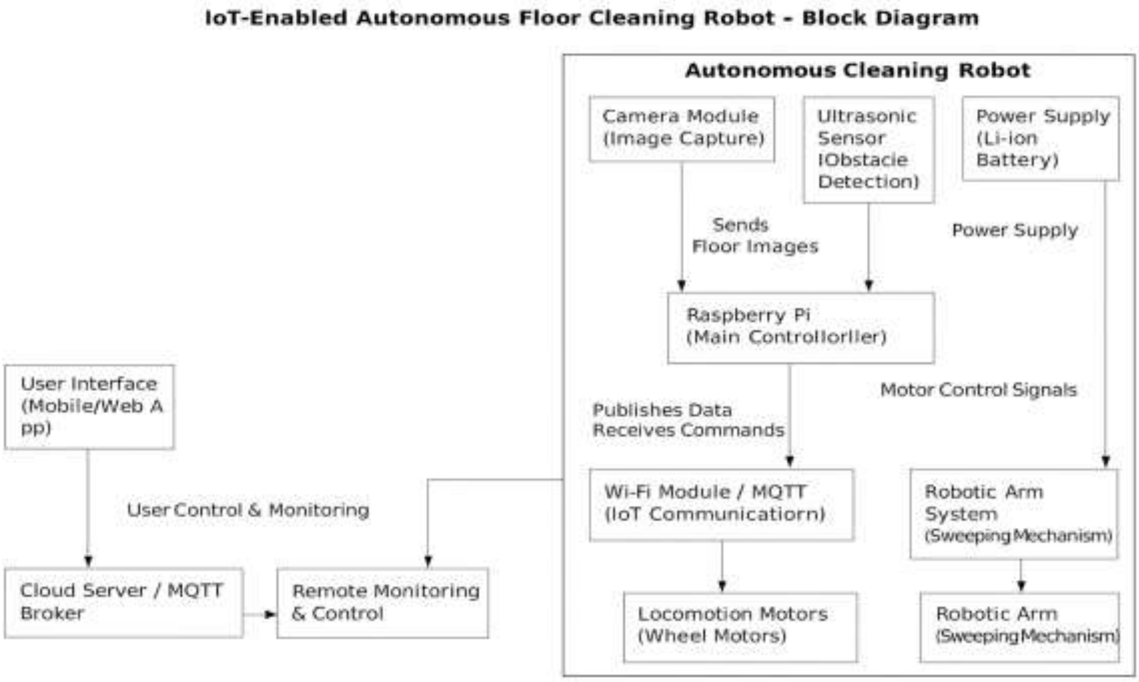

Fig. 1 — IoT-Enabled autonomous floor cleaning robot System Architecture

echnology like machine learning, robotic actuation and cleaning, obstacle detection, and IoT communication together enable autonomous cleaning. Primary processing units, Raspberry P is, execute two functions, analyzing captured images of the floor while crossing distance thresholds with ultrasonic sensors to determine the presence of obstacles, and to avoid clutter collisions. With the data processed, the Pi commands the locomotion servos and the robotic arm, efficiently deployed via the sweeping mechanism. An MQTT-enabled Wi-Fi module allows the autonomous IoT device to interface with the cloud for live monitoring and user commands through the mobile or web portal. The Pi achieves intelligent dirt detection and cleaning, while the cloud functionality executes seamless IoT interactions.

CONCLUSION

The survey results prove that computer vision, robotic actuation, IoT communication, and intelligent navigation serve as indicators that fully integrate together for the autonomous cleaning systems of the future. Research has shown improvements as to how accurately dirt is detected, how energy efficient systems operate, and how smart other systems interact. Still, vast majorities of cleaning robots continue to operate using the same uniform cleaning patterns, and fail to utilize their technology to target specific areas for a cleaning sweep. This directly implies the need for the Smart Robotic Arm–Based Broom with Dust Detection Using IoT and Computer Vision. The proposed project combines vision-based dirt detection and a servo-driven robotic arm mechanism to move beyond the conventional use of a vacuum for cleaning to deliver a more efficient and energy saving approach. The use of IoT systems with MQTT provides remote monitoring and control to the user, to ensure that thoughtful navigation is optimized to move to dirtied areas that have to be cleaned. The surveyed literature help to confirm the proposed ideas, and demonstrate the extent of the ideas that will help to advance the project more to the proposed vision, and the positive correlation they will have to a more autonomous approach to improving indoor cleaning.