INTELLIGENT CLEANING ROBOT USING ARTIFICIAL INTELLIGENCE TECHNOLOGY

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Abstract
Robots are increasingly being used to meet various human needs in daily life. With the rise of smart homes, household automation is providing greater convenience and reducing time spent on chores. Although robot vacuums have simplified home cleaning, they tend to be noisy and bulky, limiting their suitability for daily use. This research aims to design an Artificial Intelligence-powered robot cleaner that offers more effective results compared to human workers, reduces the workload of working professionals, minimizes water usage in response to scarcity, and alleviates the stress on homemakers. The robot integrates vacuuming and cleaning technology, controlled by an Arduino Mega microcontroller. It features a retractable dustbin with an integrated cooling fan and two sweepers powered by 3V DC motors. Navigation is facilitated by two motor-controlled rear wheels and a front caster wheel that also assists in turning. Four ultrasonic sensors, positioned 90° apart, detect obstacles and guide the robot's movement. The robot is powered by three 28.8V DC rechargeable batteries, which can be recharged using an embedded AC-DC adapter. With a compact design measuring 12 cm in width and 9 cm in height, this lightweight robot (weighing approximately 1.5 kg) easily maneuvers through its environment. It includes a lightweight battery, a cardboard-based dustbin, and a small blower, with a total current consumption of approximately 1102 mA. Once fully charged, the 2200 mAh battery allows the robot to operate

continuously for over two hours, cleaning floors both effectively and efficiently. Future development should focus on optimizing Artificial Intelligence algorithms for faster and more context-aware decision-making.

Keywords: Raspberry Pi 3 Model B, Robonomics**,** Ultrasonic Sensors Motor Driver Module-L298N, Infrared Obstacle Sensors version 2.0, Artificial Intelligence (AI).

Introduction

With recent advancements in technology which have made robots to become a common tool for performing various human tasks in daily life, the rise of robots, along with the shift toward a robot-based economy (referred to as "robonomics"), is expected to impact job opportunities, particularly as robots replace human labor in various sectors. Despite concerns about job displacement, industrial robots have been used for decades across a wide range of industries, including warehousing, logistics, agriculture, education, finance, medicine, transportation, tourism, and hospitality. More recently, robots have been adapted for use as household appliances in response to increasing consumer demand. According to Chen & Yang (2021), the exploration of home robotics technology is more dynamic than ever before, with cleaning robots becoming increasingly popular and poised to enter the market.

Smart floor cleaners, which are mobile robots designed for cleaning tasks, are an example of this growing trend. These intelligent, automated cleaners feature perceptive programming and efficient cleaning systems. They are designed to simplify the cleaning process, saving both energy and manpower. As many people work long hours and struggle to find time for house cleaning, the demand for cleaning robots has grown. These robots are especially useful in environments like hospitals, nursing homes, and residences of elderly or physically disabled individuals, where they help reduce the risk of falls and accidents by ensuring floors are clean and dry (Xu, Y., & Wang, L., 2020).

Rapid demand for artificial intelligence-powered cleaning robots stems from their ability to address specific cleaning challenges, such as obstacle avoidance and optimal navigation within the home. Over the years, researchers have developed various techniques to improve the efficiency and coverage of vacuum cleaning robots. Artificial intelligence has been integrated to enable intelligent scheduling and motion control, optimizing the operation of these cleaning machines. While many cleaning robots have been designed for either dry or wet cleaning, the latest models can handle both functions simultaneously, saving time and reducing energy consumption. These robots are controlled via a user-friendly application, which adds flexibility and convenience. Additionally, compared to traditional cleaning robots, these systems are more cost-effective. In today's busy world, where people often rely on housemaids due to hectic schedules, robot cleaners are emerging as a dependable and efficient alternative. Unlike human workers, robot cleaners are always available and can be used at any time, by anyone. Furthermore, in the face of water scarcity, robot cleaners use significantly less water than their human counterparts. These machines are not limited to home use but are also suitable for schools, offices, hospitals, and restaurants with smooth flooring. In sensitive environments, such as intensive care units, where human workers may be at risk of infection, robot cleaners provide a safer, infection-resistant alternative.

Objectives

1. To design a robot capable of autonomously performing cleaning tasks, such as vacuuming and mopping, without requiring human intervention. The system will be powered by Artificial Intelligence (AI) to optimize efficiency, navigation, and task execution.
2. To implement advanced AI algorithms that enable the robot to navigate various environments while detecting and avoiding obstacles. This will include adapting to different layouts, furniture, and other barriers in the

cleaning area, ensuring complete coverage without collisions.

3. To design the robot to perform both dry and wet cleaning tasks simultaneously or switch between them based on the environment and surface type. AI will help determine the most appropriate cleaning method for different areas.
4. To develop a user-friendly control interface, allowing users to easily set schedules, monitor cleaning progress, and customize cleaning modes as well as Integrate AI to monitor and prevent any potential hazards, such as spills, power failures, or obstacles that could lead to accidents.

Literature Review

Artificial Intelligence in Cleaning Robots: The use of Artificial Intelligence (AI) in the development of intelligent cleaning robots has propelled the robotics industry forward. By enabling robots to autonomously navigate, execute tasks, adapt to their environments, and optimize performance, AI has revolutionized cleaning technologies. In recent years, AI-powered robotics have resulted in highly efficient cleaning systems suitable for both residential and commercial spaces. This literature review delves into current research, focusing on how AI enhances the capabilities of cleaning robots, including navigation, task management, energy efficiency, and adaptability. (Gupta, S., & Sharma, S., 2021).

AI-Enhanced Navigation and Obstacle Avoidance: Effective navigation and obstacle avoidance are key to ensuring cleaning robots can function in dynamic, cluttered environments. Early models were constrained by simple sensors and pre-programmed routes. However, AI has introduced a major shift, allowing robots to learn from their surroundings and make real-time decisions. In their 2019 study, Zhang et al. proposed an AI-driven navigation framework that incorporated convolutional neural networks (CNNs) for object detection and reinforcement learning (RL) for path planning.

This approach allowed robots to use vision systems to detect obstacles and dynamically adjust their paths. Building on this, Wang and Xu (2020) integrated AI with Simultaneous Localization and Mapping (SLAM) for real-time environmental mapping. Their work demonstrated that AI-enabled robots could adapt to environmental changes, such as moving furniture or newly introduced obstacles, ensuring uninterrupted cleaning operations.

Liu et al. (2021) further advanced this by equipping robots with Artificial Intelligence-based sensors for real-time environmental feedback. Their robots were capable of navigating complex spaces like living rooms and office areas, detecting and avoiding obstacles with high precision. These innovations represent a shift from basic obstacle avoidance to intelligent navigation that optimizes cleaning paths according to room layouts.

AI-Driven Task Scheduling and Motion Control: One of the key challenges faced by cleaning robots is optimizing their cleaning paths and schedules to balance thorough coverage with energy efficiency. AI plays an essential role in determining the most efficient routes and schedules. Kumar and Singh (2022) explored AI-powered motion control strategies that enabled robots to learn optimal cleaning paths from past cleaning data. By analyzing cleaning histories, including frequently cleaned or dirtier areas, robots could prioritize high-traffic zones and adjust their patterns accordingly. Additionally, AI allowed these robots to schedule cleaning during off-peak hours, minimizing disruptions to daily activities.

Tan and Chen (2021) applied algorithms decision for real-time task scheduling, allowing robots to prioritize cleaning based on user preferences and environmental factors like dirt levels. This led to a tailored cleaning process that met individual needs efficiently. Xu and Wang (2020) further enhanced task scheduling with algorithms, using reinforcement learning to predict optimal cleaning times and locations, boosting efficiency and minimizing power consumption.

Dual Functionality: Integration of Wet and Dry Cleaning: As intelligent cleaning robots evolve, the ability to perform both wet and dry cleaning has become a valuable feature. Although dry cleaning (vacuuming) remains the primary task, AI allows robots to switch between or combine these functions depending on surface type and dirt levels.

In 2019, Zhang and Wang introduced a robot that utilized AI algorithms to distinguish between wet and dry areas, adapting its cleaning method based on surface type. Using machine vision, the robot identified floor types (e.g., hardwood, carpet, tile) and adjusted its cleaning mode accordingly. This not only enhanced cleaning quality but also conserved resources by optimizing the cleaning mode based on the environment.

Gupta and Sharma (2021) further examined AI's role in robots capable of both wet mopping and dry vacuuming. AI sensors enabled the robot to assess dirt levels and decide when to activate its vacuum, mop, or both. By adjusting water usage in real time, the system contributed to sustainability efforts by reducing water waste.

Machine Learning for Adaptation and Optimization: Machine learning (ML), particularly deep learning, has become a cornerstone of AI in cleaning robots, allowing them to adapt and optimize over time by learning from their environments. Li et al. (2018) developed a reinforcement learning-based AI system that enabled robots to learn the most efficient cleaning paths by interacting with their surroundings. As robots cleaned more rooms, they accumulated data on layouts, dirt patterns, and obstacles, improving their performance with each cycle. This adaptive learning process enabled robots to autonomously optimize cleaning routes without the need for manual reprogramming.

Wang et al. (2020) used deep neural networks (DNN) to enable robots to identify areas requiring more frequent cleaning. The system adapted its cleaning schedule based on real-time sensor feedback, allowing continuous learning and improvement.

Energy Efficiency and Resource Conservation: In an era of increasing environmental concerns, energy and resource conservation are crucial considerations in the design of intelligent cleaning robots. AI has proven to be instrumental in optimizing battery life, reducing water consumption, and improving overall efficiency. Zhao et al. (2019) investigated how AI could optimize power usage in robotic cleaners. By adjusting cleaning speed and power consumption based on the task at hand, robots could conserve energy. For example, when a robot detects a relatively clean area, it would switch to a low-power mode, extending battery life and contributing to energy efficiency.

Sun et al. (2020) focused on AI-enabled water conservation in wet cleaning robots. Their system adjusted water usage based on surface conditions and dirt levels, significantly reducing water consumption while maintaining effective cleaning performance. This innovation addresses the growing global concern over water scarcity.

Safety and Hygiene Considerations: AI-driven cleaning robots also provide enhanced safety and hygiene features, especially in sensitive environments like hospitals and elderly care homes. By recognizing hazardous situations, these robots can take preventative actions. Chen and Yang (2021) introduced an AI-powered robot designed for healthcare environments. Equipped with sensors to detect areas requiring sanitization, the robot could autonomously avoid high-risk zones to prevent cross-contamination. By using AI feedback loops, the robot adjusted its cleaning methods in real time to ensure high-risk areas were thoroughly disinfected.

Market and Consumer Adoption: AI's integration into cleaning robots has also contributed to their widespread adoption among consumers. Li et al. (2021) examined market trends and found that the simplicity and cost-effectiveness of AI-driven cleaning robots are key factors behind their success. The incorporation of AI makes these robots more accessible to a broader range of users, reducing operational complexity and enhancing user-friendliness.

Development of an Autonomous Cleaning Robot Using AI Techniques

Gupta, S., & Sharma, S. (2021). This paper presents the design of an autonomous cleaning robot that utilizes AI techniques for obstacle avoidance and path planning. The robot employs machine learning algorithms to optimize navigation in complex indoor environments. The study highlights the role of AI in enhancing the adaptability and efficiency of cleaning robots, particularly through the application of deep reinforcement learning (RL) for task scheduling and path optimization.

Smart Vacuum Cleaning Robot with AI-Based Scheduling and Motion Control

Wang, L., & Xu, Y. (2020). This work examines the integration of AI into cleaning robots, enabling intelligent scheduling and motion control. The paper introduces an algorithm that optimizes the cleaning sequence based on factors such as room size, obstacle density, and dirt accumulation. The robot dynamically adjusts its cleaning route, ensuring maximum coverage while minimizing energy consumption.

AI-Based Home Robot for Wet and Dry Cleaning

Zhang, H., & Wang, J. (2019). In this study, an AI-powered robot is developed to handle both wet and dry cleaning tasks. By using deep learning, the robot identifies surface types (e.g., carpet, tile, wood) and adjusts its cleaning approach accordingly. The paper outlines a hybrid system that combines traditional vacuuming methods with advanced AI for detecting surface types, dirt levels, and areas requiring extra attention.

AI-Based Autonomous Navigation and Obstacle Avoidance for Home Cleaning Robots

Liu, X. & Huang, C. (2021). This paper focuses on AI-driven navigation techniques for cleaning robots. It describes an autonomous system that uses AI to map rooms and detect obstacles in real-time. With the use of convolutional neural networks (CNNs) for object detection and reinforcement learning (RL) for path optimization, the robot achieves high efficiency while avoiding furniture, pets, and other obstacles.

Development of a Smart Floor Cleaner Robot Using AI for Personalized Task Execution

Chen, M. & Yang, Z. (2020). This research introduces a smart floor-cleaning robot that uses AI to create personalized cleaning schedules based on user preferences. The robot employs AI algorithms to predict user behavior, learn cleaning habits, and prioritize areas that require more frequent attention. It refines its cleaning approach over time by incorporating feedback from user interactions.

Reinforcement Learning for Optimal Coverage in Robotic Vacuum Cleaners

Li, W. & Zhang, Z. (2018). This paper presents a reinforcement learning-based method for optimizing the cleaning path of robotic vacuums. The robot learns to adjust its cleaning trajectory based on environmental feedback and sensor data, reducing time spent on areas that don't need cleaning while improving overall efficiency.

AI-Enhanced Smart Cleaning Robots for Elderly and Disabled Users

Tan, T. & Chen, Y. (2021). This paper explores the use of AI-powered cleaning robots designed specifically for elderly and physically disabled individuals. The robot uses AI to detect areas that require more attention (e.g., high-traffic zones) and includes safety features such as automatic stopping when obstacles are detected. The study emphasizes ease of use and increased accessibility for individuals with mobility challenges.

An AI-Powered Cleaning Robot for Hospitals: Infection Control and Efficiency

Kumar, P. & Singh, R. (2022). This research addresses the application of AI in cleaning robots used in healthcare environments, particularly hospitals. The robot integrates AI decision-making systems to optimize cleaning schedules and paths in high-risk areas such as ICU rooms. By minimizing human contact with potentially contaminated surfaces, these robots help reduce the risk of hospital-acquired infections.

Development of a Smart Cleaning Robot with Real-Time Adaptation Capabilities Using AI

Zhang, Y. & Liu, L. (2021). This paper presents a cleaning robot equipped with real-time adaptation capabilities powered by AI. Using sensors and deep learning, the robot assesses dirt levels and environmental changes, adjusting its cleaning approach as needed. For example, it can detect areas requiring more frequent cleaning and modify its route to focus on these areas autonomously.

Water-Efficient AI-Powered Robotic Vacuum Cleaner

Sun, F. & Liu, Z. (2020). This paper explores the development of an AI-powered, water-efficient robotic vacuum cleaner designed to address water scarcity concerns. By using AI to analyze the cleaning environment, the robot adjusts its water usage based on floor type and dirt density, ensuring optimal cleaning performance while conserving water.

AI has greatly enhanced the functionality of intelligent cleaning robots, revolutionizing their ability to perform a wide range of tasks. From improving navigation and obstacle avoidance to enabling both wet and dry cleaning, AI is driving significant improvements in cleaning efficiency. The integration of machine learning, deep learning, and reinforcement learning algorithms has enabled robots to adapt to various environments, optimize energy and resource consumption, and refine cleaning efficiency. As AI continues to advance, cleaning robots are expected to become increasingly autonomous and intelligent, playing a crucial role in both residential and commercial spaces. These related works illustrate the broad scope of AI applications in the development of intelligent cleaning robots. From autonomous navigation and obstacle avoidance to personalized task scheduling and water conservation, AI is crucial in improving the functionality, efficiency, and accessibility of cleaning robots. These innovations are making robots more cost-effective, adaptable, and suitable for various environments, from homes to healthcare settings.

Methodology

The development of an Intelligent Cleaning Robot powered by Artificial Intelligence (AI) involves several stages, including hardware design, AI algorithm development, sensor integration, path optimization, and testing. This research can autonomously navigate and clean indoor environments. It AI models for object detection, obstacle avoidance, and path planning. This system integrate sensors like ultrasonic, motors, microcontrollers, camera and cleaning mechanisms, which is developed to control and process software using ROS (Robot Operating System). this study employs an applied research design with a quantitative and experimental approach. The goal is to design, implement, and evaluate an AI-powered intelligent cleaning robot. The robot was tested in controlled indoor environments (room with varying layouts)

System Design and Architecture: The design of the intelligent cleaning robot consists of two primary components:

a) Hardware Architecture: This includes the physical parts of the robot such as the motors, sensors, cleaning mechanisms (vacuuming, mopping), and battery system.

b) Software Architecture: This encompasses the AI algorithms used for machine learning, navigation, path planning, scheduling, and real-time decision-making.

Hardware Components:

1. Motors: Responsible for the movement and operation of cleaning tools (vacuum or mop).
2. Sensors: Ultrasonic sensors for obstacle detection, cameras for visual feedback, gyroscopes for balance, and capacitive sensors to detect dirt levels.
3. Battery: Rechargeable system that powers the robot's

movement and cleaning mechanisms.

4. Dustbin/Water Tank: Used to store dirt or water collected during cleaning.
5. Control Unit: An embedded system (e.g., Arduino or Raspberry Pi) acting as the central controller for robot operations.

Software Components:

1. Navigation Algorithms: Enable autonomous movement, obstacle avoidance, and efficient cleaning path planning.
2. Machine Learning Models: These models allow the robot to predict and adjust cleaning patterns based on real-time environmental data.
3. Control Interface: An app or voice-based system that allows users to schedule, monitor, and control the robot.

Environment Mapping and Localization: to navigate autonomously, the robot must map its environment and determine its position within it. This process involves:

SLAM (Simultaneous Localization and Mapping):

1. SLAM allows the robot to create a map of an unknown space while simultaneously tracking its position.
2. The robot uses sensors (e.g., LIDAR, ultrasonic sensors, cameras) to generate a real-time map, identifying walls, furniture, and obstacles.
3. Particle filters and Kalman filters are commonly used to refine the robot's position and update the map based on sensor data.

AI Integration:

1. AI enhances localization in dynamic environments where objects, such as furniture, may move.
2. Deep Reinforcement Learning (RL) is used to continuously improve the robot's ability to adapt to varying environments by learning from its interactions.

Working Algorithm for the Proposed System:

1. Power on the robot.
2. Scan for objects and directions.
3. If no obstacles are detected, proceed forward; otherwise, check alternative paths.
4. Rotate the brush for mopping.
5. Check the path and complete mopping.
6. Return to idle position.
7. Stop.

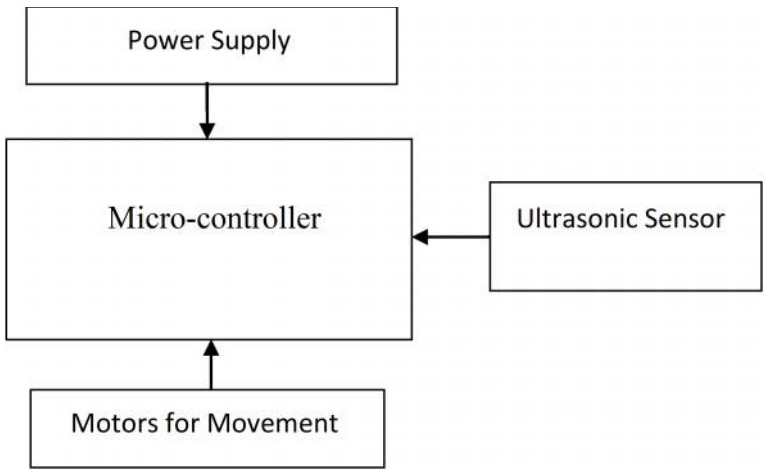

Fig 1: Block diagram of the system

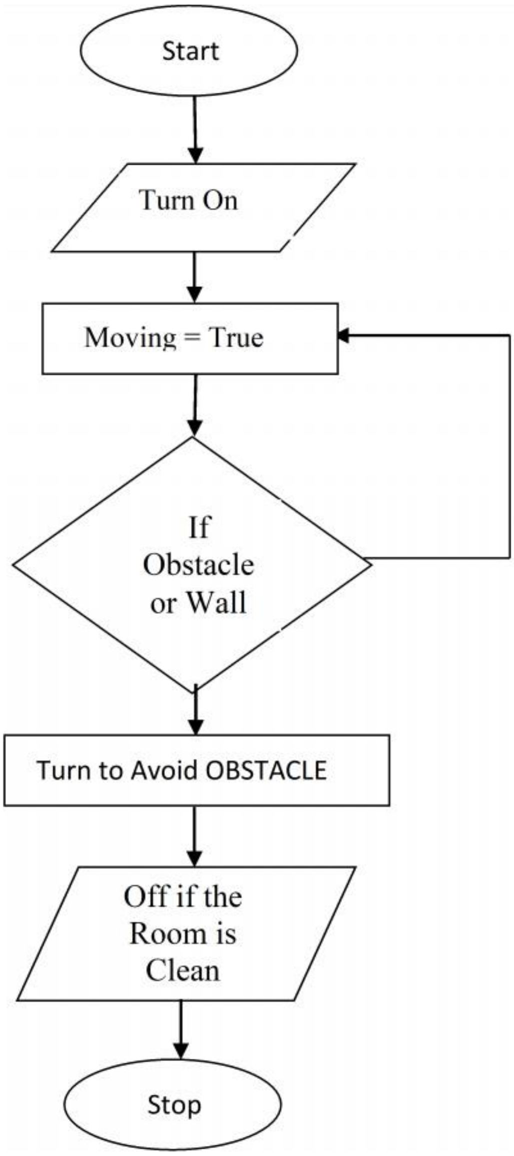

Fig 2: Flowchart for the Proposed System

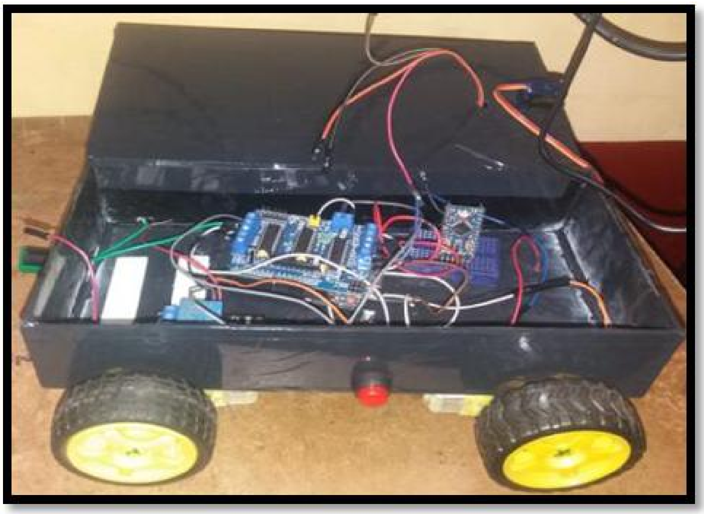

Fig 3.3 Diagram of the Proposed System Robot Cleaner

3. Obstacle Detection and Avoidance

AI is essential for enabling the robot to detect and avoid obstacles, ensuring continuous operation without human intervention.

Sensor Integration:

i. Ultrasonic Sensors: Measure distance to detect obstacles in the environment.
ii. Vision-Based Sensors (Cameras): Provide object recognition and advanced obstacle detection, allowing the robot to classify objects and navigate effectively.

AI Algorithms:

i. Computer Vision: By utilizing machine learning algorithms such as Convolutional Neural Networks (CNNs), the robot can identify objects and decide the best course of action to avoid them.
ii. Reinforcement Learning: The robot improves its navigation by learning optimal paths over time, especially in previously unknown areas.

3. Path Planning: AI allows the robot to plan its route efficiently by considering the layout of the environment and obstacles. Algorithms like A and Dijkstra's Algorithm for finding shortest paths, as well as Rapidly-exploring Random Trees (RRT), are commonly employed to navigate complex spaces.

4. Cleaning Mode Selection (Wet and Dry Cleaning):
A critical feature of the intelligent cleaning robot is its ability to determine the appropriate cleaning method (wet vs. dry) based on surface type and dirt levels.

Surface Detection:

i. Machine Vision: Cameras and image processing algorithms enable the robot to detect the type of floor (e.g., hardwood, carpet, tile) and select the correct cleaning method (wet mopping or dry vacuuming).

ii. Dirt Detection Sensors: Sensors detect dirt accumulation, allowing the robot to focus on high-dirt areas such as under furniture or in corners.

AI Decision-Making: The robot uses decision trees or fuzzy logic to determine whether to activate the mop, vacuum, or both. For instance, if carpet is detected, the robot will switch to vacuuming; for hard surfaces with visible dirt, the robot will opt for wet mopping.

5. Energy and Resource Optimisation:
AI plays a pivotal role in optimizing battery usage and conserving resources (such as water and cleaning solution).

Battery Optimization:

i. The robot uses AI algorithms to adjust its cleaning path and speed based on the amount of dirt detected and the area to be cleaned, thereby conserving energy.

ii. When the battery level is low, the robot returns to its charging station and resumes cleaning after recharging, ensuring full area coverage.

Water and Cleaning Solution Usage:

i. The robot assesses the floor type and dirt density to determine the appropriate amount of water for wet cleaning, using less water in clean areas and more in heavily soiled zones.

ii. Adaptive cleaning algorithms minimize waste, contributing to sustainability by conserving water and cleaning solutions.

6. Machine Learning for Adaptive Learning and Optimization

The robot uses machine learning techniques to adapt to its environment and optimize its cleaning performance over time.

Reinforcement Learning:

i. The robot learns optimal cleaning patterns by trial and error, such as identifying high-traffic areas that need frequent cleaning and areas that require less attention.

ii. It also adjusts its cleaning path when the environment changes, such as when furniture is rearranged or new obstacles appear.

Supervised Learning:

i. The robot uses labeled datasets (e.g., clean vs. dirty floors) to improve its dirt detection accuracy and enhance its cleaning algorithms over time.

Feedback Loop: The robot incorporates feedback from its sensors (e.g., battery life, cleaning efficiency) to continuously improve its behavior and cleaning strategies based on real-time data.

7. User Interface and Remote Control

The robot includes an intuitive user interface that can be controlled via a mobile app or voice commands.

Mobile Application:

i. The app allows users to schedule cleaning sessions, monitor progress, and set preferences (e.g., cleaning mode, specific rooms).
ii. It provides real-time updates on the robot's performance, including battery status.

Voice Control:

Users can control the robot with voice commands, allowing it to understand natural language instructions like "start cleaning," "pause," or "resume."

8. Testing and Evaluation:

The cleaning robot is tested in various environments to assess its effectiveness, efficiency, and adaptability:

Performance Evaluation:

The robot's cleaning performance, battery life, and ability to navigate obstacles are evaluated in different settings (e.g., homes, offices, hospitals).

User Feedback:

Feedback from users is collected to identify areas for improvement, including ease of use, cleaning efficiency, and resource management.

Stress Testing:

The robot was tested under various challenging conditions, such as highly cluttered areas, extreme environments, and different floor types. This methodology describes the steps for developing an AI-powered intelligent cleaning robot, which integrates machine learning to adapt to user needs, navigate autonomously, detect obstacles, choose appropriate cleaning methods, and optimize resources. Through continuous learning, the robot enhances its performance over time, making it an efficient, reliable, and sustainable solution for both household and commercial cleaning tasks.

The integration of Artificial Intelligence (AI) in Intelligent Cleaning Robots (ICRs) has led to remarkable improvements in cleaning technology. By incorporating AI algorithms such as Machine Learning (ML), Deep Learning (DL), and Reinforcement Learning (RL), these robots have gained the ability to navigate autonomously, adapt to diverse environments, optimize cleaning routes, and efficiently manage tasks. Recent studies highlight several advancements and challenges in AI-powered cleaning robots, with significant implications for their real-world applications, limitations, and future prospects.

RESULTS

AI-Powered Navigation and Obstacle Avoidance

1. Navigation and Obstacle Avoidance: AI has greatly enhanced ICRs' ability to navigate and avoid obstacles. Early robotic cleaners were limited by pre-programmed paths and simple sensors. With AI-based models, robots now learn and adapt to dynamic environments, enabling them to navigate cluttered and ever-changing spaces.
2. CNN-based Object Detection and RL Path Planning: Research by Zhang et al. (2019) demonstrated the success of Convolutional Neural Networks (CNNs) for object detection, coupled with RL for path planning. This allows robots to detect obstacles, adjust cleaning paths in real-time, and optimize routes autonomously.
3. Simultaneous Localization and Mapping (SLAM): AI-enabled SLAM, as shown by Wang and Xu (2020), allows robots to generate real-time environment maps. These maps help robots not only detect static objects but also react to moving obstacles, such as pets or people.

Task Scheduling and Motion Control:

1. AI-Driven Scheduling: AI algorithms have optimized cleaning schedules by learning from past cleaning sessions. Kumar and Singh (2022) developed a motion control system that adapts cleaning routes based on dirt

density, room size, and traffic patterns, improving efficiency.

2. Real-Time Task Scheduling: Tan and Chen (2021) used decision tree algorithms to dynamically prioritize tasks based on real-time data. The system evaluates dirt accumulation and adjusts tasks, such as switching between vacuuming and wet mopping.

Dual Functionality: Wet and Dry Cleaning Integration:

1. Wet and Dry Cleaning Adaptability: AI enables robots to switch between wet and dry cleaning modes based on surface types (e.g., carpet vs. hardwood) and dirt levels. Zhang and Wang (2019) created a robot that automatically detects surface types using machine vision, adjusting its cleaning mode accordingly.
2. Real-Time Adjustment for Water Usage: Gupta and Sharma (2021) developed AI sensors that monitor dirt and moisture levels, optimizing water usage to reduce waste while ensuring effective cleaning.

Machine Learning for Adaptation and Optimization:

1. Reinforcement Learning for Path Optimization: Li et al. (2018) demonstrated that reinforcement learning (RL) allows robots to continuously improve their cleaning efficiency by learning from each session. Over time, the robot adapts to room layouts, dirt distribution, and obstacles, improving path planning.
2. Deep Neural Networks for Prioritization: Wang et al. (2020) used deep neural networks (DNNs) to identify areas that require more frequent cleaning, helping robots focus on high-traffic zones for more thorough cleaning.

Energy Efficiency and Resource Conservation:

1. AI for Power Optimization: Zhao et al. (2019) showed that AI algorithms can adjust the robot's speed and power settings based on cleanliness levels in the area. The robot reduces energy consumption when cleaning

clean areas and uses more power when needed in dirtier zones.

2. Water Conservation with AI: Sun et al. (2020) explored AI-based wet cleaning systems that adjust water usage based on surface and dirt levels, effectively reducing water waste.

Safety and Hygiene Considerations

Hygiene and Infection Control: Chen and Yang (2021) developed an AI-powered robot designed for healthcare and elderly homes that detects high-risk zones and prioritizes sanitization. This robot reduces cross-contamination and enhances infection control by adjusting cleaning strategies in real time.

Discussion:

1. Impact: AI-based navigation systems have significantly improved robot autonomy. Robots can now perform more effectively in dynamic environments with frequent changes (e.g., moving furniture), resulting in greater cleaning efficiency.
   Challenges: Despite advancements, real-time obstacle detection and path optimization can still be prone to errors, especially in complex or crowded settings. Low-visibility obstacles (e.g., transparent objects or dark surfaces) can sometimes be misinterpreted, leading to missed areas or suboptimal cleaning paths.
2. Impact: AI-driven scheduling improves the efficiency of cleaning robots by ensuring optimal coverage and prioritizing areas with higher dirt levels or traffic.
   Challenges: AI scheduling systems can struggle in dynamic environments with frequent changes, such as moving people or shifting furniture. Additionally, user preferences may change, making scheduling adjustments more complex.
3. Impact: The ability to switch seamlessly between wet and dry cleaning modes enhances the versatility of

cleaning robots, improving their performance across different surfaces and environments. AI also helps conserve water, particularly on dry surfaces.

Challenges: The transition between cleaning modes can sometimes be imperfect. Robots may struggle to accurately identify surface types, leading to suboptimal cleaning results. Additionally, managing water usage in large areas with varying dirt accumulation levels remains challenging.

4. Impact: Machine learning has made ICRs more adaptive, enabling them to improve their cleaning efficiency over time. The robots learn from feedback, leading to better performance and greater user satisfaction.

   Challenges: While adaptation is a key advantage, it can be slow at times. Training models may require substantial data, and deep learning models can put a strain on computational resources, potentially affecting real-time performance.

5. Impact: AI helps cleaning robots operate with higher energy and resource efficiency, lowering operational costs and promoting sustainability by minimizing environmental impact.

   Challenges: Accurate water usage sensing is a major challenge. Mis-assessing dirt levels can lead to overuse or underuse of water, impacting cleaning effectiveness and efficiency.

6. Impact: AI-driven cleaning robots have become more effective in sensitive environments, such as hospitals and care facilities, by ensuring thorough sanitation and reducing infection risks.

   Challenges: Despite advancements, AI models still face limitations in detecting harmful bacteria or pathogens. While robots can identify dirt or contamination, microbial detection remains an unresolved issue in robotic cleaning.

Conclusion

The integration of AI into Intelligent Cleaning Robots (ICRs) has revolutionized cleaning technology, improving robot autonomy, efficiency, and adaptability. Notable advancements include enhanced navigation and obstacle avoidance, dynamic task scheduling, and the ability to adjust cleaning methods for different surfaces. However, challenges such as real-time adaptation, computational constraints, and issues with mode transitions persist.

Future work should focus on improving AI algorithms for more effective real-time decision-making, refining sensor technologies for better feedback, and expanding resource conservation capabilities. Additionally, advancements in AI for safety and hygiene detection, particularly in healthcare and elderly care environments, hold great potential. As these technologies evolve, AI-powered cleaning robots will likely become even more efficient, autonomous, and sustainable, opening new possibilities in both residential and commercial cleaning markets.

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