DEVELOPMENT OF AN IOT-BASED MOBILE ROBOT FOR HAZARDOUS GAS DETECTION

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ABSTRACT

The escalating concerns regarding environmental safety and the potential hazards posed by poisonous gases necessitate innovative approaches for efficient detection and monitoring. This paper introduces a novel solution in the form of a remote-controlled mobile robot equipped with advanced gas-sensing technologies. The robotic system aims to autonomously navigate hazardous environments, identifying and quantifying the presence of poisonous gases in real time. The methodology involves the integration of state-of-the-art gas sensors on the four wheeled mobile robot, enabling it to perform comprehensive gas detection while being remotely controlled for optimal safety. The paper details the design and implementation of the mobile robot sensors and navigational controls, emphasizing its adaptability to various terrains and its ability to transmit real-time data to an Internet of Things (IOT) application. Results from experimental trials demonstrate the efficiency and effectiveness of the proposed system in detecting and mapping poisonous gas concentrations, providing a valuable tool for environmental monitoring and emergency response.

Keywords*:* Four-wheel mobile robot, Autonomous Navigation, Advanced gas sensing, IoT, Gas detection

INTRODUCTION

In an era where environmental safety and rapid response to potential threats are paramount, the need for efficient and safe detection of poisonous gases has become paramount (Ali *et al.*, 2018). Poisonous gases pose significant threats to both the environment and human health (Owolabi *et al.*, 2021). Accurate and swift detection of these gases is essential for effective emergency response, pollution control, and overall environmental safety (Ali *et al.*, 2018). Traditional methods often involve human intervention, which can be hazardous and time-consuming (Bayat *et al.*, 2017). To address this challenge, this paper presents the design and implementation of an advanced gas-sensing technology payload for a remote-controlled robotic vehicle (mobile robot) designated for environmental monitoring. The integration of robotics in gas detection not only enhances safety by minimizing human exposure to hazardous environments but also allows for swift and accurate identification of poisonous gases (Hanafi *et al.*, 2016; Vincent *et al.*, 2019; Xu, 2023).

In the context of toxic gases, several key terms are essential for understanding and managing the associated risks. The Parts per Million (PPM) Threshold Limit signifies the concentration of a substance in air below which nearly all individuals can be repeatedly exposed without adverse effects (Owolabi *et al.*, 2021). Permissible Exposure Limit (PEL) is the maximum allowable concentration established by regulatory bodies, such as the Occupational Safety and Health Administration (OSHA), to protect workers during an 8-hour workday. The Immediately Dangerous to Life and Health (IDLH) value indicates the maximum concentration from which an individual could escape within 30 minutes without irreversible health effects (Andrews *et al.*, 2005). Additionally, the Gas Hazard Class categorizes gases based on their potential health effects and physical hazards, aiding in the implementation of appropriate safety measures. These concepts play a vital role in assessing and mitigating the risks associated with toxic gas exposure in diverse environments, ensuring the safety and well-being of individuals (Li *et al.,* 2019). Table 1 below shows some toxic gases and measurement levels according to OSHA.

Central to this exploration is the integration of gas-sensing technology payload to a robotic vehicle which will enable navigation of environments where the presence of poisonous gases demands vigilant monitoring (Kwok, 1999; Wandel *et al.,* 2001; West *et al.,* 2019). Equipped with state-of-the-art gas sensors, the mobile robotic may be operated either manually or autonomously, systematically scanning the surroundings for gas concentrations. The capability to remotely control the robotic system enhances safety by reducing human exposure to potentially harmful environments. Real-time data transfer is a pivotal component of this technological advancement (Neto, 2019). The mobile robot not only detects poisonous gases but also promptly transmits the collected data to a control centre. This feature ensures that decision-makers receive instantaneous information, enabling swift and informed responses to emerging environmental threats. The integration of real-time data transfer optimizes the efficiency of emergency protocols, offering a proactive approach to environmental safety.

This research aims to contribute to the field of autonomous environmental monitoring, offering a reliable solution to the pervasive issue of gas detection in industrial and public spaces. Through the utilization of cutting-edge robotics, this innovative gas-sensing technology mobile robotic pay-load system seeks to redefine the landscape of gas-sensing technology, making it more accessible, efficient, and adaptable to various settings.

Table 1: Toxic gases with Hazard class and exposure levels (Andrews *et al.,* 2005)

S/N	Gas	Formula	Hazard Class	PPM Threshold Limit	Permissible Exposure Limit	IDLH
1	Ammonia	NH_3	III	25	50	500
2	Carbon Monoxide	C0	IV	20	200	1200
3	Chlorine	Cl_2	II	0.5	1	10
4	Hydrogen Sulphide	H_2S	II	10	10	100
5	Nitric Oxide	NO	II	25	25	100
6	Ozone	O_3	I	0.5	0.1	5

Moreover, the paper contributes advancements to existing methods by introducing key improvements. Primarily, conventional Bluetooth communication has been replaced with internet connectivity (WiFi), enabling global data transmission rather than the limited range offered by Bluetooth. Additionally, the inclusion of a manual control method enhances gas detection, allowing users to directly manipulate the robot in their preferred direction. This research endeavours to contribute significantly to the advancement of technologies dedicated to safeguarding our environment and ensuring the well-being of communities at large.

MATERIALS AND METHOD

The approach to the design and development of the gas detection mobile robot is divided into two segments: the hardware and software, as illustrated in Figure 1.

The hardware is centered on a 4-wheeled mobile robot and designed to execute four primary functions which include environmental navigation, gas and temperature detection facilitated by gas and temperature sensors, location tracking with the assistance of a Global Positioning System (GPS) module, and wireless data transmission supported by a WiFi module. The hardware is housed in two separate compartments mounted atop the 4-wheeled robot chassis (Figure 2). The wireless transceiver, wireless camera, GPS tracker as well as Obstacle avoidance sensors are housed in the command module of the mobile robot. Gas sensors, temperature sensors and humidity sensors are housed in the sensors module. The entirety of the hardware framework is constructed around an AT-mega 2560 (Arduino Mega) Microcontroller. This microcontroller, featuring 54 Digital I/O pins and 16 Analog I/O pins, facilitates the interfacing of numerous sensors and actuators essential for achieving the intended functionalities. The microcontroller's 8-bit resolution ADC pins are employed to read and process analog signals from the analog gas sensors, with Table 2 detailing the microcontroller pins used in conjunction with other sensors.

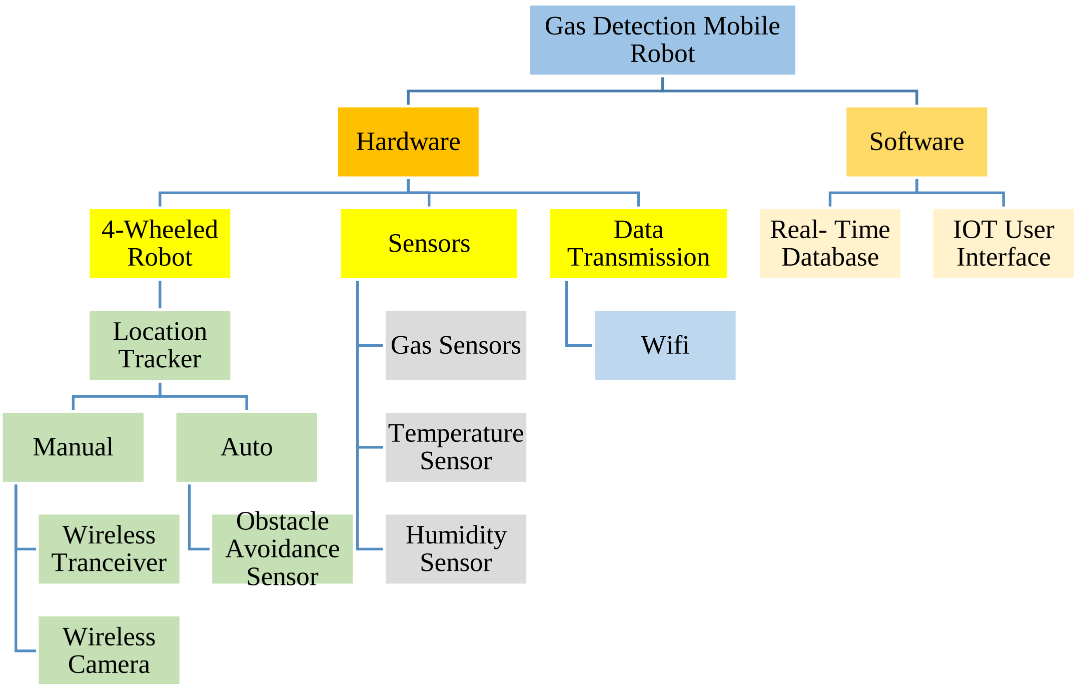

Figure 1: Overview of IOT-Based Gas Detection Mobile Robot

Each wheel of the 4-wheeled robot is operated by a Pololu 37D DC motor, while Stepper and DC Motor Driver Module, 2A, L298 are used to control the motors. The robot operates in two modes: manual and automatic. In the manual mode, a wireless remote control directs the robot's movement, utilizing the NRF24L01 transceiver module for wireless signal transmission of up to 100 m between the robot and the remote. Additionally, a wireless camera mounted on the robot provides real-time visuals to the operator. In the automatic mode, obstacle detection sensors and gas sensors govern the robot's motion. The robot autonomously moves toward the direction with the highest gas detection intensity, concurrently navigating around obstacles using ultrasonic sensors.

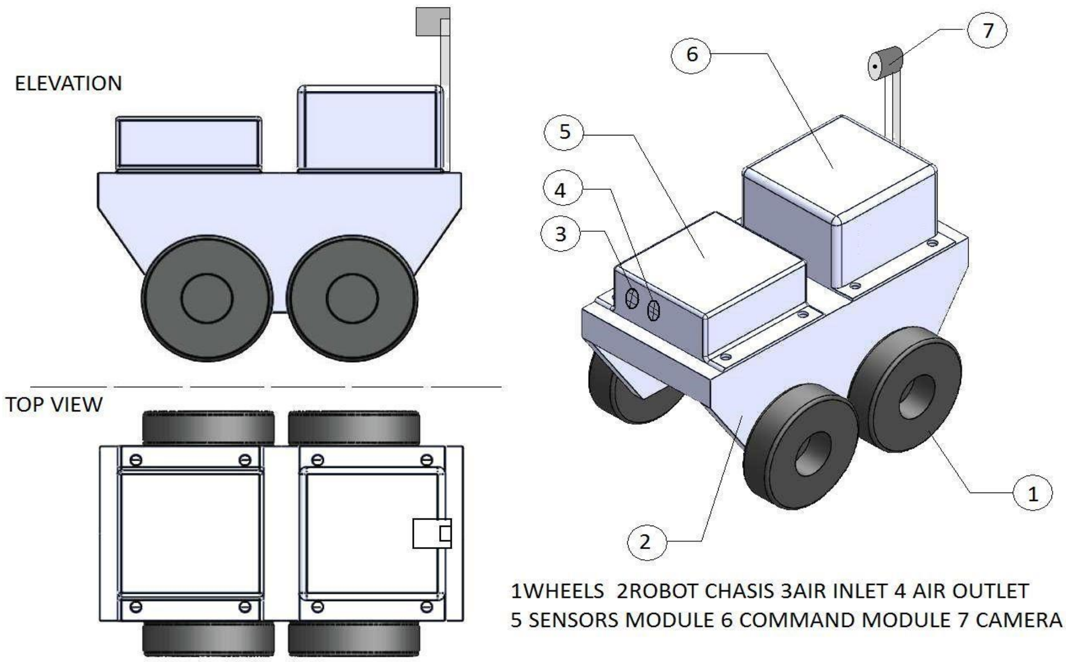

Figure 2: An overview of the Gas Detection Mobile Robot

Table 2: Gas Sensors with Assigned Microcontroller Pins

S/N	Gas sensor	Gas to be detected	Analog pin	Reading range (PPM)
1	MQ-7	Carbon Monoxide	A0	10 - 1000
2	MQ-131	Ozone	A1	10-1000(ppb)
3	MQ-135	Sulphur dioxide	A2	10-1000
4	MQ-136	Hydrogen sulphide	A3	100-10000
5	MQ-137	Ammonia	A4	5-200

Data collected from the sensors during robot navigation, along with latitude and longitude information during gas detection, are transmitted to the database through a WiFi-based ESP01 microcontroller. Figure 3 and 4 illustrates the block diagram and component composition of the mobile robot, while Figures 5 and 6 depicts the block diagram and component composition of the Wireless Remote Controller.

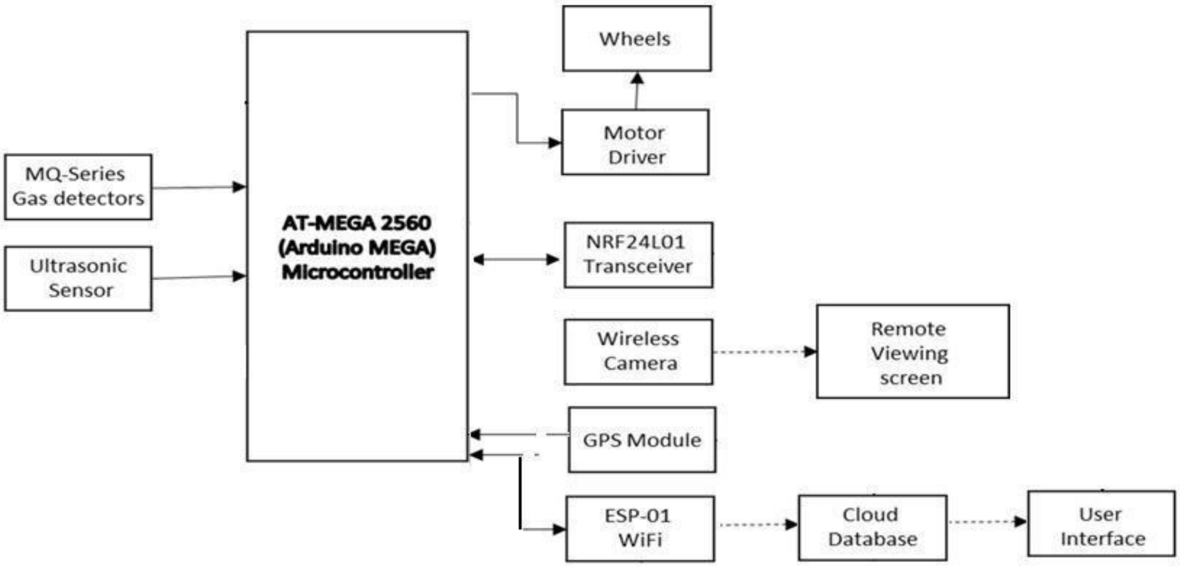

Figure 3: Block Diagram of Gas Detection mobile robot (Hardware)

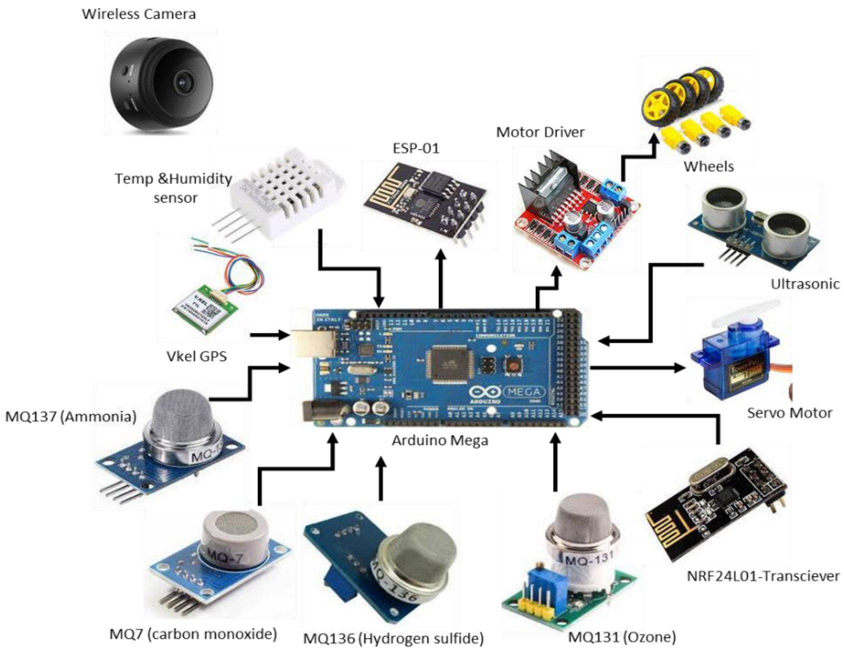

Figure 4: Component Composition of Gas Detection Mobile Robot (Hardware)

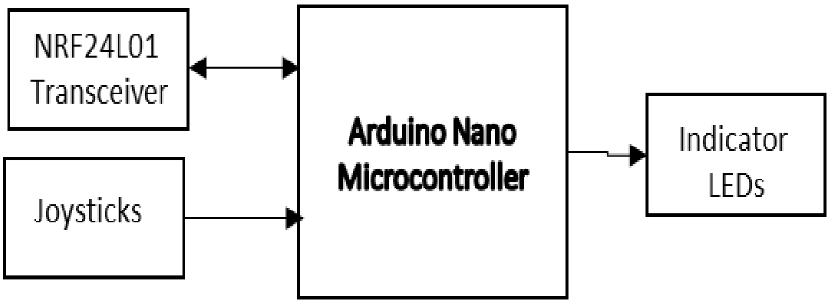

Figure 5: Block Diagram of Wireless Remote Controller

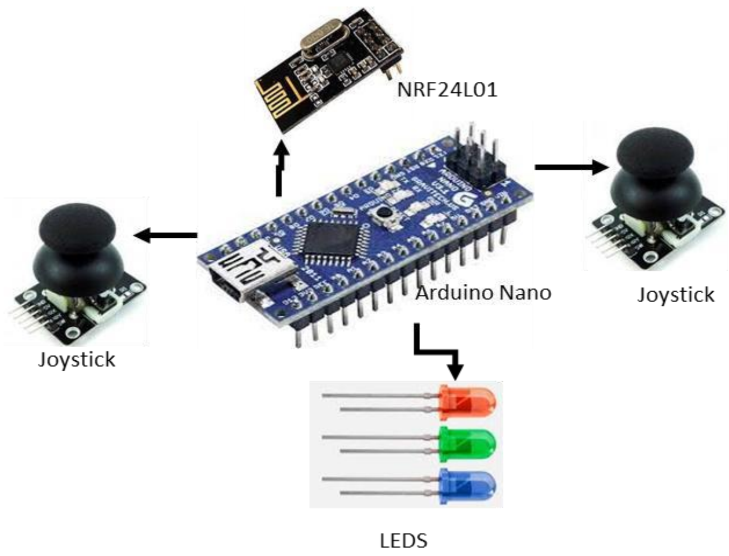

Figure 6: Component Composition of Wireless Remote Controller

The MQ series sensors feature an internal heater that initiates heating when a 5V voltage is applied. The internal resistance of the sensor varies with changes in the density of detectable gases. To ensure accurate data, the following steps were initially taken: The MQ sensors require 24-48 hours of preheating time. 5v DC was supplied to the sensors to preheat for the necessary duration until it is ready. The Analog pin AO provides an analog value based on the gas concentration, while the digital pin DO on the module returns HIGH if the gas concentration exceeds a specific threshold set by the potentiometer on the board. Before usage, the gas modules were calibrated. Finally, on the software section, Firebase was used as a real-time database to store data transmitted from the hardware. Subsequently, the data is relayed to the Blynk IoT platform, enabling real-time monitoring of gas and temperature readings.

For evaluation tests, toxic gases were released in levels (or trials) in incremental small quantities in a confined space measuring 3.0 x 3.6 x 3m (L x W x H) and the robot was deployed to test the efficiency of its MQ Sensors array. Alongside the robot, a standard measuring instrument (Dragar gas detector) for each of the gases was also deployed to obtain separate readings. The readings obtained from the robot were then compared with those obtained from a standard gas detector sensor to assess the error margin and, consequently, the accuracy.

RESULTS AND DISCUSSION

The average error margin provides a consolidated view of the overall accuracy of each MQ sensor compared to standard sensors for the respective gases. On average, the MQ7 sensor displayed readings approximately 8.36% lower than those of the standard CO sensor. Similarly, the MQ135 sensor exhibited readings around 6.16% lower compared to the standard SO2 sensor. The MQ136 sensor reported an average reading approximately 9.88% lower than the standard H2S sensor, while the MQ137 sensor demonstrated readings on average 8.36% lower than those obtained from the standard NH3 sensor. Figure 7 shows the Blynk IOT interface for displaying data read from the sensors while Figure 8 shows graphs obtained from experiment carried out.

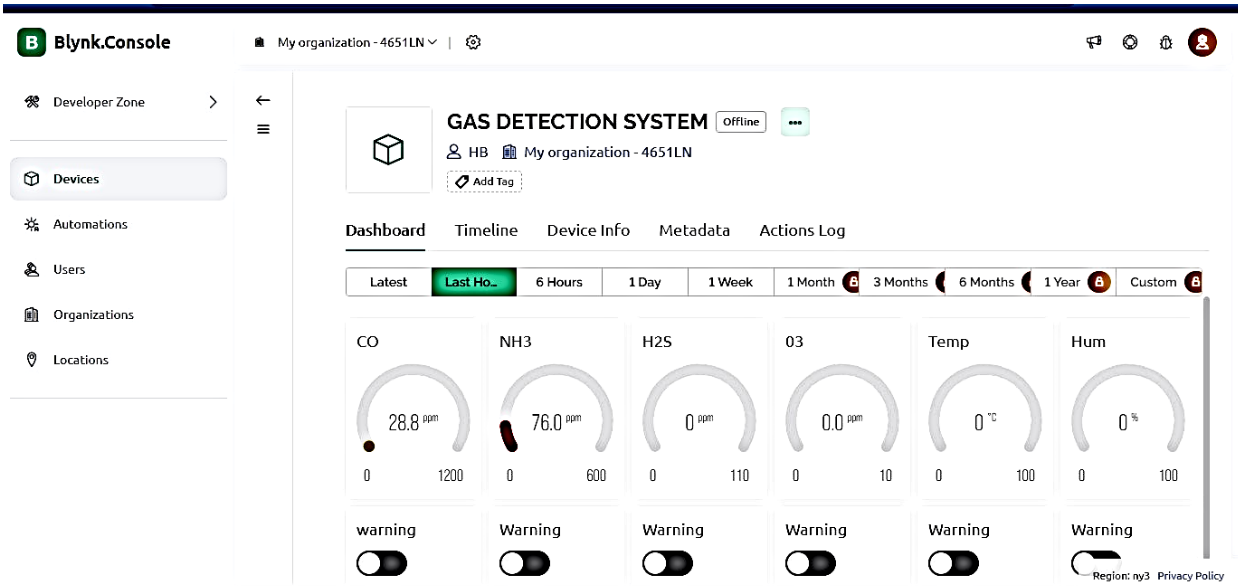

Figure 7: Blynk IOT Interface

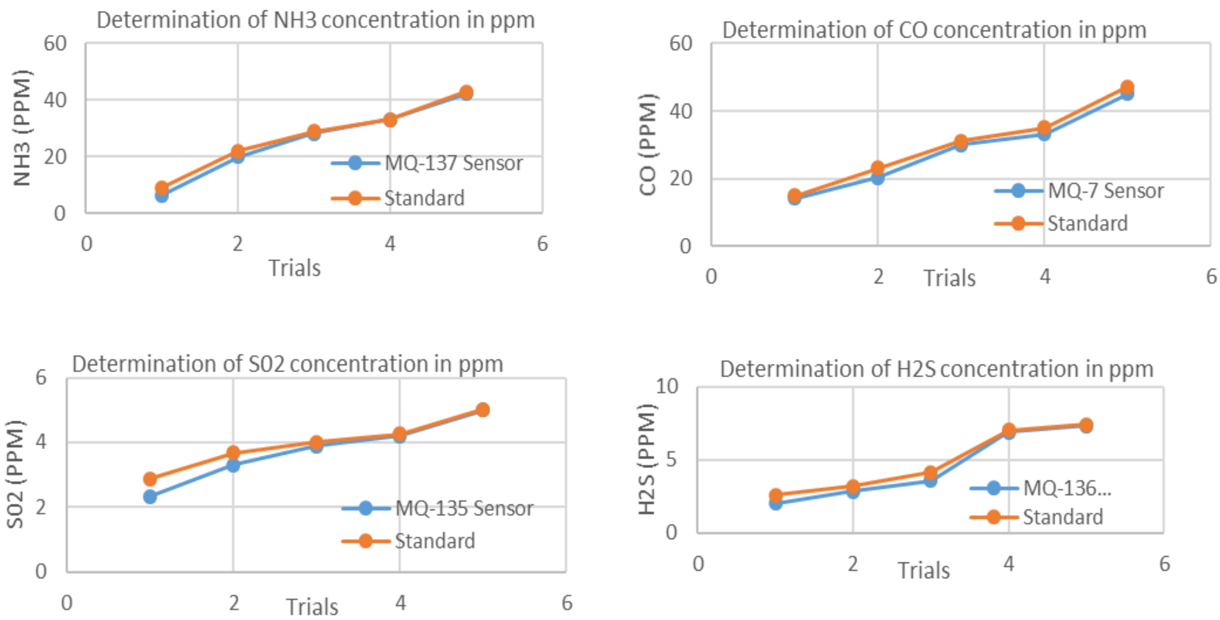

Figure 8: Graphs Obtained From Experiments

From the graphs of NH_3, CO, SO_2 and H_2S as measured by MQ series sensors compared with the standard, the trend shows that as the trial values increases, the values for MQ series sensors tends to match those obtained from the standard measuring instrument (Dragar gas detector) both in general trends and in magnitude. Figure 9 are the graphs depicting correlation between values obtained from MQ series sensors and the standard measuring instruments. The correlation coefficients (R2) are 0.9907, 0.9969, 0.8550, and 0.9978 for NH_3, CO, SO_2 and H_2S respectively.

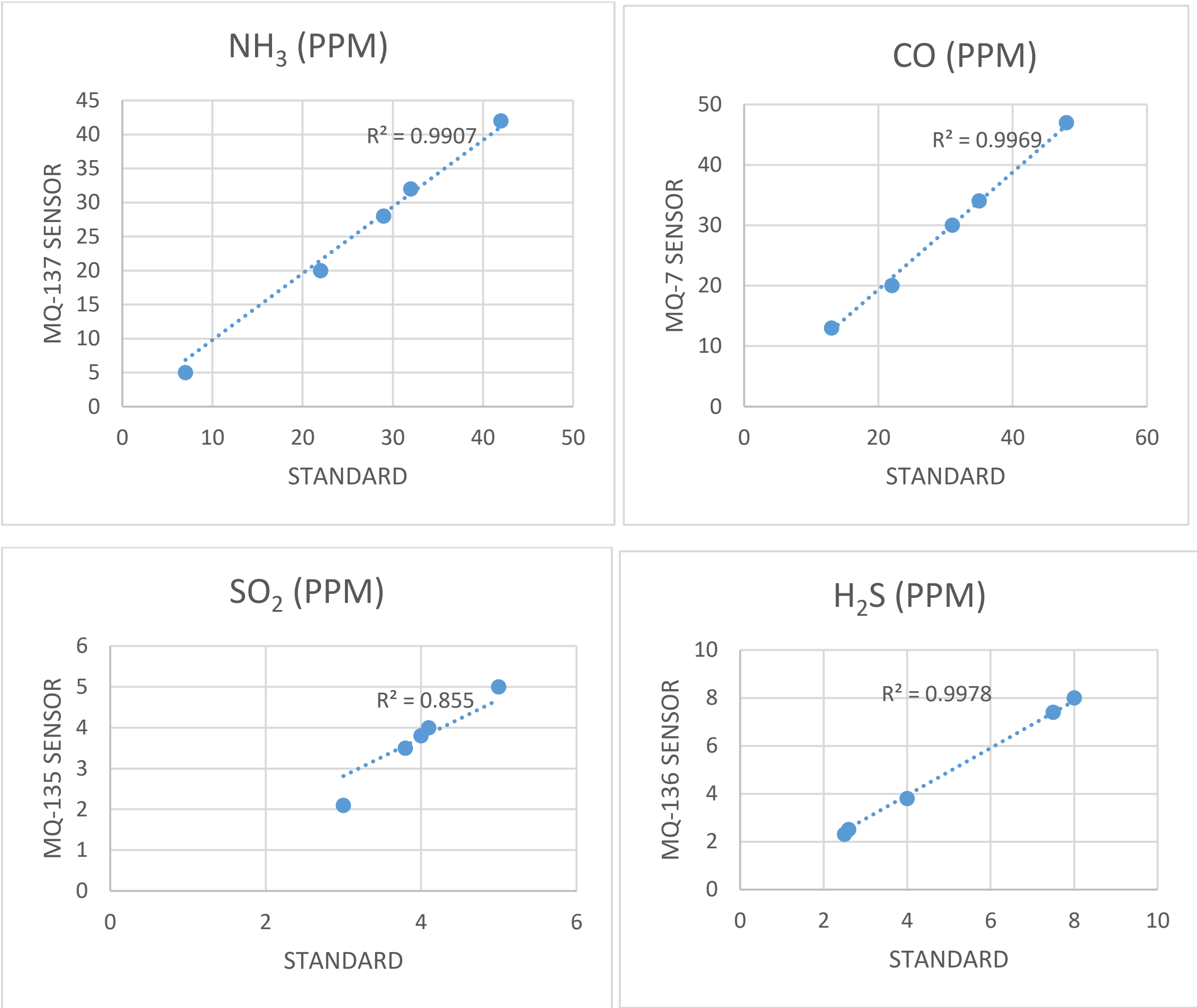

Figure 9: Correlation between gas concentration as measured by the standard gas detector and as measured by MQ Series sensors.

This high correlation values indicated that the MQ series sensors as deployed in the robot compare favourably well with a standard gas measuring equipment.

CONCLUSION

In conclusion, the experiment evaluated MQ series gas sensors integrated into a robotic car for detecting poisonous gases. Despite systematic underestimation by the MQ sensors, the robotic car showcased innovation in real-time gas detection. Its adaptability to various terrains and data transmission to an IoT application highlights its potential for environmental monitoring. The study emphasizes the need for calibration improvements to enhance the system's accuracy. Overall, the robotic car offers promise in addressing environmental safety concerns and emergency responses involving toxic gases.

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