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Robotic Oil Filter Removing Unit: Advancement in Autonomous Robot in Field of Automotive Maintenance

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Abstract*: The process of changing the oil filter under an automobile presents various challenges, especially on safety, efficiency, and the health of workers. Traditionally, this is done using heavy machinery like jacks to elevate the car, which poses a failure risk and possible accidents. Moreover, the working space beneath the car is usually congested and poorly lit, which may cause discomfort and safety risks to the technician, including possible suffocation due to poor ventilation. The physical demands while working in such conditions also have adverse effects on the hygiene and well-being of the worker. This paper presents the conceptualization of an autonomous robotic system aimed at mitigating these challenges. The robot will safely elevate the car, change the oil filter, and mitigate the risks associated with traditional manual methods, such as accidents, exposure to harmful fumes, and physical strain. The system integrates automation to enhance the safety of workers, improve operational efficiency, and ensure better hygienic conditions while performing automotive maintenance tasks*

Keywords: automobile

I. INTRODUCTION

Oil filter changing in an automobile is a routine but cumbersome task, especially when it involves working underneath the vehicle. The traditional approach usually requires heavy equipment like jacks for lifting the car, which brings about important safety hazards. Workers are seriously threatened by potential failure of the lifting equipment, and the confined, poorly lit working space under the car can make them uncomfortable, limiting visibility and potentially causing suffocation due to inadequate ventilation. Moreover, such tasks impose physical strain on workers and can affect their hygiene and well-being, making the task even more difficult.

In order to address the above concerns, we propose an autonomous mobile robotic manipulation system that can perform oil filter replacement under the car without lifting the vehicle. All the hazards from lifting will be eliminated by this proposed solution, and the general safety and comfort of the technician will be further improved. The robot will be able to move under the car, remove the old oil filter, and collect residual oil into a tank specifically designed for that purpose. The system will be controlled remotely by the technician for a safer, more efficient, and hygienic replacement of the oil filter than the manual procedure. The automotive maintenance will be ensured to be performed with the minimum intervention of human beings in the mobile robotic system, where the risk associated with the process will be reduced while operational efficiency is enhanced.

II. LITERATURE REVIEW

The development of mobile manipulators has brought the robot closer to real-world applications that require complex manipulation tasks. These systems embody mobility and dexterity, enabling robots to perform actions in dynamic environments with unstructured settings. This literature review aims at influential papers that have substantively contributed to the development of mobile robotic arms with regard to autonomous manipulation and control strategies and their real-world applications.

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Mobile Manipulation: The State of the Art

Cacace et al. (2017) give an overall survey on mobile manipulation that covers the integration of mobile robots with robotic arms for the execution of complex tasks in object handling, human-robot interaction, and environmental exploration. This paper represents a fundamental source for assessing the current status of mobile robotic arms in several applications. It underlines the challenges and solutions concerning the combination of mobility with manipulation, including coordination between the mobile base and robotic arm and control systems necessary for autonomous operation. The review emphasizes the importance of developing efficient algorithms for motion planning, control, and interaction between mobile robots and their environment for performing tasks in unstructured and dynamic environments.

Autonomous Mobile Manipulation: The Robotic Arm as a Mobile Agent

Kormushev et al. (2011) discuss autonomous mobile manipulation in the context of integrating robotic arms with mobile platforms to perform independent operations in unstructured environments. The authors detail the challenges in autonomy in mobile manipulation systems, including the need for advanced perception, decision-making, and motion control algorithms. Solutions are presented for enabling a robotic arm to manipulate objects in different complex and unpredictable environments. Their work applies to the combination of robotic arms with mobile bases for achieving autonomy, which is very essential in tasks that require interaction with dynamic surroundings. This research provides a solid framework for understanding the mechanisms behind autonomous mobile manipulation systems.

Mobile Manipulation with a Robotic Arm on a Mobile Platform for Indoor Applications

Lippiello et al. (2013) discusses the application of mobile manipulation with a robotic arm mounted on a mobile platform in indoor environments. This work details the specific challenges, including navigation through narrow corridors and avoidance of obstacles to name a few, to overcome in performing indoor mobile manipulation. In addition, integration of motion control with manipulation strategies is discussed and a few approaches are introduced by the authors for higher accuracy and effectiveness of a robotic arm when interacting with the environment. The research of the authors focuses primarily on real-time control and adaptation, allowing the robot to perform autonomously and independently of human intervention. Results presented in this manuscript have direct application in many confined environments where mobility and manipulation are fundamental to achieving the operation at hand.

Towards Mobile Manipulation for Robotic Systems in Agricultural Applications

Schultz et al. (2021) discuss the use of mobile robotic arms in agriculture, specifically for such tasks as autonomous harvesting and crop inspection. Integration of mobile platforms with robotic arms realizes effective manipulation in outdoor environments with dynamic and sometimes hostile conditions. This paper highlights the application of mobile manipulation systems in agriculture to perform repetitive tasks with high precision. The authors argue that challenges involved include navigation in large, open environments and the need for strong manipulation techniques to handle fragile crops. Their work shows that mobile robotic arms might provide a marked potential for revolutionizing agricultural practices and open up considerable opportunities for farming automation.

A Mobile Robot with a Manipulator for Dynamic Environments: From Planning to Execution

Lee et al. (2008) focus on mobile robot manipulation in dynamic environments, discussing both motion planning and control strategies necessary for robotic arms integrated with mobile platforms. The paper emphasizes the challenges of maintaining stability and precision when the robot is navigating through environments that are subject to change, such as varying terrain or the presence of obstacles.

The authors propose a framework for real-time planning and execution, allowing the robot to adapt its movements based on the dynamic conditions of the environment. This research contributes to the understanding of how mobile robotic arms can maintain effectiveness in environments where unpredictability is a constant factor, making them suitable for a wide range of applications, including logistics and disaster response.

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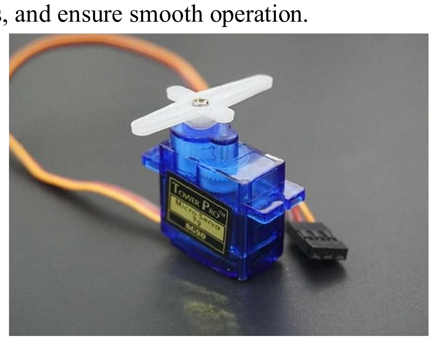
III. COMPONENT SELECTION

ESP32 Microcontroller

The ESP32 microcontroller is selected for its powerful processing capabilities, real-time control, and support for various sensors and actuators. It serves as the central unit for managing the robot's movements and manipulation tasks.
Features such as wireless communication, sensor integration (IR, camera, Ultrasonic sensors) and motor control make it suitable for controlling both the mobile base and the manipulator.

Servo Motors

servo motors are chosen for their ability to provide sufficient power for the robot's movements and manipulation tasks. These motors are selected based on the required torque for driving both the mobile base and the robotic arm. They must be capable of handling the forces associated with moving the robot and performing tasks such as object manipulation or assembly.
The servo motors are chosen for precise control and feedback. These motors will allow the system to maintain stability, avoid unnecessary jerks or vibrations, and ensure smooth operation.



Mobile Base and Polymer Construction

The mobile base is made from lightweight, high-strength polymer to reduce the overall weight of the robot while ensuring durability and strength. Polymers like ABS plastic are commonly used in robotics for their excellent strength-to-weight ratio, low cost, and ease of fabrication.
The lightweight structure ensures that the robot can move efficiently across various terrains or pathways without being weighed down, while the high-strength nature of the material ensures that the base can withstand the forces during operation.

Sensors (Line Detection and Camera Integration)

Infrared or Optical Sensors: These sensors are integrated for line-following capabilities. They are mounted on the robot to detect the line on the floor, ensuring the robot stays aligned with the predetermined path

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Camera: A high-resolution camera is integrated for enhanced vision-based navigation and object manipulation. The camera will help detect obstacles, identify objects, and allow for the manipulation of items based on visual data. The ESP32 controller processes the camera feed to make real-time decisions based on the robot's environment.

IV. METHODOLOGY: DESIGN AND DEVELOPMENT OF AN INTEGRATED MOBILE ROBOTIC Manipulator

The methodology for developing a mobile robotic manipulator integrated with the ESP32 microcontroller, high-torque servo motors, and a lightweight, high-strength polymer robotic base involves multiple stages, including system design, component selection, integration, and testing. The goal is to create a robot capable of performing autonomous tasks, such as path- following and manipulation, with high precision and efficiency.

System Design Overview

The robotic system consists of several key components:

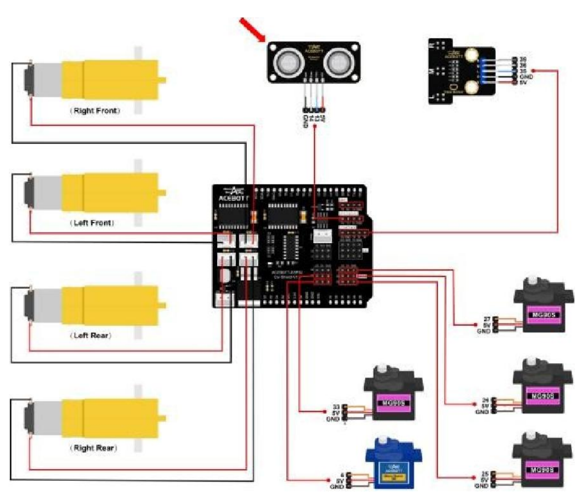
Microcontroller: The ESP32 microcontroller serves as the brain of the robotic system, responsible for controlling the entire robot, including the mobile base, robotic manipulator, sensors, and communication interfaces.

Mobile Base: The mobile base is designed to allow the robot to move autonomously along a predetermined path or navigate through a dynamic environment. It is made from a lightweight, high-strength polymer to ensure durability and reduce weight, allowing for better mobility.

Servo Motors: These motors are used to drive robotic manipulator. These motors ensures that the robot can carry out tasks, such as manipulation and handling of objects.

Sensors and Camera: The system will be equipped with various sensors, including infrared sensors for line-following and cameras for object detection and environmental awareness.

System Integration



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Controller and Motor Integration

The ESP32 microcontroller is connected to both the high-torque servo motors that control the mobile base and the manipulator. The controller is responsible for receiving inputs from the sensors and making real-time decisions to adjust the robot's speed and trajectory.

The motor drivers interface between the ESP32 and the motors, allowing the microcontroller to control the speed, direction, and position of the motors accurately.

Sensor and Camera Integration

The infrared sensors used for line-following are connected to the ESP32 via analog or digital inputs. These sensors provide continuous feedback about the robot's position relative to the line, allowing the robot to adjust its path dynamically.

The camera is connected to the ESP32 through a serial interface (e.g., UART, I2C, or SPI), enabling it to process the visual data in real- time. Computer vision algorithms (such as edge detection, color segmentation, or object recognition) are implemented to interpret the camera feed and assist in tasks such as obstacle detection and manipulation.

Robotic Arm Integration

The robotic manipulator is integrated with the ESP32 using high-torque servo motors or stepper motors, depending on the desired precision and force. The robot arm can be controlled via the ESP32 to perform various tasks such as picking up, moving, or placing objects.

The feedback from the arm's sensors (e.g., force sensors) is sent to the ESP32 to adjust the manipulation behavior in real-time.

Algorithm Development

Line Following Algorithm

A line-following algorithm is developed to control the movement of the robot along the designated path. The algorithm processes the sensor inputs from the infrared sensors, making continuous adjustments to the robot's speed and direction based on the deviation from the line.

Popular algorithms include PID (Proportional- Integral-Derivative), which helps in reducing the error in the robot's path-following by adjusting motor speeds accordingly.

Object Detection and Manipulation Algorithm

The camera feed is processed using computer vision algorithms to detect objects along the robot's path. Object recognition algorithms identify the type, position, and orientation of objects, providing the necessary input for the robotic arm to interact with them.

The robotic manipulator uses an inverse kinematics algorithm to determine the necessary joint movements to perform manipulation tasks. This algorithm is integrated with the ESP32 to ensure precise control over the arm.

5.3.C. Sensor Fusion and Feedback Control

Sensor fusion techniques are implemented to integrate data from the line-following sensors, camera, and manipulator sensors. This allows the robot to adjust its movements in real-time based on the comprehensive data, improving its ability to navigate and manipulate objects autonomously.

Feedback loops from the sensors and the manipulator's force sensors ensure that the robot adapts its actions based on environmental conditions and task requirements.

Testing and Calibration

Prototype Testing

The integrated robot is tested under controlled conditions, including path-following and object manipulation tasks. The testing ensures that the system operates as expected, with the mobile base following the line and the manipulator executing the desired actions.

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Different test scenarios, such as line intersection, obstacle avoidance, and object manipulation, are simulated to evaluate the robot's performance and robustness.

Calibration

The line-following sensors are calibrated to detect lines of various colors and widths. The robot's trajectory and response to deviations from the line are fine-tuned during testing.

The camera is calibrated to optimize object detection and recognition, ensuring the robot can identify objects reliably in different lighting and environmental conditions.

The manipulator's precision is also calibrated to ensure the robotic arm can perform tasks accurately and safely without damaging the objects it interacts with.

Final Implementation and Deployment

After successful testing and calibration, the final robot is deployed for real-world tasks. The ESP32 controller, high-torque servo motors, mobile base, and robotic arm are all integrated into a cohesive system capable of performing autonomous navigation and manipulation.

The system is designed to be scalable, allowing additional sensors or features to be integrated for more complex tasks in the future.

V. RESULTS

6.1 Result Analysis

Option 1: Emphasizing the relationship between Duty Cycle and RPM

Measured Voltage (V): This is the
constant source voltage you are applying.

Effective Voltage (V): This is calculated as (Duty Cycle / 100) * Measured Voltage.

Measured RPM: This is what you measure with your tachometer or encoder.

Duty Cycle (%)	Measured Voltage (V)	Effective Voltage (V)	Measured RPM
0	12	0	0
25	12	3	500
50	12	6	1000
75	12	9	1500
100	12	12	2000

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Option 2: Emphasizing the relationship between Voltage and RPM (if you vary the source voltage)

Voltag e (V)	Duty Cycle (%)	Effective Voltage (V)	Measured RPM
3	100	3	500
6	100	6	1000
9	100	9	1500
12	100	12	2000

Here, you would be keeping the duty cycle constant (e.g., 100%) and varying the source voltage.

Option 3: A more comprehensive table (if you vary both voltage and duty **cycle)**

Voltage (V)	Duty Cycle (%)	Effective Voltage (V)	Measured RPM
6	50	3	250
6	100	6	500
12	25	3	500
12	50	6	1000
12	75	9	1500

This option shows how changing both the source voltage and duty cycle affects the effective voltage and RPM.

Table 7.1 Analysis of the effect of PWM on RPM of Motor

IR Sensor Testing:

Basic Functionality Test (with an LED) - Qualitative Data

Test Condition	LED State	Interpretation
No Object	OFF	Sensor is not detecting anything.
Object at 10cm	ON	Sensor detects the object within its range.
Object at 30cm	OFF	Object is outside the sensor's detection range.
Ambient Light (Bright)	ON (or flickering)	Ambient light is interfering with the sensor.

Since this test is mostly visual, the data is qualitative (descriptive) rather than quantitative (numerical).

Using a Multimeter - Quantitative Data

Test Condition	Distance to Object (cm)	Output Voltage (V)
No Object	N/A	0.2
Object at 1cm	1	4.5
Object at 5cm	5	3.0
Object at 10cm	**10**	**1.5**
Object at 15cm	**15**	**0.5**

Interpretation: The output voltage decreases as the object moves further away, indicating a decreasing signal strength.

Using a Microcontroller - Digital Data

Test Condition	Distance to Object (cm)	Digital Reading
No Object	N/A	0
Object at 2cm	2	1
Object at 8cm	8	1
Object at 12cm	12	0

Interpretation: The sensor reliably detects objects up to 8cm. Beyond that, it no longer registers the object.

Testing an IR Emitter (Remote Control) - Qualitative Data
This test is also mostly visual.

Remote Button Not Pressed	No visible light	Emitter is not transmitting.
Remote Button Pressed	Bright light visible	Emitter is transmitting IR light.

VI. CONCLUSION

The development of a Robotic Oil Filter Removing Unit signifies a significant stride towards the integration of advanced robotics into the automotive maintenance sector. This innovative system demonstrates the potential of autonomous robots to revolutionize traditional labor-intensive tasks, enhancing efficiency, safety, and precision within automotive workshops.

In conclusion, the Robotic Oil Filter Removing Unit represents a significant step towards the future of automotive maintenance, demonstrating the potential of advanced robotics to revolutionize traditional practices. By enhancing efficiency, safety, and quality, while minimizing environmental impact, this technology has the potential to transform the automotive maintenance landscape and pave the way for a new era of innovation and productivity in the industry

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