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Drain Inspection Rover

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ABSTRACT: Drain Inspection Robot designed to inspect underground drainage systems safely and efficiently. The robot is equipped with DC motors, a camera module, and a control unit. It allows remote inspection of drains by transmitting real-time video to the operator, eliminating the need for human entry into hazardous environments such as sewer lines and narrow pipelines. This robot has the wired connection for joystick to control the movement.

I. INTRODUCTION

Drainage and sewer systems are an essential part of modern urban and industrial infrastructure. They are responsible for carrying wastewater safely away from residential areas, industries, and public spaces, thereby maintaining cleanliness, hygiene, and environmental safety. Over time, drainage systems can develop problems such as blockages due to waste accumulation, cracks caused by corrosion, leakage, or structural damage. If these issues are not identified and resolved at an early stage, they can lead to serious problems such as overflow, water contamination, foul odor, and health hazards.

Traditionally, drain inspection is carried out manually by sanitation workers who enter drainage lines or inspect them using basic tools. This method is extremely risky and challenging. Drainage environments often contain toxic gases, harmful bacteria, low oxygen levels, and slippery surfaces, which can cause serious health issues or even fatal accidents. In addition to safety concerns, manual inspection is time-consuming and does not always provide accurate or clear information about the internal condition of drains. Due to poor visibility and limited access, many defects remain undetected until they become severe.

With the advancement of technology, robotics and embedded systems have provided safer alternatives for performing hazardous tasks. The use of robotic systems for inspection reduces direct human involvement and improves efficiency. A drain inspection robot equipped with a camera and wireless control can travel through drains and transmit real-time visual information to the operator. This allows inspection to be carried out from a safe distance while maintaining better accuracy and documentation.

The Drain Inspection Rover developed in this project is designed to address the limitations of conventional inspection methods. The rover is a compact, battery-powered robotic system capable of moving inside drainage paths and providing live video feedback. It uses an ESP32 microcontroller for control and wireless communication, along with an ESP32-CAM module for real-time video streaming. The rover can be controlled using a mobile phone through a simple web interface, making it easy to operate without the need for complex equipment. This project aims to demonstrate how modern embedded systems and robotics can be applied to real-world problems such as drain inspection.

SURVEY AND SPECIFICATION

Technical Specifications

1. Control Unit

- Controller: Raspberry Pi 3B+
- Power: 5V stable supply
- Operating System: Linux-based OS
- Function: Motor control, camera handling, and system coordination

2. Drive System

- Motors: DC geared motors
- Motor Driver: L298N (12V)
- Control: Direction and speed control

3. Camera System

- Camera Module: Raspberry Pi Camera (V1)
- Function: Live video streaming for inspection

4. Power Supply

- SMPS 24V 5A
- Buck Converter (LM2596): Voltage regulation(24v to 12v conversion)

II. LITERATURE SURVEY

Drain inspection has been an important area of research due to the increasing need for safe and efficient maintenance of sewer and drainage systems. Earlier methods of drain inspection were mostly manual, where workers physically entered drainage lines to check for blockages or damage. Although this method was commonly used, it exposed workers to serious health risks such as toxic gases, infections, and accidents caused by slippery and confined environments. Due to these risks, researchers began exploring mechanical and electronic solutions to reduce human involvement.

Initial technological solutions included the use of wired camera systems, where a camera was attached to a long cable and inserted into drains. These systems provided basic visual feedback but had several limitations. The movement of the camera was restricted by the cable length, and navigation inside complex or curved drains was difficult. Additionally, wired systems were prone to damage in wet and dirty environments and required trained operators. With the development of microcontrollers and wireless communication, robotic drain inspection systems started gaining attention. Many researchers developed robots using microcontrollers such as Arduino combined with RF or Bluetooth modules. These robots were capable of basic movement and inspection but suffered from limited range and low data transmission reliability. Bluetooth-based systems, in particular, were not suitable for long-distance or underground inspection due to signal loss.

Recent studies focus on the use of Wi-Fi-enabled microcontrollers for inspection robots. The ESP32 microcontroller has become popular because of its built-in Wi-Fi, high processing capability, low power consumption, and affordability. Several research projects have demonstrated the effectiveness of ESP32-based robots for remote monitoring and control applications. The integration of camera modules such as ESP32-CAM has further improved inspection systems by enabling real-time video streaming without the need for expensive external cameras.

Some advanced systems include autonomous navigation, gas sensors, and artificial intelligence-based defect detection. However, these systems are often complex, costly, and difficult to implement at a student or small-scale level.

III. SYSTEM DESIGN DISCUSSION AND METHODOLOGY

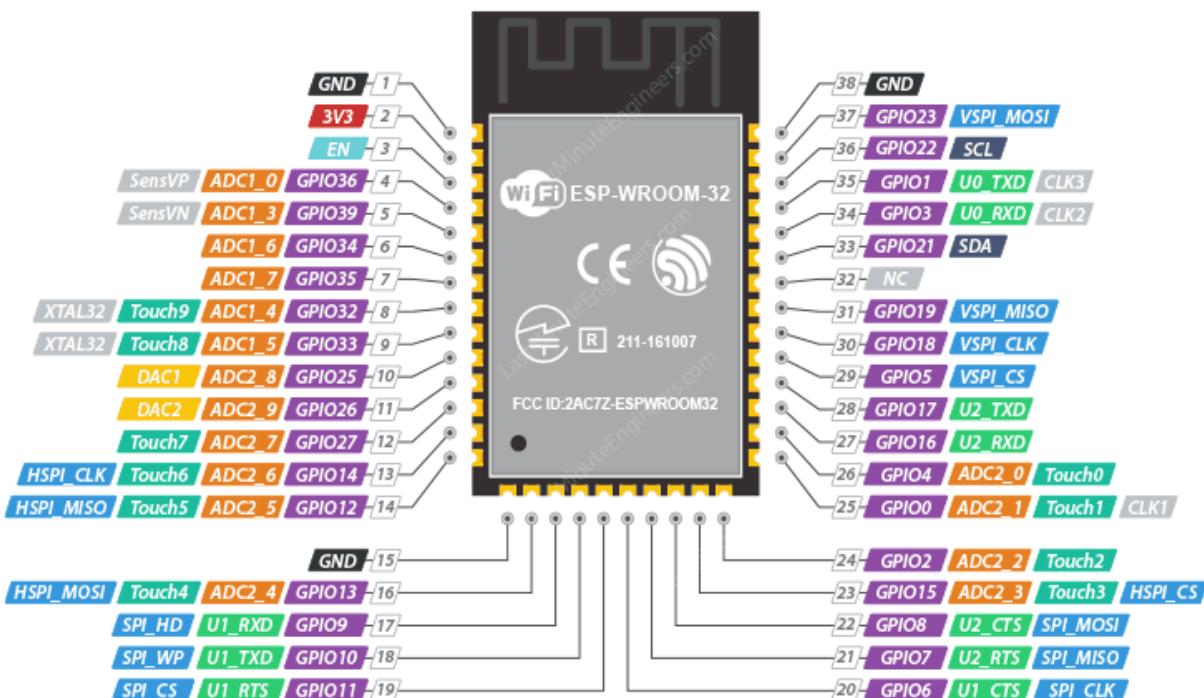
The methodology of the Drain Inspection Rover project focuses on the systematic design, development, and testing of a robotic system capable of inspecting drainage systems safely and efficiently. The first step in the methodology involves understanding the practical problems associated with manual drain inspection and identifying the functional requirements of the rover. Based on these requirements, suitable hardware components such as the ESP32 microcontroller, ESP32-CAM module, DC motors, motor driver, battery, buck converter, and chassis are selected. The selection of components is done by considering factors such as cost, power consumption, availability, and compatibility.

After finalizing the components, the hardware assembly of the rover is carried out. The ESP32 microcontroller is mounted on the chassis and connected to the motor driver for controlling the DC motors. The motors are fixed securely to the chassis to provide stable movement inside the drain. The ESP32-CAM module is positioned at the front of the

rover to capture a clear view of the drainage path. A rechargeable battery is used as the power source, and a buck converter is connected to regulate the battery voltage and supply stable power to all electronic components. Proper wiring and insulation are ensured to avoid short circuits and damage due to moisture.

The next stage involves software development. The ESP32 is programmed using the Arduino IDE. The program is designed to initialize the Wi-Fi connection, create a web server, and generate a simple web-based control interface. This interface allows the user to send movement commands such as forward, backward, left, right, and stop through a mobile phone or computer browser. Pulse Width Modulation (PWM) is used to control the speed of the DC motors. The ESP32-CAM is configured to stream live video over the Wi-Fi network using the rover's IP address.

Once the hardware and software integration is completed, the system is tested in controlled conditions. The rover's movement, wireless connectivity, and video streaming performance are verified. Any errors related to motor control, power supply, or network communication are identified and corrected. After successful testing, the rover is tested in a drain-like environment to observe its performance under practical conditions.



IV. RESULTS AND ANALYSIS

The Drain Inspection Rover was successfully designed, assembled, and tested to verify its performance. During testing, the rover responded accurately to wireless control commands sent through a mobile web browser. The movement of the rover in forward, backward, left, and right directions was smooth and reliable. The ESP32-CAM module provided clear real-time video streaming, allowing effective visual inspection of the surrounding environment.

The system demonstrated stable Wi-Fi connectivity within the available network range. The buck converter efficiently regulated the battery voltage, ensuring continuous and safe operation of all components. The rover performed well in drain-like conditions, proving its suitability for confined and hazardous environments. Overall, the results confirmed that the project objectives were successfully achieved.

The Drain Inspection Rover has wide practical applications. It can be used by municipal corporations for inspecting sewer lines and drainage systems. It is also suitable for industrial pipeline inspection, underground tunnel monitoring, and inspection of hazardous or confined spaces where human entry is unsafe. Additionally, the system can be used for

educational and research purposes to demonstrate the application of embedded systems and robotics in real-world problems.

APPLICATIONS AND PRACTICAL CONSIDERATIONS

- Underground drain inspection
- Sewer line monitoring
- Municipal drainage maintenance
- Industrial pipeline inspection
- Hazardous environment inspection

Limitations and Mitigations

1. Manual control required
2. Performance depends on drain size and conditions
3. Advanced robots can be expensive to build or purchase.
4. Battery-powered robots have limited operation time.

V. CONCLUSION AND FUTURE WORK

The Drain Inspection Rover project successfully demonstrates a safe, efficient, and economical solution for inspecting drainage systems. By using an ESP32 microcontroller, wireless control, and real-time video streaming, the system reduces human exposure to dangerous environments and improves inspection accuracy. The rover is portable, easy to operate, and cost-effective, making it suitable for practical deployment as well as academic learning.

The project fulfills all its objectives and highlights the importance of robotics and embedded systems in solving real-world safety problems. It also provides hands-on experience in hardware integration, programming, wireless communication, and system testing.

The future scope of this project is significant. Additional sensors such as gas sensors, water level sensors, or temperature sensors can be integrated to enhance inspection capability. Features like autonomous navigation, obstacle detection, longer-range communication, and mobile application control can further improve system performance. With these enhancements, the Drain Inspection Rover can become a more advanced and intelligent inspection system.

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