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Autonomous Robotic Vacuum Cleaners

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Abstract:

The progression of household cleaning has witnessed a shift from manual methods to automated technologies, typified by the emergence of autonomous robotic vacuum cleaners. These innovations employ robotic systems equipped with sensors to autonomously navigate spaces, making real-time adjustments based on environmental data. Infrared sensors play a pivotal role in detecting obstacles, enabling the robot to navigate around them by controlling its wheel movement through a microcontroller and motor driver mechanism. Additionally, a novel disc-shaped robotic vacuum cleaner has been developed, incorporating adaptive manufacturing technology and an Arduino microcontroller. Powered by a rechargeable Li-polymer battery, this device operates for 30-40 minutes and includes features such as a motor shield, voltage regulator, and a single operational switch. Through simulation and analysis, efforts are directed towards optimizing its design to provide a cost-effective and efficient solution for both household and industrial cleaning tasks, thereby minimizing reliance on manual labour.

Keywords **—Cleaning Robot, VSLAM (Visual Simultaneous Localization and Mapping), Automation, 3D Printing, Raspberry Pi, Arduino, Vacuum Dusting, Collision Prevention, Path Planning.**

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I. INTRODUCTION

In contemporary society, robots have become indispensable across a spectrum of sectors, spanning from industrial environments to household chores, entertainment, and security applications. Their adaptability enables them to fulfill roles as companions, caregivers, and assistants, offering solutions to an array of challenges. Particularly amidst the ongoing global pandemic, upholding hygiene and sanitation standards is paramount. Autonomous robotic vacuum cleaners have emerged as a practical remedy to address these urgent concerns, providing efficient and effective cleaning capabilities with minimal human oversight. These robots excel in executing intricate cleaning tasks such as mopping, waste disposal, and both wet and dry vacuuming, each presenting unique advantages and limitations. Leveraging state-of-the-art technology, including command transmission from Android devices and incorporation of robotic arms for heightened efficiency, these systems epitomize the innovative potential of automation. Despite their considerable contributions to simplifying daily routines and enhancing productivity, the widespread integration of robots prompts apprehensions regarding potential technological displacement of jobs and ethical quandaries, particularly in military contexts. As we delve into the evolution of robotic vacuum cleaners, we confront the intricacies of robotics and its ramifications for our future, striving to strike a balance between advancement and ethical considerations

II. LITERATURE SURVEY

In the initial study [1] scrutinized within the review, the primary focus revolved around robot vacuum cleaners. These cleaners are governed by an Arduino Leonardo and are equipped with ultrasonic sensors to facilitate obstacle avoidance. Sensor data plays a crucial role in directing the brush motor and preventing collisions by controlling the wheel motor.

The subsequent investigation [2] amalgamated IoT technology with the 8051 microcontroller, alongside smart trash cans and vacuum cleaners. This system is devised for waste segregation utilizing 8051 and humidity sensors, alongside executing vacuuming tasks. Ultrasonic sensors ascertain the bin's capacity, while a GSM module dispatches text alerts to designated recipients when the bin requires emptying.

In the third scholarly article [3], an Arduino, Wi-Fi module, and proximity sensor converge to construct a robotic vacuum cleaner. Upon activation, the motor controller initiates operation, propelling the robot forward. However, if an obstacle is detected within a 3 cm proximity, a command is issued to reverse motor operation, prompting the robot to change direction.

The fourth publication [4] delineates the blueprint of a vacuum system employing both Raspberry Pi and Arduino as the primary controllers. Leveraging LIDAR for mapping and proximity sensors for path planning enables autonomous navigation within the robot's environment. Furthermore, a GPS module facilitates positioning, while the authors introduce an automated battery charging mechanism termed "automatic docking and charging process," obviating the necessity for human intervention and ushering in fully automated robots.

III. DESCRIPTION OF SYSTEM

1. Block Diagram:

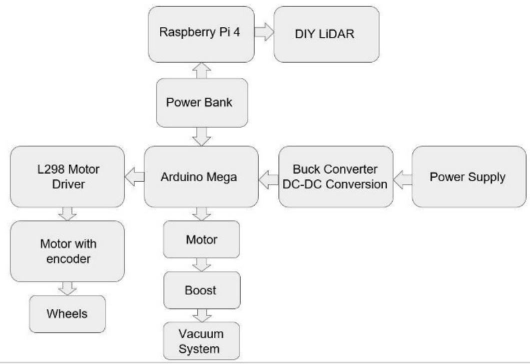

Fig. 1

The Arduino Mega and Raspberry Pi are connected through a serial cable, enabling data exchange via the serial communication protocol. This protocol transmits data sequentially, bit by bit, facilitating communication between the devices. Each device has a distinct role: the Arduino Mega manages motor control using a motor driver, specifically the IC L293D. This motor driver, with its 16-pin configuration, enables the Arduino to regulate the speed and direction of two motors, accommodating bidirectional current flow ranging from 5V to 36V.

In contrast, the Raspberry Pi, equipped with a DIY LIDAR, acts as the high-level controller, issuing commands to the Arduino, which serves as the low-level controller. This setup is logical given the Arduino's proficiency in interfacing with motors and motor drivers.

Power is provided to the system through Li-ion batteries, with a power bank serving the Raspberry Pi and LIDAR components. Additionally, the motor connected to the Arduino is optimized for idle performance, enhancing overall system efficiency. When the LIDAR detects obstacles like walls or furniture, it communicates this information to the Raspberry Pi, which then directs the Arduino to adjust the robot's trajectory—either turning left, right, or continuing forward—to navigate and clear the mapped area effectively.

2. Electronic System:

LIDAR

LIDAR, short for Light Detection and Ranging, represents a cutting-edge technology leveraging laser beams to accurately gauge distances to objects or surfaces. This advanced mechanism functions by emitting laser pulses and gauging the time taken for these pulses to return to the receiver upon encountering a target. Such precision enables LIDAR to construct highly detailed 3D digital representations of diverse landscapes, encompassing terrestrial as well as aquatic domains.

In contrast to conventional mapping techniques, LIDAR stands out for its ability to capture intricate details with exceptional granularity, achieving resolutions as fine as 30 centimeters (12 inches) in terrain features. Its adaptability extends to a wide array of materials, ranging from non-metallic objects to aerosols and chemical compounds. Additionally, LIDAR's capability to accommodate various wavelengths of light facilitates comprehensive imaging, rendering it indispensable across multiple domains, including environmental surveillance, urban planning, and disaster mitigation efforts.

With its unparalleled precision and adaptability, LIDAR continues to spearhead innovation in industries and scientific endeavours, furnishing invaluable insights into our surroundings and the ever-evolving landscapes of our planet

INFRARED SENSOR

Infrared sensors, sophisticated electronic devices, discern environmental cues by detecting emitted signals. These sensors are typically classified as active or passive, each employing distinct methodologies. Active sensors are equipped with both transmitters and receivers, utilizing light-emitting diodes (LEDs) or laser diodes to emit signals and then receive their reflections. In contrast, passive sensors exclusively feature receivers, detecting external infrared emissions without emitting any signals themselves. Thanks to their swift interpretation of environmental changes, these sensors offer benefits such as low power consumption and rapid response times. They find widespread application in security systems, motion detection, and temperature sensing, demonstrating remarkable efficacy across various environments by detecting subtle alterations in infrared radiation with exceptional precision.

ULTRASONIC SENSOR

The ultrasonic sensor functions as an electronic device that gauges the distance to a target object by emitting ultrasonic waves and converting the rebounded sound into an electrical signal.
These waves, traveling faster than audible sound, are emitted by a transmitter typically equipped with piezoelectric crystals, while a receiver captures the sound after reflection. Commonly utilized in proximity sensing applications, ultrasonic sensors play pivotal roles in automotive self-parking and collision avoidance systems, as well as in robotic obstacle detection and various manufacturing processes.

In contrast to infrared sensors, ultrasonic sensors offer heightened resistance to interference from smoke, gas, and airborne particles. Additionally, they serve as effective level detectors in closed liquid containers, particularly in chemical plants. Furthermore, ultrasonic sensors have revolutionized medical imaging by enabling visualization of internal organs and detection of tumors, thereby significantly contributing to prenatal care.

Among ultrasonic sensors, the HC-SR04 is noteworthy for its exceptional non-contact detection range, providing precise and reliable measurements for diverse applications

MICROCONTROLLER

The ATmega2560 is an 8-bit CMOS microcontroller based on the AVR-enhanced RISC architecture, renowned for its low-power consumption. Equipped with a powerful 8-bit RISC processor capable of executing instructions in a single clock cycle, it ensures maximum efficiency while minimizing power usage.

Featuring programmable Flash memory, the ATmega2560 offers a cost-effective solution for numerous embedded control applications. Its high speed and flexible design render it an optimal choice for a wide range of applications, allowing for versatile implementation across various projects.

MOTORDRIVER

The L298N motor driver is a single-package monolithic integrated circuit housing two H-bridge motor drivers. Engineered to manage high-voltage and high-current demands, this robust driver seamlessly interfaces with TTL logic levels. Each bridge boasts separate enable pins, enabling independent on/off control. Moreover, the interconnected emitters of the bottom transistors in each bridge allow for external sense resistor connections.

With a capacity to drive DC motors with a maximum current of 4 A, the L298N functions within supply voltages up to 46 V. Additionally, it integrates a built-in overheat protection mechanism, safeguarding circuit integrity during high-temperature operating conditions.

GEARED MOTORS

Gear motors, also referred to as geared motors, combine an electric motor with a gearbox, consolidating multiple functions into a single system for simplified operations. Typically featuring a robust motor such as an Electrically Commutated Motor paired with a gear reducer, these motors minimize alignment challenges and streamline setup processes.

Widely utilized across various applications, including can openers, garage doors, electric alarm clocks, and commercial equipment like hospital beds and cranes, gear motors operate within a range of 1,200 to 3,600 cycles per minute (RPMs), exhibiting specific speed and torque specifications.

One notable example is the 100 rpm Single Shaft BO Motor – Straight, renowned for its versatility, high torque, and speed, particularly at lower voltages. Characterized by a compact design with a small axle and matching wheels for optimal performance, this motor suits various applications and is suitable for constructing small to medium-sized robots. With an operational voltage range of 3 to 12 V, it offers a reliable alternative to metal gear DC motors, making it an excellent choice for a wide array of projects.

BUCKCONVERTER

The Buck Converter, also referred to as a step-down chopper, is instrumental in converting DC input signals into lower-magnitude DC output signals. The LM2596 DC-DC Buck converter step-down module represents a switching power supply boasting high efficiency, adept at accommodating 3A loads. Operating at a frequency of 150 kHz, it employs smaller filter components compared to lower frequency regulators. Featuring precision potentiometers, it offers compatibility with various mainboards.

Internally compensated, this converter simplifies power supply design, although it is advisable to utilize a heatsink for output currents exceeding 2.5A. Notably, it outperforms linear regulators, particularly at higher input voltages.

RASPBERRY PI

The Raspberry Pi is a budget-friendly computer that runs on Linux and offers a set of GPIO (general-purpose input/output) pins, enabling users to control electronic components for physical computing and explore the Internet of Things (IoT). Raspberry Pi 4 has undergone rigorous compliance testing, meeting various regional and international standards.

A notable enhancement to the Pi 4B is the availability of three distinct DDR4 SDRAM capacities: 1GB, 2GB, or 4GB. Paired with a faster 1.5GHz quad-core processor, this configuration empowers the Pi 4B to handle large programs and tasks with improved speed. Additionally, it features Bluetooth 5.0, two USB 3.0 ports, and genuine Gigabit Ethernet for swift wired and wireless communication.

Furthermore, the dual-band wireless LANs now come with modular compliance certification, simplifying the integration of cards into final products and reducing conformance testing requirements. This enhances cost efficiency and shortens marketing timeframes.

IV.EXPERIMENTATION AND RESULTS

Based on our prototype, three studies were conducted. The first experiment assessed the fundamental functionality of the components. Mechanical, electrical, and control aspects of the robot were scrutinized to verify normal operation. Ratings were assigned on a scale from 1 to 3, with "1" indicating good performance and "3" representing optimal functionality, signifying that all system components operate efficiently. Results indicate that 100% of the components performed effectively in this test.

The second trial evaluated the robot's cleaning capability. In this experiment, the robot was manually operated, and a predetermined quantity of garbage was placed at a specified location.

cleaning performed by the robot = weight of content *100
total contentweight

The outcomes of the experiment fluctuated between 2-68.

During the third experiment the robot's ability to avoid collisions was evaluated using followingformula:

Rate ofCollisions =

number of collisiontakingplace *100 number of obstacles placed in theenvironment

The results of this experiment varied between 20-50%. Overall, the efficiency of the robot system reached 68% when tested in a controlled environment.

The robot's battery system comprises two packs, each consisting of 10-cell 3.7V, 3600mAh Li-ion batteries. With 10 cells connected in series, each pack generates a total voltage of 37V. When the two packs are connected in parallel, the current rating increases, resulting in a total capacity of 7,200mAh or 7.2Ah, with an input capacity of 266.4Wh.

The power consumption of the robot is 30W for the vacuum system and 72W for the 4 DC geared motors, totaling 102W. With a full charge, the robot can operate continuously for 3.7 hours. However, the robot is equipped with autonomous docking capability, enabling it to recharge itself without human intervention, thereby alleviating concerns about battery life.

V. CONCLUSION

After extensive prototyping and testing, it has become evident that autonomous robot vacuum cleaners have undergone a modern evolution, with the implementation and testing of new technologies such as Arduino and Raspberry Pi. Integrating these technologies with IoT, modern sensors, and motors has enabled more efficient cleaning processes at lower costs. However, a drawback is that these devices are not fully autonomous and require some human involvement. This issue can be addressed by incorporating advanced technologies such as Artificial Intelligence (AI) and Machine Learning (ML) from the field of computer science.

While algorithms are used in some cases for optimization, they are not as effective as what Machine Learning can provide. By leveraging Machine Learning technologies such as Object Detection, we can further enhance the performance of these devices. We propose constructing an IoT-based ARVC (Autonomous Robot Vacuum Cleaner) that can function effectively in unfamiliar environments by utilizing a makeshift LIDAR system. This will enable the robot to map out the room with precise and accurate detail, resulting in improved cleaning with fewer collisions and increased efficiency.

Ultimately, this robot will minimize human interaction and effort in household cleaning tasks, thereby allowing for a more productive and comfortable lifestyle.

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