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Design & Development of Pipe Inspection Robot

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Abstract: *Pipelines are crucial for fluid and gas transportation, but pipeline leaks caused by corrosion and cracks can result in disastrous accidents. Periodical inspection is necessary to prevent such incidents, and autonomous robots have emerged as a viable solution. This paper presents the design, modeling, and simulation of an autonomous mobile robot for pipeline inspection equipped with an IR sensor for movement and a camera for visual inspection to detect cracks and corrosion. The robot also has a blockage cleaning functionality to remove any obstructions within the pipeline. Inner images of the pipe are captured for further investigation. The robot's control and mapping are performed using the Raspberry Pi Operating System and Proteus is used for simulating the robot. The proposed inspection robot provides an effective and efficient solution for pipeline inspections*

Keywords: Pipe Inspection, Autonomous Robot, Visual Inspection, Crack Detection

I. INTRODUCTION

Pipelines are extensively used for transporting different types of fluids, including toxic and flammable substances. However, pipeline leaks caused by corrosion and cracks can result in disastrous accidents that can cause harm to people and the environment. To prevent such accidents, regular inspection of pipelines is necessary, and autonomous robots have emerged as a promising solution to improve inspection efficiency and reduce manpower.

In this context, this paper presents a pipeline inspection robot designed to detect pipeline cracks accurately. The robot can move from one point to another within the pipeline and use a camera to detect defects inside the pipe. The robot's active revolute mechanism enables it to move in pipes and ducts with round and square cross-sections.

Engineering disasters due to miscalculations, manufacturing issues, and negligence in detecting cracks have caused harm to the environment and mankind. Thus, it is necessary to take preventive measures and detect cracks more accurately. Current methods, such as using sonic vibrations or relying on a human workforce, have limitations and may not provide accurate results.

Therefore, this robot aims to prevent engineering disasters caused by pipeline leaks by developing a highly precise pipeline inspection robot. By integrating advancements in engineering and computer science, the proposed system provides a more reliable solution to detect pipeline cracks, limiting the occurrence of disastrous events in the industry.

1.1 Problem Statement

To maintain the pipe, one needs to inspect the pipe periodically or regularly and these pipes are constructed to transport all kinds of fluids, some toxic, some highly flammable, and others fairly unreactive. However, depending on the material from which it is fabricated, every pipe deteriorates progressively with time, and it becomes prone to cracks and heavy corrosion. Many accidents have occurred from fluid leaks owing to the cracks and corrosion of pipelines. Pipes are to be checked from the inside and outside also, thus to do that we need to inspect pipes. It is a challenging task for humans to work manually. Certain areas are inaccessible to humans and also the pipe diameter may be very small and as a result, one cannot reach inside. Sometimes the oxygen level in the pipe will also be low making it difficult for human assistance and a bystander should also be there near the pipe for help.

1.2 Hardware used

Bearing in mind the tasks to be performed by the robot, such as motion and visual inspection, we have integrated distinct electronic and mechanical components in the platform, mounted within a functional internal architecture:

- Raspberry Pi 3 A+
- Raspberry Pi Camera Module V2 - 8 Megapixel, 1080p
- Ultrasonic sensor
- IR sensors
- L293D Motor Driver
- 12V DC Motor
- Chassis

Specifications

Raspberry Pi 3 A+

- Processor: Broadcom BCM2837B0, Cortex-A53 64-bit SoC @ 1.4 GHz
- Memory: 512MB LPDDR2 SDRAM
- Connectivity: 2.4 GHz and 5 GHz IEEE 802.11.b/g/n/ac wireless LAN, Bluetooth 4.2/BLE
- Access: Extended 40-pin GPIO header, full-size HDMI port, MIPI DSI display port, MIPI CSI camera port, 4-pole stereo output and composite video port
- Multimedia: H.264, MPEG-4 decode (1080p30); H.264 encode (1080p30); OpenGL ES 1.1, 2.0 graphics
- SD card support: Micro SD format for loading operating system and data storage
- Input power: 5 V/2.5 A DC via micro USB connector, 5 V DC via GPIO header
- Environment: Operating temperature, 0–50°C

Fig. 1 Raspberry Pi 3 A+

Raspberry Pi Camera Module

- Sensor : Sony IMX708
- Resolution : 11.9 MP
- Sensor size : 7.4 mm sensor diagonal
- Pixel size : 1.4 x 1.4 µm
- Horizontal/vertical : 4608 x 2592 pixels
- Common video modes : 1080p50, 720p100, 480p120
- Output : RAW10
- IR cut filter : Integrated in standard variants; not present in NoIR variants
- Autofocus system : Phase Detection Autofocus
- Ribbon cable length : 200 mm
- Cable connector : 15 x 1 mm FPC

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- Dimensions : 25 x 24 x 11.5 mm (12.4 mm height for Wide variants)

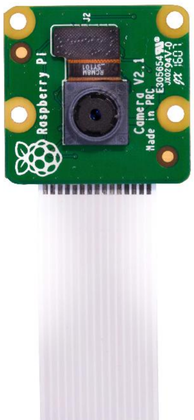

Fig. 2 Raspberry Pi Camera Module

Ultrasonic Sensor HC-SR04

- Input Voltage: 5V
- Current Draw: 20mA (Max)
- Digital Output: 5V
- Digital Output: 0V (Low)
- Working Temperature: -15°C to 70°C
- Sensing Angle: 30° Cone
- Angle of Effect: 15° Cone
- Ultrasonic Frequency: 40kHz
- Range: 2cm - 400cm

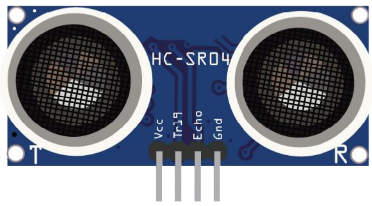

Fig. 3 Ultrasonic Sensor HC-SR04

IR sensor

- The operating voltage is 5VDC
- Mounting hole
- The range is up to 20 centimeters
- The supply current is 20mA
- The range of sensing is adjustable
- Fixed ambient light sensor
- I/O pins – 3.3V & 5V

Fig. 4 IR Sensor

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L293D Motor Driver

- Supply voltage range: 4.5V to 36V
- Output current per channel: 600mA (1.2A peak)
- Total output current: 1.2A (2.4A peak)
- Output voltage range: 0V to VCC
- Maximum power dissipation: 4W
- Number of channels: 2
- Input logic voltage: TTL/CMOS compatible
- Thermal shutdown protection: Yes
- Output diodes to protect against back EMF (electromotive force): Yes
- Pin count: 16

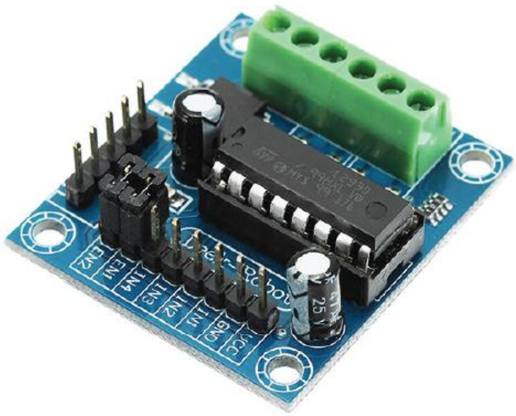

Fig. 5 L293D Motor Driver

1.3 Advantages

- Reduce equipment/plant downtime and improve maintenance and inspection procedures thoroughly.
- The robot has great application in accessing the pipe regions to which humans don't have reach.
- It is a compact and portable device and allows the operator to inspect the pipes at a higher speed.
- The service life of the pipeline is increased due to the removal of the sludges and scales formed inside thepipelines
- The maintenance cost of the entire operation is reduced as the same robot can be used multiple times

1.4 Applications

- Oil and gas (To clean slug and other deposits formed in the pipes)
- Water pipes (To detect leakage and save water)
- Survey (To relay video information)
- Allow inspection of inaccessible and/or hazardous equipment or work areas.
- Provide online inspection/maintenance without loss of equipment/plant availability & remove humans from potentially hazardous work situations.
- Provide information about the health and condition of critical plant components to facilitate decision making regarding plant life management.
- Reduce equipment/plant downtime and improve maintenance and inspection procedures through better coverage and documentation.
- The robot has great application in accessing the regions of pipe to which humanity doesn’t have reach.

- It could be mounted with a camera which would send us pictures of the inside and would help in our inspection.
- It could be fitted with ultrasonic sensors and can pinpoint the location of a hole.
- It even has an application in painting up the old installed pipe from the inside very easily.
- It could be even used for the dosing purpose through a pipe as its pitch is fixed.
- We could attach some material to be dosed and control the feeding of the material inside where we want.

II. LITERATURE REVIEW

2.1 Literature Survey

The Literature Review For This Project Covers Several Previous Works Related To Robots Used In Pipe Inspection And Cleaning.

[1] - In-Pipe Cleaning Mechanical System For Develop Robot - Developing Water Loss Prevention : Discusses The Development Of A Mechanism For Pipe-Joint Redevelopment In The Developed Lop Project. This Mechanism Involves Removing Corrosion With A Power Tool, Using A Wet And Dry Vacuum Cleaner To Suck Up Debris, And Applying A Restoration Material To Seal The Pipe Joint To Prevent Water Loss And External Contamination. The Mechanism Is Designed Like A Double "Flexible" Cylindrical Robot, Able To Cover The Inner Pipe Surface For Different Pipe Diameters.

[2] - Oil Pipelines/Water Pipeline Crawling Robot For Leakage : describes An Original Mobile Pipeline Robot With A Crawler Drive Unit, Power And Monitor Unit, Central Control Unit And Ultrasonic Wave Inspection Device That Inspects Flaws And Corrosion In Seabed Crude Oil Pipelines.

[3] - Fully Autonomous Pipeline Cleaning Robot : Presents A Fully Autonomous Pipeline Cleaning Robot That Cleans Mud Or Dirt Inside Pipes Using Four Tracks Attached To Foldable Linkages. The Robot Is Equipped With Wire Brushes That Rotate To Clean The Mud When Sensors Detect It.

[4] - Design Of A Fully Autonomous Mobile Pipeline Exploration Robot : Presents The Design And Implementation Of A Fully Autonomous Mobile Pipeline Exploration Robot That Can Move Horizontally And Vertically In Pipelines For Exploring Pipeline Structures Autonomously.

[5] - Advanced Pipe Inspection Robot : Discusses The Development Of An Advanced Pipe Inspection Robot Using Wireless Radio Communication Systems For Inspecting Long Complex Pipes And Long-Distance Pipes Including Straight, Vertical, And Bend Lines.

2.2 Recent Trends

Recent trends in the field of pipe inspection robots include the use of advanced sensor technologies such as 3D imaging sensors, thermal imaging cameras, and advanced ultrasonic sensors. These sensors provide higher accuracy and resolution in detecting cracks, corrosion, and other defects in pipes.

Another trend is the use of machine learning and artificial intelligence algorithms to analyze the data collected by these sensors. This enables the robot to automatically detect and classify defects in real-time, reducing the need for human intervention and improving the speed and accuracy of the inspection process.

Wireless communication technologies such as 5G and Li-Fi are also being explored for use in pipe inspection robots, as they enable faster data transfer and more reliable communication in challenging environments.

Finally, there is an increasing focus on developing pipe inspection robots that are more compact, lightweight, and agile, enabling them to navigate through narrow and complex pipes with greater ease. This is achieved through the use of advanced robotics technologies such as micro-actuators, flexible sensors, and bio-inspired locomotion systems.

III. DESIGN & DEVELOPMENT

3.1 Block Diagram

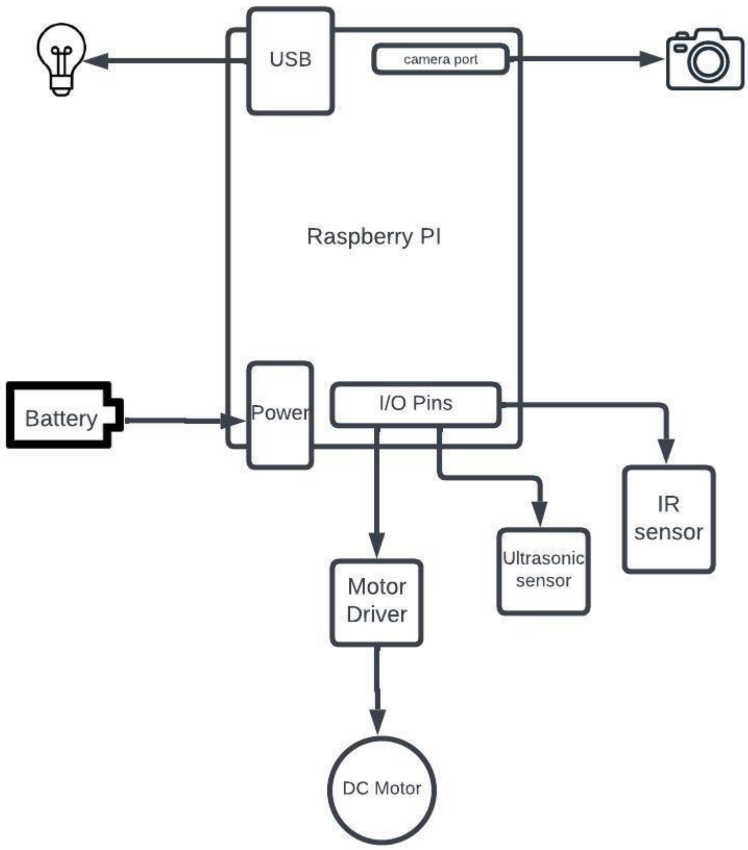

Fig. 6 Block Diagram

3.2 Algorithm

1. Initialize the robot's IR and ultrasonic sensors, and camera module.
2. Connect the Raspberry Pi to the robot's control system and the VNC server software.
3. Move the robot into the pipe to be inspected.
4. Continuously read data from the IR and ultrasonic sensors to detect blockages and cracks in the pipe.
5. If a blockage is detected, stop the robot and send an alert to the remote inspector.
6. If a crack is detected, mark the location and send an alert to the remote inspector.
7. Continuously capture images using the robot's camera and transmit them to the VNC server software for remote viewing.
8. If the robot encounters an obstacle, use the data from the sensors to navigate around it and continue the inspection.
9. Once the inspection is complete, transmit a report containing all data collected and alerts generated during the inspection to the remote inspector.
10. Shut down the robot.

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3.3 Flowchart

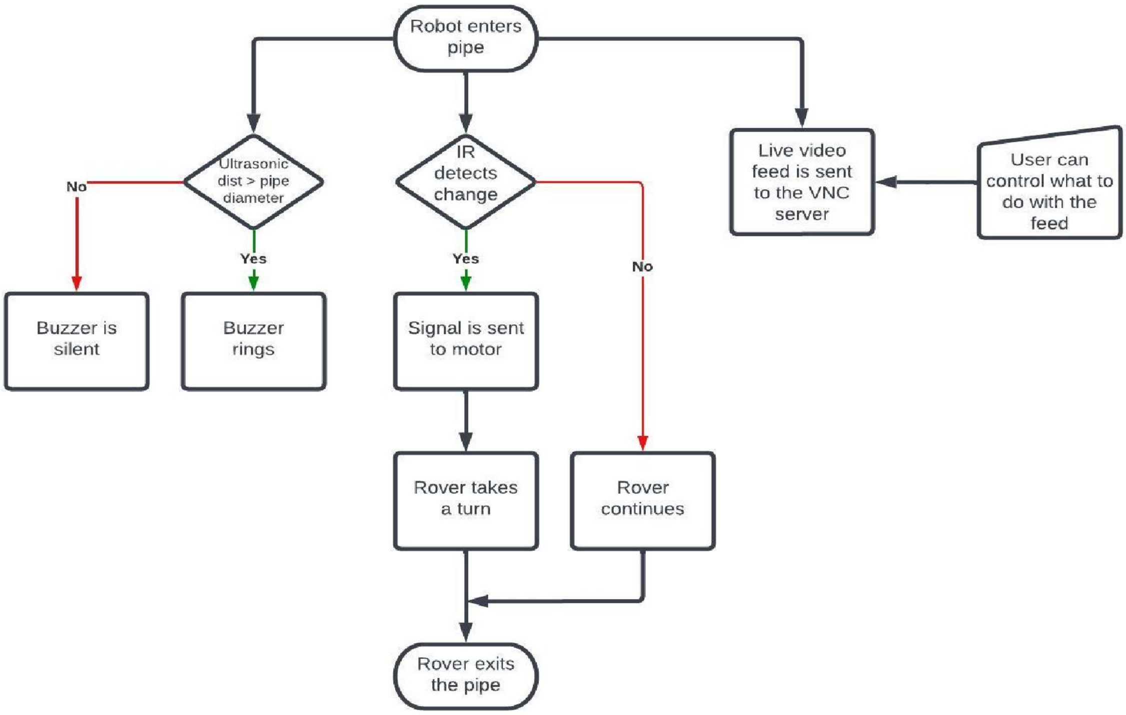

Fig. 7 Flowchart

IV. RESULT AND DISCUSSIONS

4.1 Discussions

The development and implementation of a pipe inspection robot have shown significant potential in improving pipeline inspection processes and addressing the challenges associated with manual inspection techniques. The pipe inspection robot demonstrated exceptional performance in accurately detecting blockages and cracks, facilitating visual inspection, enabling remote inspection capabilities, ensuring efficient mapping and navigation, and enabling real-time data transmission.

The IR sensor identified blockages with high accuracy, allowing efficient cleaning and maintenance of the pipeline. The ultrasonic sensor successfully detected cracks and corrosion, enabling timely maintenance actions to prevent potential accidents. The camera provided valuable visual inspection capabilities, complementing the sensor-based detection. Remote inspection through the Raspberry Pi and VNC server software allowed real-time access to the robot's camera feed and remote control of its movements, reducing costs and improving overall efficiency.

4.2 Result

The pipe inspection robot demonstrated high detection accuracy for both blockages and cracks. The IR sensor effectively detected blockages within the pipeline, allowing the robot to perform efficient cleaning operations. The ultrasonic sensor successfully identified cracks and corrosion on the pipe surface, enabling timely maintenance actions.

The camera mounted on the robot provided clear and detailed images of the inner pipe surface. This facilitated thorough visual inspection and allowed for the identification of potential issues such as corrosion, leaks, and structural abnormalities.

The integration of Raspberry Pi and VNC server software enabled remote inspection of the pipeline. Users were able to access the live video feed from the robot's camera and control its movements remotely. This feature proved to be highly advantageous, as it reduced the need for physical presence at the inspection site and improved overall efficiency.

The robot's capability to transmit captured data in real-time provided valuable insights for analysis and decision-making. The data captured by the sensors and camera were transmitted to a central system, allowing for immediate processing and assessment of the pipe's condition.

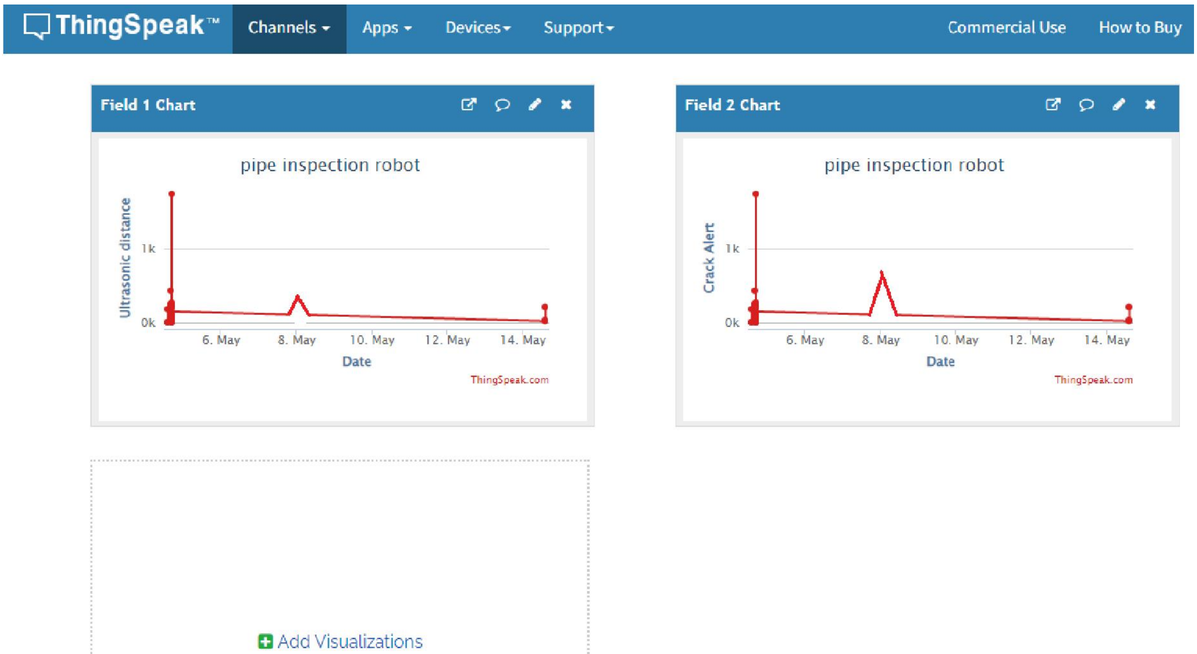

Fig. 8 Web Output

V. CONCLUSION AND FUTURE SCOPE

5.1 Conclusion

In this study, we have successfully designed, modeled, and simulated an autonomous mobile robot for pipe inspection. The robot incorporates various sensors and functionalities, including an IR sensor for blockage detection, an ultrasonic sensor for crack detection, a camera for visual inspection, and a blockage cleaning mechanism. The integration of the Raspberry Pi, and VNC server software enables remote inspection and real-time data transmission, enhancing the efficiency and effectiveness of the inspection process.

The results obtained from the pipe inspection robot demonstrate its capability to accurately detect blockages, cracks, and corrosion within the pipeline. The IR sensor effectively identifies blockages, allowing the robot to efficiently clean the pipeline and maintain its operational efficiency. The ultrasonic sensor proves successful in detecting cracks and corrosion, enabling timely maintenance actions to prevent potential accidents and minimize the impact on pipeline operations. The visual inspection provided by the camera offers additional insights into the condition of the pipeline, facilitating detailed examination and identification of various issues.

The remote inspection capability of the robot proves advantageous by eliminating the need for physical presence at the inspection site. It allows for real-time access to the robot's camera feed and remote control of its movements, reducing costs and improving overall efficiency.

5.2 Future Scope

- We can create the same rover to pass through a pipe with less diameter
- With the Help of Mechanics we can enable the rover for a vertical climb
- Driving mechanism of a developed robot can be modified to pass through a T-joint..
- Additionally, extending the camera's field of view to 360 degrees is also part of our future work, using one of several solutions, such as a rod being rotated by a DC motor and steadily turning the camera lens to cover a 360 degrees angle.

- Integration of advanced data analytics and AI can enhance pipe inspection robot capabilities. Machine learning algorithms can improve detection and decision-making abilities.

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