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Development of Pipe Climbing Robot for Flame and Gas Detection in Pipes

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Abstract—Inspection of industrial pipelines is essential for ensuring safety and preventing accidents caused by gas leakage and fire hazards. This paper presents the design and development of a pipe climbing robot capable of monitoring such conditions efficiently. The robot is equipped with an eight-wheel drive mechanism using DC geared motors, enabling it to move on both vertical and horizontal pipes with good stability and grip. An Arduino Nano microcontroller is used to control the robot's movement and sensing operations. The system integrates gas and flame sensors to continuously monitor the pipeline environment. When hazardous conditions are detected, the robot provides immediate indication for early warning.

Key Words—Pipe Climbing Robot, Arduino Nano, Gas Sensor, Flame Detection, Pipeline Inspection, Industrial Safety

I. INTRODUCTION

Pipelines play a vital role in transporting fluids such as oil, gas, and chemicals in various industries. Ensuring the safety and proper maintenance of these pipelines is essential to prevent accidents, environmental damage, and economic loss. Traditional inspection methods mainly rely on manual labor, which can be dangerous, time-consuming, and inefficient, especially in hazardous or hard-to-reach areas.

With the advancement of robotics and automation, pipe inspection robots have emerged as an effective solution for improving safety and efficiency. These robots are capable of navigating through pipelines and performing inspection tasks with minimal human intervention. In particular, detecting gas leakage and fire hazards at an early stage is crucial to avoid major industrial disasters.

This project focuses on the design and development of a pipe climbing robot capable of detecting gas leakage, flame, temperature, humidity, and liquid leakage. The robot uses an eight-wheel drive mechanism powered by DC geared motors and is controlled using an Arduino Nano microcontroller

The proposed system aims to reduce human risk, improve inspection accuracy, and provide a cost-effective solution for industrial applications. It can be widely used in oil and gas industries, chemical plants, and other pipeline-based systems. Future enhancements can further increase its efficiency by incorporating advanced features such as wireless communication and real-time monitoring.

II. LITERATURE SURVEY

Hirose Shigeo and et al. (1997) *:- Developed one of the early pipe inspection robots designed to move inside pipelines using a wheeled mechanism. Their work introduced the concept of using robotic mobility to perform inspection tasks in confined pipeline environments. The robot was capable of moving through curved pipes and detecting defects in pipeline systems.*

Satoshi Tadokoro (2004) *:- Studied the design of mobile robots for hazardous environments. His research highlighted the importance of using robotic systems for inspection tasks in dangerous locations where human access is difficult. The study emphasized integrating sensors with robotic platforms to detect environmental hazards such as gas leakage or fire.*

Yong Liu and et al. (2013) *:- Developed a pipe-climbing robot that uses adjustable wheels and a gripping mechanism to move along pipelines. Their design allowed the robot to travel on pipes with different diameters and orientations, including vertical and horizontal pipes.*

Hong Zhang (2018) *:- Proposed a modular pipe-climbing robot capable of adapting to different pipeline conditions. The robot used multiple driving wheels and a flexible structure to improve stability and mobility. The research also discussed the integration of sensors for monitoring pipeline conditions and detecting faults.*

III. METHODOLOGY

The proposed pipe climbing robot is designed to perform efficient pipeline inspection by integrating mechanical movement with real-time gas and flame detection. The methodology of the system is divided into mechanical design, electronic control, and sensing operations. Initially, the robot is constructed with a rigid frame structure mounted with eight wheels arranged symmetrically to ensure proper grip on the pipe surface. Each wheel is driven by a DC geared motor, which provides sufficient torque for climbing both vertical and horizontal pipes. The mechanical design ensures stability and prevents slippage during operation.

The control system of the robot is based on an Arduino Nano microcontroller, which acts as the central processing unit. A motor driver module is used to control the direction and speed of the motors, enabling forward, reverse, and climbing movements. The robot is powered by a rechargeable battery, ensuring portability and continuous operation. For hazard detection, the system is equipped with a gas sensor and a flame sensor. The gas sensor continuously monitors the presence of harmful gases, while the flame sensor detects fire or high-intensity light signals. These sensors send real-time data to the Arduino Nano for processing.

During operation, the robot moves along the pipeline while continuously scanning the environment. If gas leakage or flame is detected, the system immediately activates visual indicators such as LEDs to alert the user. This enables early detection and preventive action. The overall system is designed to be simple, cost-effective, and reliable, making it suitable for industrial applications. The integration of mobility and sensing in a single unit enhances inspection efficiency and reduces human intervention in hazardous environments.

Power Supply Initialization

The system is powered using a rechargeable battery connected to all modules including the Arduino Nano, motor driver, and sensors.

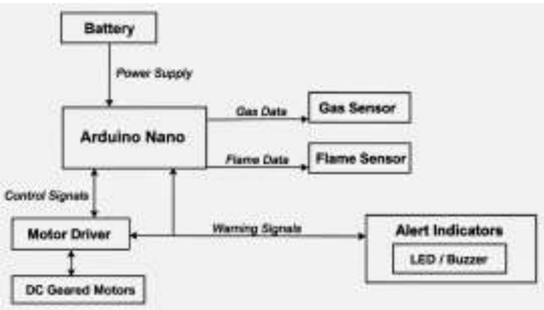

Figure-1: Block Diagram of Pipe Climbing Robot System

System Activation

When the power is switched ON, the Arduino Nano initializes all components and starts the control program.

Motor Control

The motor driver receives signals from the Arduino Nano and drives the DC geared motors, enabling the robot to move forward and climb the pipe.

Pipe Climbing Mechanism

The eight-wheel arrangement maintains proper grip on the pipe surface, allowing stable movement in both vertical and horizontal directions.

Gas Detection

The gas sensor continuously monitors the surrounding environment for the presence of harmful gases. If gas leakage is detected, it sends a signal to the Arduino.

Flame Detection

The flame sensor detects fire or high-intensity light. Upon detection, it sends a signal to the microcontroller.

Signal Processing

The Arduino Nano processes input signals from the sensors and determines if any hazardous condition is present.

Alert Indication

When gas or flame is detected, the system activates LED indicators (or buzzer if included) to provide immediate warning.

Continuous Monitoring

The robot continues moving along the pipeline while performing real-time monitoring and detection.

IV. CIRCUIT DIAGRAM

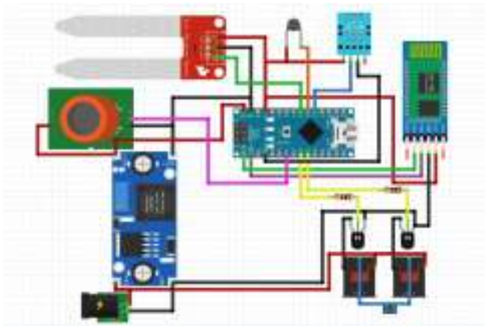

Figure-2: Circuit Diagram of Pipe Climbing Robot

The circuit diagram of the pipe climbing robot is centered around the Arduino Nano microcontroller, which acts as the main control unit. The system is powered by a 12V battery, which supplies power to both the motors and electronic components. A DC-DC buck converter is used to step down the voltage to 5V for the Arduino Nano, sensors, and other modules.

The robot is equipped with multiple sensors for environmental monitoring. The MQ gas sensor is connected to the analog input pin of the Arduino Nano to detect harmful gases. A DHT11 sensor is used to measure temperature and humidity, while a thermistor (NTC sensor) is used to sense pipe temperature. Additionally, a soil moisture sensor is included for detecting the presence of liquid or water.

For communication, an HC-05 Bluetooth module is connected to the Arduino Nano through serial communication pins (TX and RX), enabling wireless control and monitoring.

The motor control system consists of DC motors driven through NPN transistors, which act as switching devices. These transistors receive control signals from the Arduino Nano and regulate motor operation. The motors are responsible for driving the wheels that enable the robot to climb the pipe.

All components share a common ground to ensure proper circuit operation. The circuit is designed to provide efficient power management, reliable sensing, and stable motor control, making the system suitable for real-time pipeline inspection and hazard detection.

V. PROGRAMMING AND SOFTWARE IMPLEMENTATION

The Arduino Nano can be programmed with the Arduino software. The ATmega328 on the Arduino Nano comes pre-burned with a boot loader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C Header Files).We can also bypass the boot loader and program the microcontroller through the ICSP (In-circuit serial programming) header; see These instructions for details. The ATmega16U2 (or 8U2 in the rev1 and rev2

boards) firmware source Code is available. The ATmega16U2/8U2 is loaded with a DFU boot loader, which can be activated by:
1- On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.
2- On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2
HWB line to ground, making it easier to put into DFU mode. We can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header With an external programmer (overwriting the DFU boot loader). See This user-contributed tutorial for more information.

Arduino Software Interface

Figure-3: Verify in Arduino software

Figure-4: Upload in Arduino software

Open New workspace for programming

Figure-5: To create a new file in Arduino software

Open the existing project which was previously done

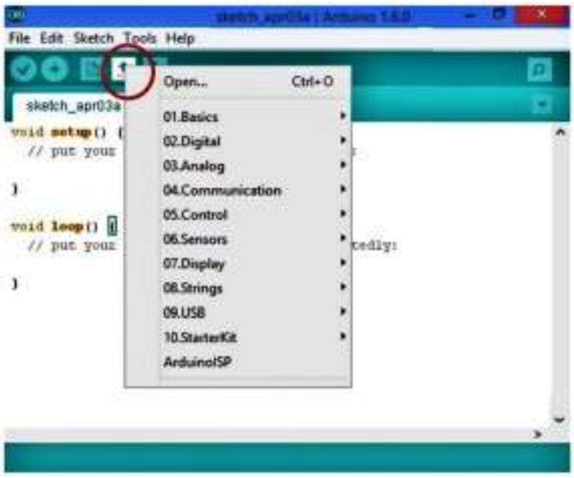

Figure-6: To open a new file in Arduino software

Save the project which was done.

Figure-7: To save an new file in Arduino software

Arduino Bluetooth controller application

This android application can establish a connection with any Arduino/microcontroller project that involves a Bluetooth module! It allows The User to set a UUID of his own Bluetooth module in order to connect the Android Application with his projects!!! The default UUID that comes with this Application Is for the HC-06 Wireless Serial 4 Pin Bluetooth RF Transceiver Module RS232. (If you use default

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UUID in order to pair the BT module with Your smartphone for The first time, you will have to give a 4-digit password. This password is '1234'.)

The following images represent the way the Bluetooth needs to be Connected And later the operation procedure to be followed. The steps for the connecting the Bluetooth and making the robot work is explained in detail in the Further part of the description. As of now, the images depict the basic working of The application that need to adapted for the pairing of the Bluetooth with the robot and later selecting the mode of operation for the controlling the robot.

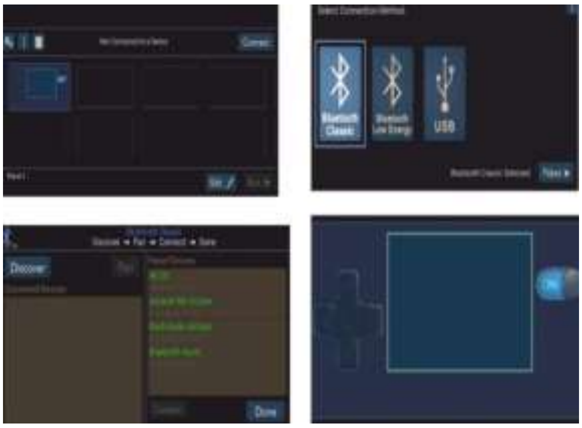

Figure-8: Arduino Bluetooth controller

Arduino Coding

```
#include "DHT.h"
#define DHTPIN 3
#define LIQ 4
#define GAS 5
#define FIR 6
#define DHTTYPE DHT11
DHT dht(DHTPIN, DHTTYPE);
#define pin1 A2
#define pin2 A1
#define Buzz 12
Char I;
Int Flag1 = 0;
Int Flag2 = 0;
Void setup()
{
Serial.begin(9600);
pinMode(pin1, OUTPUT);
pinMode(pin2, OUTPUT);
pinMode(Buzz, OUTPUT);
digitalWrite(pin1, LOW);
digitalWrite(pin2, LOW);
digitalWrite(Buzz, LOW);
pinMode(DHTPIN, INPUT);
pinMode(LIQ, INPUT);
pinMode(FIR, INPUT);
pinMode(GAS, INPUT)
dht.begin();
Serial.println("Systen Ready");
Delay(500);
}
Void loop()
{
If (Serial.available())
{
I = Serial.read();
Switch (i)
{
Case 'U':
digitalWrite(pin1, LOW);
digitalWrite(pin2, HIGH);
break;
case 'D':
digitalWrite(pin1, HIGH);
digitalWrite(pin2, LOW);
break;
case 'S':
digitalWrite(pin1, LOW);
digitalWrite(pin2, LOW);
break;
case 'A':
Flag1 = 1;
Break;
Case 'a':
Flag1 = 0;
digitalWrite(Buzz, LOW);
break;
}
}
If(Flag1 == 1)
```

```
{
If(digitalRead(GAS) == LOW && digitalRead(FIR) == LOW &&
digitalRead(LIQ) == LOW)
{
Serial.println("GAS : Leaking ");
Serial.println("FIR : Detected");
Serial.println("LEK : Detected");
Serial.println(" ");
Serial.println(" ");
digitalWrite(Buzz,HIGH);
delay(300);
}
Else if(digitalRead(GAS) == LOW && digitalRead(FIR) == LOW &&
digitalRead(LIQ) == HIGH)
{
Serial.println("GAS : Leaking ");
Serial.println("FIR : Detected");
Serial.println("LEK : NoT-Detected");
Serial.println(" ");
Serial.println(" ");
digitalWrite(Buzz,HIGH);
delay(300);
}
Else if(digitalRead(GAS) == LOW && digitalRead(FIR) == HIGH &&
digitalRead(LIQ) == LOW)
{
Serial.println("GAS : Leaking ");
Serial.println("FIR : NOT-Detected");
Serial.println("LEK : Detected");
Serial.println(" ");
Serial.println(" ");
digitalWrite(Buzz,HIGH);
delay(300);
}
Else if(digitalRead(GAS) == LOW && digitalRead(FIR) == HIGH &&
digitalRead(LIQ) == HIGH)
{
Serial.println("GAS : Leaking");
Serial.println("FIR : NOT-Detected");
Serial.println("LEK : NOT-Detected");
Serial.println(" ");
Serial.println(" ");
digitalWrite(Buzz,HIGH);
delay(300);
}
Else if(digitalRead(GAS) == HIGH && digitalRead(FIR) == LOW &&
digitalRead(LIQ) == LOW)
{ Serial.println("GAS : NOT-Leaking");
Serial.println("FIR : Detected");
Serial.println("LEK : Detected");
Serial.println(" ");
Serial.println(" ");
digitalWrite(Buzz,HIGH);
delay(300);
}
Else if(digitalRead(GAS) == HIGH && digitalRead(FIR) == LOW &&
digitalRead(LIQ) == HIGH)
{
Serial.println("GAS : NOT-Leaking");
Serial.println("FIR : Detected");
Serial.println("LEK : NOT-Detected");
Serial.println(" ");
Serial.println(" ");
digitalWrite(Buzz,HIGH);
delay(300);
}
Else if(digitalRead(GAS) == HIGH && digitalRead(FIR) == HIGH &&
digitalRead(LIQ) == LOW)
{
Serial.println("GAS : NOT-Leaking");
Serial.println("FIR : NOT-Detected");
Serial.println("LEK : Detected");
Serial.println(" ");
```

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```
Serial.println(" ");
digitalWrite(Buzz,HIGH);
delay(300);
}
Else
{
Float h = dht.readHumidity();
Float t = dht.readTemperature();
Float f = dht.readTemperature(true);
If (isnan(h) || isnan(t) || isnan(f))
{
Serial.println(F("Failed to read from DHT sensor!"));
Return;
}
Serial.print("Temp: ");
Serial.print(t);
Serial.print("C – Humi: ");
Serial.print(h);
Serial.println("%");
Serial.println(" ");
digitalWrite(Buzz,LOW);
delay(300);}}}
```

VI. RESULT

The developed pipe climbing robot successfully demonstrated stable movement along the pipe surface while accurately detecting flame, gas leakage, humidity, temperature variations, and liquid leakage, providing reliable real-time monitoring and immediate indication of hazardous conditions, thereby enhancing safety and efficiency in pipeline inspection.

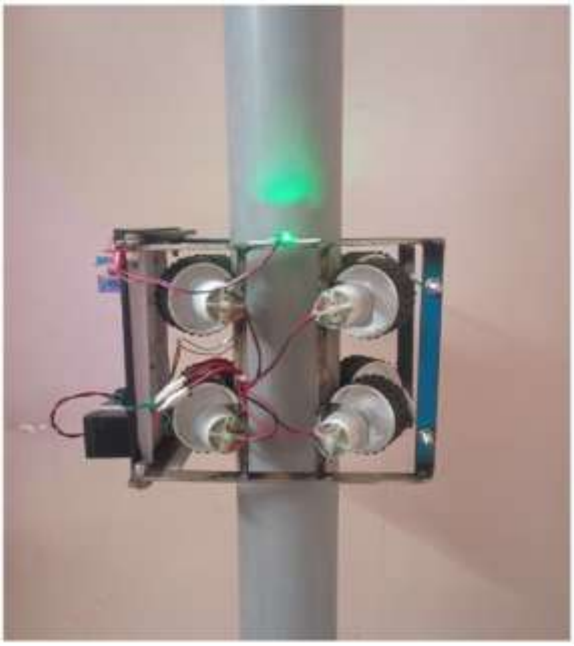

Figure-9: Robot Climbing Pipe

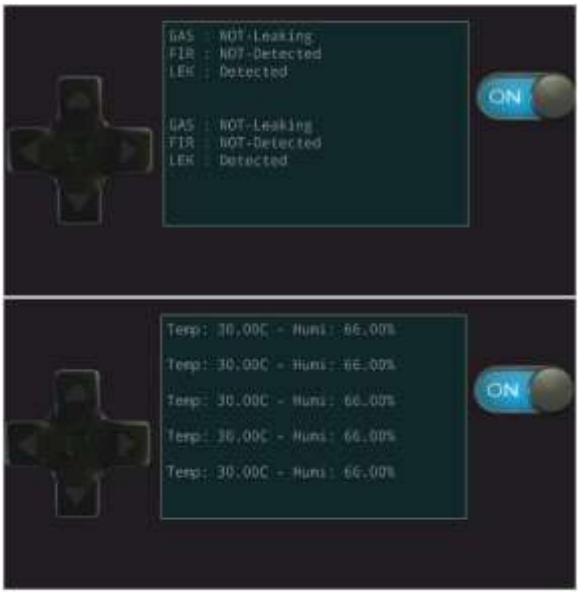

Figure-10: Detecting Temperature, Humidity and Fluid Leakage

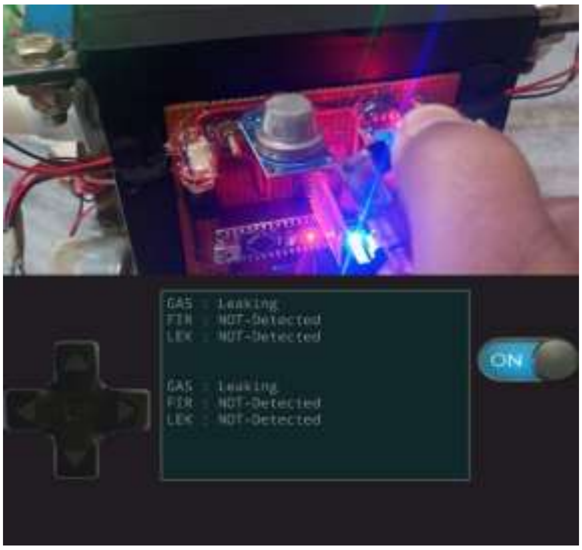

Figure-11: Detecting Gas Leakage

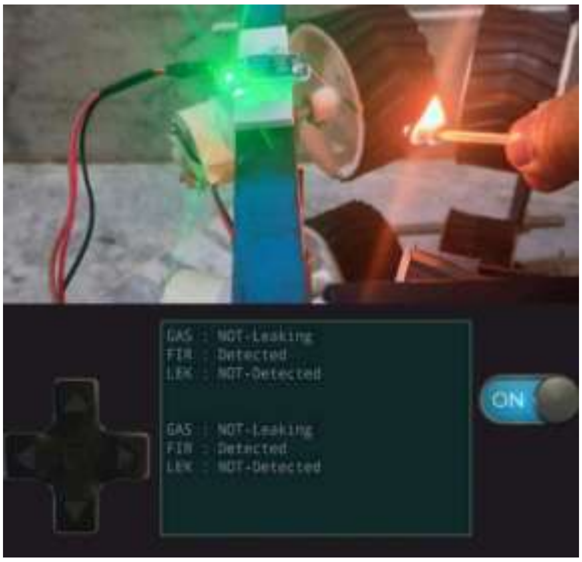

Figure-12: Detecting Flame

VII. FUTURE SCOPE

The proposed system can be further enhanced by integrating a camera module for real-time video monitoring and implementing wireless communication such as IoT for remote control and data transmission. The use of advanced sensors can improve detection accuracy, while the addition of automatic navigation and obstacle avoidance can make the robot more intelligent. The system can also be improved by increasing battery capacity for longer operation and miniaturizing the design for inspection of smaller pipes. Furthermore, the integration of GPS tracking and the application of artificial intelligence techniques can enhance monitoring and analysis capabilities.

VIII. CONCLUSION

The pipe climbing robot was successfully designed and developed for efficient pipeline inspection and hazard detection. The system is capable of detecting flame, gas leakage, humidity, temperature variations, and liquid leakage in real-time while maintaining stable movement on both vertical and horizontal pipes. The integration of sensors with the Arduino Nano ensures accurate monitoring and quick response to hazardous conditions.

The proposed system reduces human effort and risk in dangerous environments, making it a reliable and cost-effective solution for industrial applications. Overall, the robot improves safety, efficiency, and accuracy in pipeline inspection. Further enhancements can be made by incorporating advanced features such as wireless communication and real-time monitoring systems to expand its capabilities.

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