Vision-Based Anti-Collision System for Autonomous Vehicles in Toxic Gas Environments

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***Abstract*—The work signifies a Vision-Based Anti-Collision System for Autonomous Vehicles in Toxic Gas Environments focuses on enhancing the safety and operational efficiency of autonomous vehicles in hazardous conditions. It integrates computer vision, machine learning, and sensor-based technologies to navigate complex paths while detecting obstacles and monitoring air quality. A Raspberry Pi microcontroller processes video captured by a USB web camera and displays it on an HTML interface for real-time monitoring. The ultrasonic sensor detects obstacles, triggering alerts and ensuring collision prevention, while the MQ4 gas sensor continuously monitors the environment for toxic gases, uploading air quality data to the web page. The system employs a Random Forest machine learning algorithm to analyze environmental data, improving gas detection accuracy and alert generation. A buzzer provides audible warnings in abnormal conditions. The robot platform, powered by DC motors and controlled by a motor driver, enables autonomous movement. This comprehensive solution is designed to facilitate safe navigation in environments where toxic gases and physical obstacles pose significant risks.**

Key words: Autonomous Vehicles, Anti-Collision System, Random Forest Algorithm.

I INTRODUCTION

Autonomous vehicles are transforming modern transportation, yet navigating hazardous environments presents unique challenges. The Vision-Based Anti-Collision System for Autonomous Vehicles in Toxic Gas Environments addresses these challenges by integrating advanced vision and sensor technologies. At its core, a Raspberry Pi microcontroller processes real-time video from a USB web camera, displaying the feed on an HTML interface for continuous monitoring [1]. Obstacle detection is achieved using ultrasonic sensors, while the MQ4 gas sensor monitors air quality, uploading data to the web page [2]. Alerts are provided through a buzzer for immediate attention to abnormal conditions [3]. The robot platform, equipped with DC motors and controlled by a motor driver, ensures safe and autonomous vehicle movement [4]. This innovative solution offers a robust approach to navigating complex, toxic environments, enhancing both safety and operational efficiency [5].

The incorporation of machine learning algorithms, such as Random Forest, enhances gas detection accuracy by distinguishing between normal and hazardous conditions [6]. This data-driven approach refines decision-making processes, ensuring a higher level of operational efficiency and safety [7].

Traditional anti-collision systems for autonomous vehicles often rely solely on ultrasonic sensors and basic obstacle detection algorithms [8]. However, these methods may lack real-time environmental monitoring, making them inadequate for use in toxic gas environments [9]. Furthermore, the absence of live video feedback limits situational awareness, especially in low-visibility or complex environments [10]. This project bridges these gaps by integrating vision-based navigation, sensor-based monitoring, and machine learning into a single robust system [11].

Various anti-collision technologies have been explored, such as those used in unmanned aerial vehicles (UAVs) [12] and automobiles [13]. Sensor fusion techniques, including LiDAR and radar integration, have improved obstacle detection and avoidance capabilities [14]. Studies have also focused on anti-collision systems in tunneling environments to enhance safety and efficiency in confined spaces [15]. Additionally, automated anti-collision systems for electric vehicles have been developed, incorporating smart sensor technologies and artificial intelligence [16].

Hazardous environments, such as industrial zones and tunnels, present additional challenges for autonomous navigation, requiring robust detection mechanisms for toxic gases [17]. Risk assessment models have been proposed to evaluate the impact of toxic gas exposure on human movement and safety [18]. Advanced industrial safety measures for gas, oil, and chemical processes emphasize the need for real-time gas monitoring to prevent high-consequence accidents [19].

Deep learning techniques have been employed in intelligent anti-collision systems, significantly improving collision avoidance strategies in autonomous vehicles [20]. Furthermore, smart anti-collision systems for car doors have been designed to prevent accidental impacts, showcasing the broad applications of collision detection technologies beyond just vehicle navigation [21].

By continuously analyzing environmental conditions and providing real-time alerts, this system offers a reliable and scalable solution for navigating hazardous terrains. Industries dealing with chemical production, mining, and waste management can particularly benefit from such solutions, ensuring both worker safety and operational efficiency [22] As technology progresses, further enhancements in AI-driven detection and autonomous response systems will pave the way for safer and smarter autonomous vehicles.

II PROPOSED SYSTEM

The proposed vision-based anti-collision system is designed to enhance the safety and efficiency of autonomous vehicle navigation in toxic gas environments by integrating real-time video monitoring, gas detection, obstacle sensing, and machine learning. At its core, a Raspberry Pi microcontroller processes live video feeds from a USB camera, displaying them on an HTML interface to provide continuous visual feedback and improve situational awareness. This feature is particularly crucial for low-visibility or hazardous environments, such as industrial zones, chemical plants, and underground mines. For obstacle detection, an ultrasonic sensor continuously scans the surroundings, identifying potential obstructions and enabling proactive collision avoidance. To ensure air quality monitoring, an MQ4 gas sensor detects the presence of methane and other harmful gases, with real-time data uploaded to a web interface for continuous observation. The integration of machine learning algorithms, specifically the Random Forest algorithm, improves gas detection accuracy by analysing patterns in environmental data, reducing false alarms, and enhancing overall decision-making. The system also features DC motors controlled via a motor driver, allowing for autonomous movement. In the event of hazardous conditions, an alert mechanism, including a buzzer, is activated to provide immediate warnings, ensuring a quick response to potential threats. By combining vision-based navigation, environmental sensing, and machine learning, this system offers a comprehensive, intelligent, and adaptive solution for autonomous vehicles operating in complex, high-risk environments, improving both operational safety and efficiency.

DESIGN METHODOLOGY:

The design methodology for the Vision-Based Anti-Collision System for Autonomous Vehicles in Toxic Gas Environments follows a structured process that integrates hardware selection, sensor integration, data acquisition, and machine learning to enhance autonomous navigation and safety.

A. Requirement Analysis:

The first step in designing the system is identifying key requirements based on the challenges of navigating hazardous environments. The primary requirements include:

- Real-time vision-based monitoring to enhance situational awareness.
- Obstacle detection to prevent collisions.
- Toxic gas detection for safety in hazardous environments.
- Autonomous decision-making using machine learning.
- Alert mechanism for immediate response to dangers.

Based on these requirements, the system utilizes a Raspberry Pi as the processing unit, along with various sensors for data collection and processing.

B. Sensor Selection and Integration:

To achieve the system’s objectives, the following sensors and components are selected and integrated:

- USB Camera: Captures real-time video for navigation and displays it on an HTML interface.
- Ultrasonic Sensor: Detects obstacles and

calculates distance to avoid collisions.

- MQ4 Gas Sensor: Monitors air quality and detects toxic gases like methane (CH_4) in the environment.
- DC Motors & Motor Driver: Enables autonomous movement and controlled navigation.
- Buzzer: Provides an audible alert when obstacles or dangerous gas levels are detected.

These components are connected to the Raspberry Pi, which acts as the central controller for data processing and decision-making.

C. Data Acquisition and Transmission:

The system continuously collects data from the sensors and transmits it for real-time monitoring and analysis:

- The USB camera captures live video, which is streamed to an HTML interface.
- The ultrasonic sensor provides real-time obstacle detection, ensuring safe navigation.
- The MQ4 gas sensor sends continuous air quality data, which is displayed on the web interface.
- The buzzer is triggered if gas concentration exceeds a predefined threshold or if an obstacle is too close.
- The Raspberry Pi processes all sensor data and transmits it via a web server for user monitoring.

This real-time data acquisition and transmission allow for continuous monitoring of the vehicle's surroundings

D. Predictive Analytics using Random Forest:

To enhance decision-making, the system employs the Random Forest machine learning algorithm, which:

- Analyses air quality data from the MQ4 sensor to detect abnormal gas levels.
- Reduces false alarms by distinguishing between normal and hazardous conditions.
- Improves obstacle detection accuracy by processing real-time data.
- Optimizes vehicle movement based on environmental conditions.

By using predictive analytics, the system ensures more intelligent and adaptive navigation in toxic gas environments.

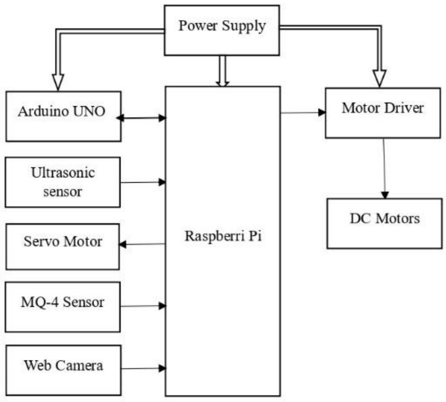

Figure 1: block diagram

III RESULT AND DISCUSSION

The Vision-Based Anti-Collision System which is shown in figure 2 was successfully developed and tested, demonstrating effective real-time monitoring, obstacle detection, and gas sensing. The Raspberry Pi processes live video from the USB camera, displaying it on an HTML interface for continuous surveillance. The ultrasonic sensor efficiently detects obstacles, allowing smooth navigation and collision avoidance. The MQ4 gas sensor accurately

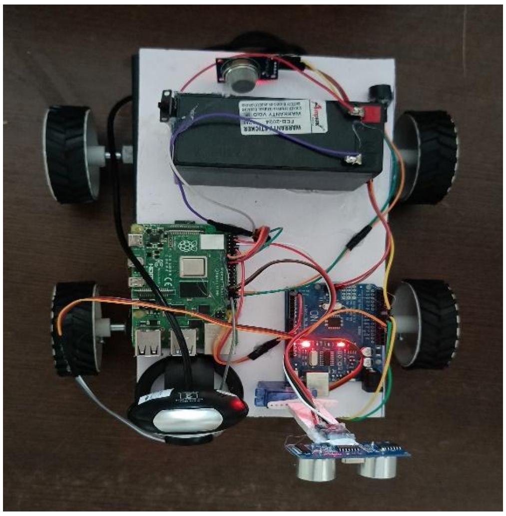

Figure 2: Hardware implementation

measures air quality, identifying hazardous gas levels. The motor driver and DC motors enable stable autonomous movement, while the buzzer provides immediate alerts in case of obstacles or toxic gas detection. The system's integration of hardware and software components ensures reliable data acquisition, analysis, and transmission. The results indicate high accuracy in obstacle and gas detection, real-time response, and improved safety in hazardous environments. The implemented approach effectively enhances operational efficiency and autonomous navigation, making it a robust solution for vehicles operating in toxic environments.

Figure 3 displays real-time sensor readings collected from the MQ4 gas sensor and ultrasonic sensor. The values indicate gas concentration levels and distance measurements from obstacles. These data points are crucial

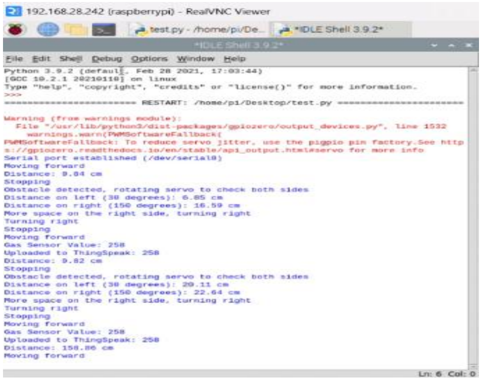

Figure 3: Sensor values

detection and ensuring safe autonomous navigation in toxic environments.

Figure 4 shows sensor data being uploaded to ThingSpeak, an IoT-based cloud platform. The system transmits real-time gas concentration levels and obstacle distances, enabling remote monitoring and data analysis. This cloud integration enhances decision-making accuracy and facilitates data-driven automation in hazardous conditions.

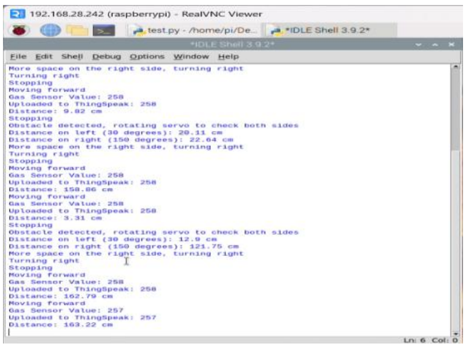

Figure 4: Sensor values uploaded to thingspeak

This figure 5 represents the visualized sensor data on ThingSpeak. The plotted graph tracks gas concentration trends and obstacle detection events over time. This real-time monitoring system helps identify patterns in air quality fluctuations and potential hazards, improving safety and predictive analytics.

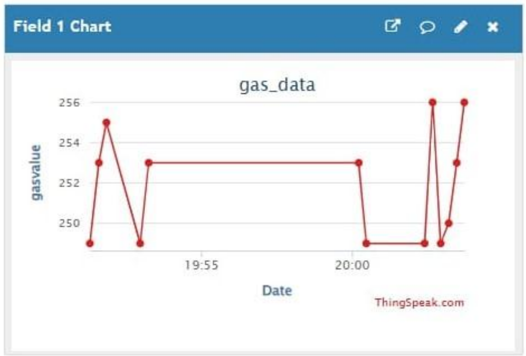

Figure 5: Output graph in thingspeak

This figure 6 illustrates how the ultrasonic sensor detects an obstacle, triggering an immediate vehicle stop. The system ensures collision avoidance by processing distance data and sending commands to halt the DC motors, preventing accidents in autonomous navigation.

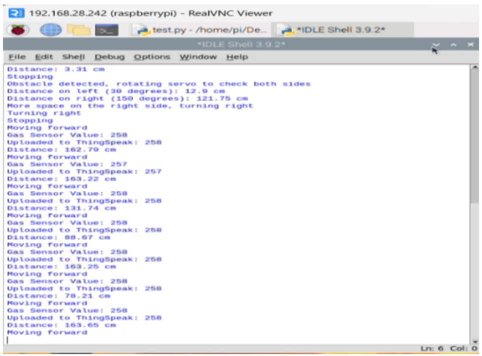

Figure 6: obstacle detection and vehicle stopping

This figure presents the web-based interface displaying real-time gas sensor readings and corresponding graphical data. The system updates continuously, allowing users to monitor toxic gas levels remotely. Alerts are triggered when threshold levels are exceeded, ensuring quick responses to hazardous conditions.

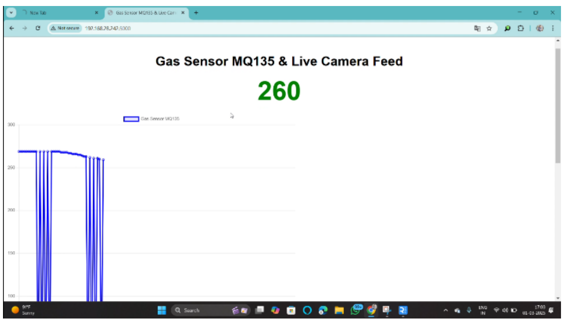

Figure7: HTML interface for gas values and graph

This figure 7 showcases the object detection system on an HTML interface. The ultrasonic sensor detects obstacles and relays the data in real-time. The user-friendly interface visually represents distance measurements, assisting operators in monitoring vehicle surroundings for safe autonomous navigation. The HTML-based video streaming interface enables real-time monitoring of the autonomous vehicle's surroundings. A USB camera captures live video, which is processed by Raspberry Pi and displayed on a web-based interface. This feature allows remote users to observe hazardous environments without direct exposure, ensuring safety and efficiency. The video feed helps in obstacle detection, navigation, and gas monitoring, enhancing situational awareness. The interface is designed for seamless interaction, providing a clear and responsive display.

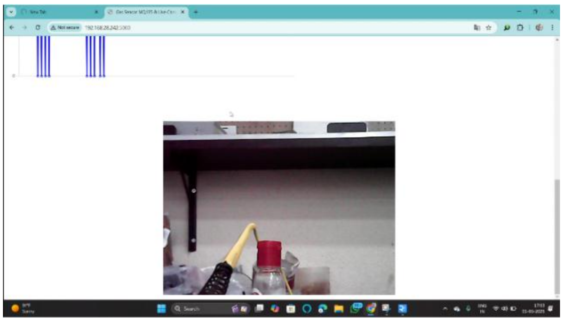

Figure 8: HTML interface for object detection

IV CONCLUSION

In conclusion, the Vision-Based Anti-Collision System for Autonomous Vehicles in Toxic Gas Environments offers a comprehensive solution to improve the safety and efficiency of autonomous operations in hazardous conditions. By integrating computer vision, machine learning, and sensors for obstacle detection and environmental monitoring, the system ensures safe navigation through complex paths while providing real-time data on air quality. The inclusion of a Random Forest machine learning algorithm enhances the accuracy of toxic gas detection and decision-making. The combination of a Raspberry Pi microcontroller, ultrasonic sensors, and MQ4 gas sensors enables effective collision prevention and environmental monitoring. With features such as real-time video streaming, audible alerts, and automated movement control, this project provides a robust framework for advancing autonomous vehicle safety in challenging environments.

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