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Modern Vehicle Safety Technology in Hazy Conditions

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ABSTRACT: Modern transportation systems rely on maintaining safe distances and detecting vehicles to help prevent accidents like rear-end collisions. This research showcases a specialized system that detects objects in real time and measures their distance, designed to work in challenging environments like foggy conditions. The system integrates an ultrasonic sensor for close-range obstacle alerts and a LiDAR module for accurate distance readings, supported by a real-time imaging component for enhanced visibility and awareness.

Featuring an ultrasonic sensor that identifies objects within 25 cm, triggering an immediate alert, and a LiDAR sensor that measures distances up to 2 meters and displays the results on a 16x2 LCD, this system provides comprehensive obstacle detection. The imaging module, powered by an ESP32-CAM and processed by a Raspberry Pi, provides real-time video displayed on a 7- inch screen

Experimental results validate the system's capability to detect obstacles and estimate distances, contributing to safer driving conditions. Future work will aim to enhance detection algorithms and adapt the system to broader environmental challenges.

KEYWORDS: Vehicle detection, foggy conditions, ultrasonic sensor, LiDAR sensor, ESP32-CAM, real-time processing, collision prevention, distance measurement, advanced driver assistance systems (ADAS), safety enhancement.

I. INTRODUCTION:

As the number of vehicles on the road continues to rise, traffic accidents, including rear-end collisions, have become a significant concern. These types of accidents often lead to serious injuries and damage, making it crucial to develop solutions that can enhance road safety and reduce such incidents. Real-time vehicle detection and the ability to maintain safe distances are essential for preventing accidents, particularly in challenging conditions such as fog due to low visibility.

To address these issues, Modern vehicle detection systems use a variety of technologies, including LiDAR, ultrasonic sensors, and real-time imaging, to address these problems. With the help of these technologies, objects can be precisely identified and their distance can be measured, enabling drivers to keep a safe distance and respond quickly to possible threats.

This research presents a vehicle detection and distance measurement system designed to improve safety, especially in adverse weather conditions. The system combines ultrasonic sensors, LiDAR modules, and real- time imaging to detect obstacles and estimate distances accurately. By providing timely alerts and real-time data, the system aims to help reduce traffic accidents and promote safer driving.

II. PROPOSED METHOD:

The object detection and distance measurement system proposed in this paper combines multiple technologies to improve road safety, especially in challenging conditions like fog and haze. The system incorporates an ultrasonic sensor (HC-SR04) that detects nearby objects within a range. When an object is detected within 25 cm, the system activates a buzzer to alert the driver. Additionally, a LiDAR sensor (VL53L0X) is employed to measure longer distances, up to 2 meters, providing high precision in various weather conditions. The distance data from the LiDAR sensor is processed by an ESP32 microcontroller and displayed on a 16x2 LCD screen, offering real-time feedback on objects or vehicles detected up to 150 to 180 cm away.

The ESP32 microcontroller plays a crucial role in managing data from the sensors and controlling the overall system. An ESP32-CAM module is included to capture live images or videos, which are wirelessly transmitted to a Raspberry Pi for processing.

The processed visuals are displayed on a 7-inch touchscreen display, providing the driver with an updated, clear view of the road ahead. This feature enhances situational awareness by providing both visual and distance-based data in real-time.

The combined use of the ultrasonic sensor and LiDAR allows for precise object detection and distance monitoring, while the ESP32 and ESP32-CAM deliver live video feedback, which is processed by the Raspberry Pi and shown on the touchscreen.

This multi-sensor approach ensures enhanced road safety by alerting the driver to nearby hazards and improving visibility.

III. SYSTEM DESIGN:

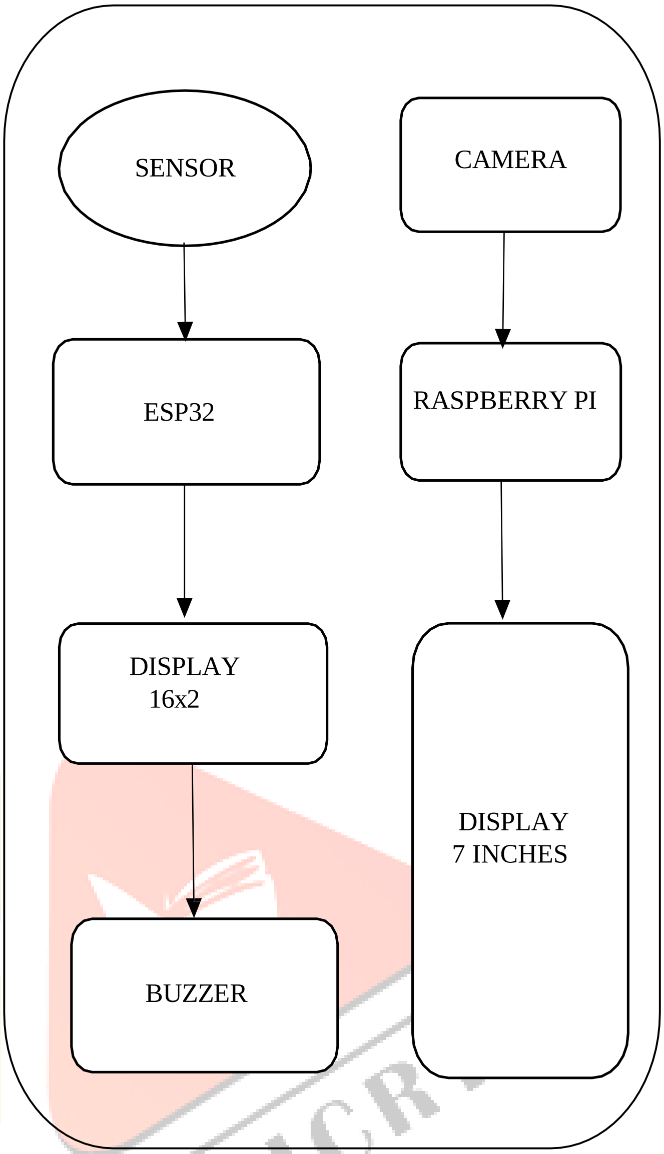


Fig 1: - System Architecture

The system design for the vehicle detection and distance measurement system is composed of multiple interconnected components, each serving a distinct role to ensure effective operation and safety. The design involves both hardware and software integration, where the sensors, microcontrollers, and display units work in synergy to achieve real-time vehicle detection and distance monitoring.

ULTRASONIC SENSOR (HC-SR04):

The HC-SR04 ultrasonic sensor is used for short-range object detection. It operates with a 5V power supply and measures distances between its range, with an accuracy of ±3 mm. When an object enters within a critical range (25 cm), the sensor triggers the buzzer, alerting the driver.

LiDAR SENSOR (VL53L0X):

The LiDAR sensor provides precise long-range distance measurements up to 2 meters, using infrared light. It operates on a 2.6V to 5.5V supply and communicates through I2C, making it ideal for measuring distances accurately in real-time. This sensor's data is displayed on a 16x2 LCD screen, which provides the driver with real-time information about nearby obstacles.

ESP32 MICROCONTROLLER:

The ESP32 acts as the central processing unit for the system. It receives data from both the ultrasonic and LiDAR sensors, processes this information, and controls other components, such as activating the buzzer when necessary. The ESP32 also communicates wirelessly with the ESP32-CAM module and Raspberry Pi for the live video feed and system control.

ESP32-CAM MODULE:

The ESP32-CAM captures live images or videos from the vehicle's front. It has Wi-Fi capabilities that allow it to wirelessly transmit video data to the Raspberry Pi for further processing and display. The camera's input helps to enhance the system's situational awareness by providing real-time visuals of the vehicle's surroundings.

7-INCH TOUCHSCREEN DISPLAY:

A 7-inch touchscreen display is used to provide a user interface for the driver. It shows the processed images from the ESP32-CAM and the distance data from the LiDAR sensor. The touchscreen interface is responsive, allowing for easy interaction and viewing of the system's data, improving the driver's awareness of the road conditions.

POWER SUPPLY:

A 5V, 1.5A power supply unit is used to provide the necessary power to the system. The components, including the ESP32, LiDAR sensor, ultrasonic sensor, and display, are powered by this regulated source, ensuring stable operation.

ESTIMATION FOR DISTANCE MEASUREMENT

1. Ultrasonic Sensor (Hc-Sr04) Distance Calculation

The ultrasonic sensor measures the distance to an object by emitting a sound wave and timing how long it takes for the wave to bounce back after hitting an object. The distance is calculated using the speed of sound and the time taken for the pulse to travel to the object and back.

The basic equation for calculating the distance is:

DISTANCE = 2/ (SPEED OF LIGHT * TIME)

2. LiDAR Sensor (VL53L0X) Distance Calculation

LiDAR sensors measure distance using the time-of-flight (TOF) principle, where the sensor emits a laser pulse and calculates the time it takes for the pulse to travel to the object and back. The distance is then calculated based on the time and the speed of light.

The basic equation for calculating the distance is:

DISTANCE = 2/(SPEED OF LIGHT * TIME)

Where:

- Speed of Light = 3×10^8
- Time = Time taken for the laser pulse to travel to the object and return

IV. SYSTEM OVERVIEW:

The Modern Vehicle Safety Technology in Hazy Conditions is designed to improve safety by providing real-time proximity alerts and visual feedback to drivers. It integrates several key components: an ultrasonic sensor, a LiDAR sensor, an ESP32 microcontroller, an ESP32-CAM, a Raspberry Pi, and a 7-inch display.

The ultrasonic sensor (HC-SR04) measures the distance between the vehicle and nearby objects by emitting sound waves and measuring the time it takes for the waves to reflect back. When an object is detected within 25 cm, a buzzer is triggered to alert the driver of a potential collision.

The LiDAR sensor (VL53L0X) provides more precise distance measurements, with a range of up to 2 meters, and displays this information on a 16x2 LCD screen. The ESP32 microcontroller processes input from the ultrasonic and LiDAR sensors, controls the buzzer, and enables communication with the ESP32-CAM.

The ESP32-CAM captures live images or video footage, which are wirelessly transmitted to the Raspberry Pi for further processing. The Raspberry Pi processes the images and displays them on the 7-inch touchscreen, offering the driver a real-time visual representation of the surrounding environment. This system, with its combination of proximity sensors and real-time visual feedback, is designed to provide drivers with the necessary information to prevent accidents and enhance safety, especially in challenging conditions such as fog and haze.

V. FUTURE SCOPE:

The proposed Modern Vehicle Safety Technology in Hazy Conditions has significant potential for future enhancements and applications. Its current implementation provides a foundation for advanced safety features, which can be further developed to meet the evolving demands of intelligent transportation systems and autonomous vehicles. Here are some potential areas for future development:

Artificial Intelligence (AI) and Deep Learning:

Incorporating more advanced machine learning models, could significantly improve the vehicle detection capability of the system. These models can be trained on a broader range of conditions, including different fog densities and lighting conditions, improving the system's robustness in real-world scenarios. AI-based models can also be used to predict vehicle behavior and alert the driver even earlier, enhancing safety.

Real-Time Data Sharing and Cloud Integration:

Implementing cloud-based systems for real-time data sharing could allow vehicles to exchange information about obstacles or hazards detected in fog, creating a networked system of vehicles improving overall road safety. Research into vehicle- to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication has shown that such networks can enhance the awareness of surrounding environments

Scalability for Smart City Integration:

The system could significantly support smart city initiatives by gathering real-time traffic data and transmitting it to centralized management systems. This information can be analyzed to track traffic patterns, identify congestion points, and forecast traffic flow. Such capabilities would enable city planners to optimize traffic signals, efficiently manage road closures, and provide timely updates to drivers. By enhancing traffic management, the system could help reduce congestion, decrease emissions, and improve road safety for all commuters.

Enhanced Driver Assistance:

The system could be enhanced by integrating it with Advanced Driver Assistance Systems (ADAS) to offer features like lane departure warnings, adaptive cruise control, and autonomous braking. These advanced functionalities would not only improve the overall driving experience but also play a vital role in enhancing road safety by proactively reducing the chances of accidents. By combining real-time detection capabilities with ADAS technologies, the system can provide drivers with timely alerts and automated responses in critical situations.

VI. CHALLENGES:

Detecting objects in fog or harsh environmental conditions presents several challenges. However, various solutions have been proposed and implemented to overcome these hurdles. Below are some key challenges.

Limited visibility in fog presents a significant challenge for vehicle detection systems, as it hinders the effectiveness of sensors like cameras and ultrasonic sensors. Even using individual advanced technologies such as LiDAR can face difficulties due to light scattering and signal interference in dense fog.

To address this, integrating multiple sensors, including LiDAR, ultrasonic sensors, and camera can help overcome the limitations of individual components.

LiDAR performs better in adverse weather conditions as it is less impacted by visual obstructions compared to cameras. Combining data from these sensors enables more accurate and reliable vehicle detection (Shao et al., 2018; Cao et al., 2019).

Furthermore, real-time processing of sensor data is a critical challenge, as handling inputs from multiple sensors requires significant computational resources, which can lead to delays in decision-making.

This is particularly critical in foggy conditions, where timely detection is essential. Using edge computing solutions, such as local processing devices like ESP32 or Raspberry Pi, can address this issue by offloading computational tasks to these devices.

This reduces latency and improves response times, ensuring timely alerts and enhanced safety for drivers (Zhao et al., 2021).

VII. RESULTS:

The Modern Vehicle Safety Technology in Hazy Conditions was successfully developed, integrating various hardware and software components. The system demonstrated effective performance under different conditions, including the detection of vehicles at various distances in foggy environments. Below are the key results of the project.

1. OBJECT DETECTION ACCURACY:

The ESP32-CAM successfully detected vehicles in real time by processing images and identifying objects using computer vision techniques. Bounding boxes were drawn around the detected vehicles on the 7-inch display, providing a clear visual indication of the detected vehicles.

The Object Detection Accuracy was found to be satisfactory, with vehicles consistently being detected within the specified distance ranges.

2. SENSOR PERFORMANCE:

The Ultrasonic sensor (HC-SR04) triggered the buzzer when a vehicle was detected within 25 cm of the system. The buzzer served as an immediate alert for proximity detection. The LiDAR sensor (VL53L0X) successfully provided accurate distance measurements up to 2 meters, which were displayed on the 16x2 LCD. The measurements were displayed in real-time, helping to visualize the distance of nearby objects.

3. REAL-TIME IMAGE PROCESSING:

The Raspberry Pi processed the image data from the ESP32- CAM for object detection. It displayed the processed frames on the 7-inch touchscreen with bounding boxes drawn around detected vehicles.

The system demonstrated low latency between capturing and displaying the image, ensuring a near real-time response in vehicle detection.

4. SYSTEM INTEGRATION:

The integration between the ESP32, Raspberry Pi, and the connected peripherals (Ultrasonic sensor, LiDAR, LCD, and display) was successful. The sensors' data were transmitted wirelessly, and the system was able to process and display the results seamlessly.

The communication between the ESP32 and Raspberry Pi via Wi-Fi was reliable, with minimal delays observed in data transmission and processing.

5. BUZZER ALERT:

The buzzer functioned as expected, providing an audible alert whenever a vehicle came within 25 cm of the system. This feature proved to be an important safety aspect, alerting users to potential danger or proximity of vehicles in a foggy environment.

6. USER INTERFACE**:**

The 7-inch display provided a user-friendly interface to monitor the real-time vehicle detection results. The display showed processed video frames with bounding boxes around detected vehicles, while the 16x2 LCD displayed the distance data from the LiDAR sensor.

7. SYSTEM EFFICIENCY:

The system demonstrated high efficiency, with the ESP32 and Raspberry Pi seamlessly handling data acquisition, processing, and transmission, all within the constraints of the 5V power supply.

By leveraging low-power components, the design ensured stable performance and minimized energy consumption. Real-time processing was achieved without significant delays, owing to the optimized coordination between sensors and microcontrollers. Furthermore.

the efficient use of resources allowed the system to remain operational for extended periods, making it practical for deployment.

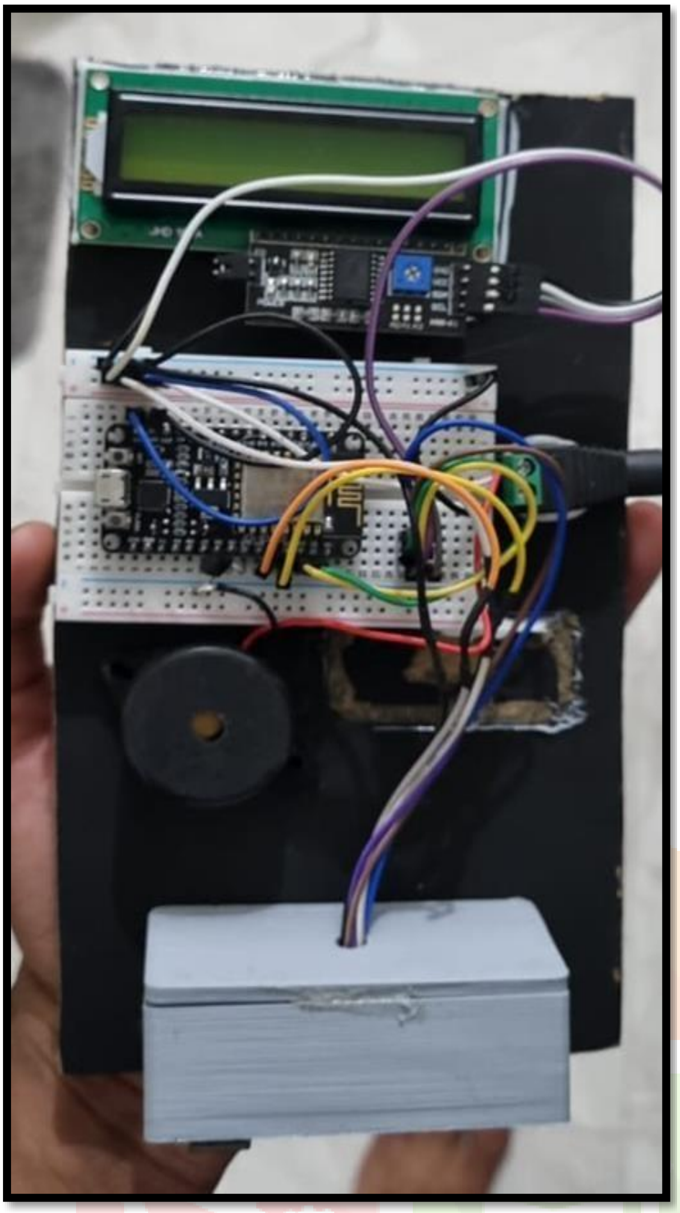


Fig 2: - circuit

The circuit shown is a prototype Modern Vehicle Safety Technology in Hazy Conditions designed to measure distances and provide warnings for nearby obstacles. At its core is an ESP8266 or ESP32 microcontroller, which processes inputs from an ultrasonic sensor positioned at the bottom of the setup.

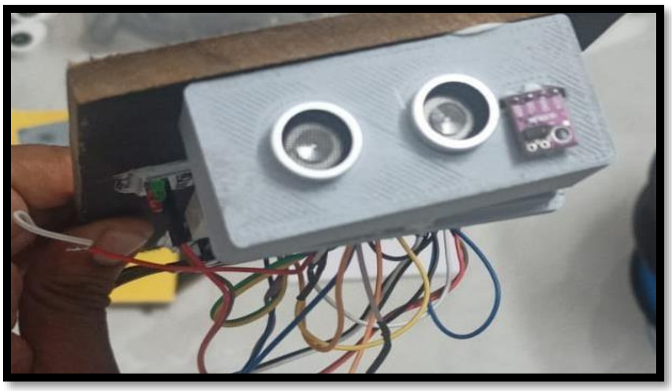


Fig 3: - sensors

The ultrasonic sensor calculates the distance to an object by emitting ultrasonic waves and measuring the time taken for the reflected waves to return. This data is then displayed in real-time on a 16x2 LCD screen connected to the microcontroller.

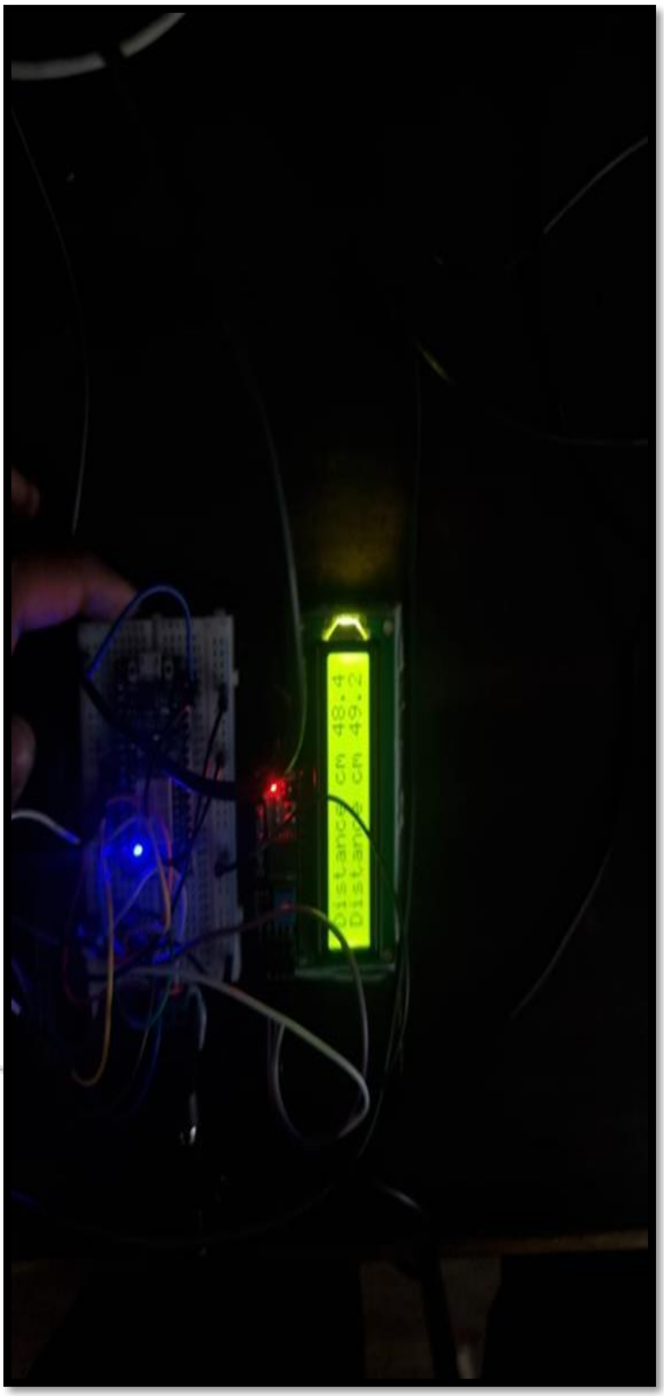


Fig 4: - captured output of 16x2 LCD

Additionally, a buzzer is included to act as an alert mechanism, sounding an alarm if an object is detected within a predefined distance threshold. The components are interconnected on a breadboard for prototyping, with power supplied via a USB connection or an external power source. This setup provides a compact and functional system for testing obstacle detection and warning mechanisms.

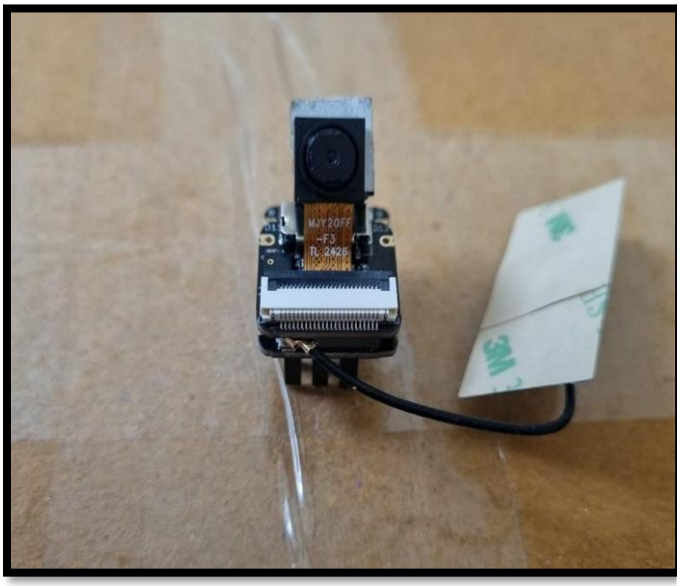
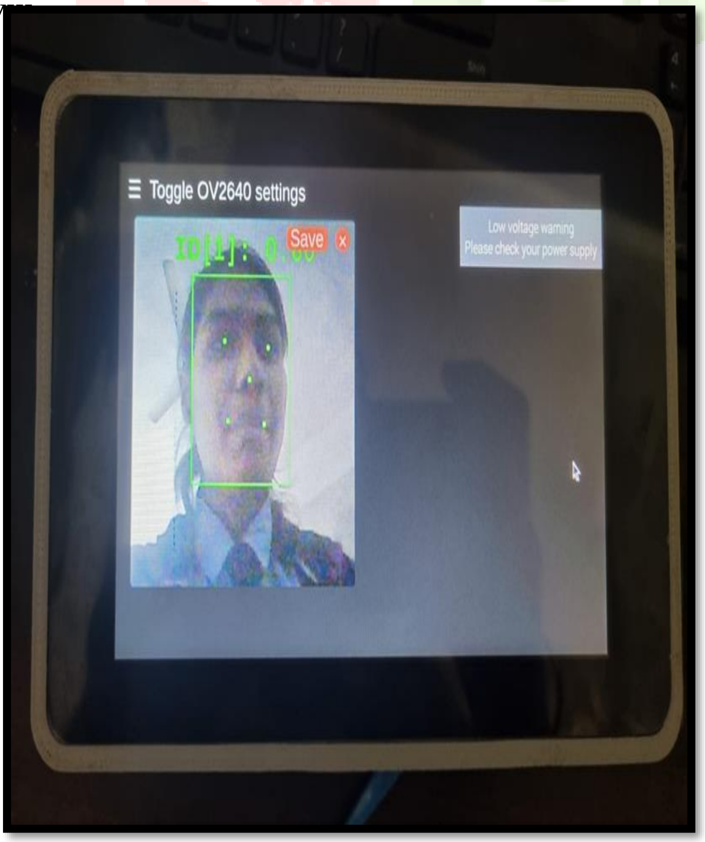


Fig 5: - camera module

The ESP32-CAM effectively detected object in real-time by employing advanced computer vision techniques to process live images and identify objects. Detected obeject were highlighted with precise bounding boxes displayed on a 7- inch screen, ensuring clarity and situational awareness for the user. The system demonstrated consistent object detection accuracy across specified distance ranges, maintaining reliability even under challenging visibility conditions.

Fig 5: - captured output



CONCLUSION:

In conclusion, the proposed vehicle detection and distance monitoring system offers a practical solution for improving road safety, especially in challenging visibility conditions such as fog. By utilizing an ultrasonic sensor for close-range obstacle detection and integrating a LiDAR module for precise distance measurement, the system ensures accurate and reliable performance. The incorporation of a real-time display and an alert mechanism further enhances its usability, providing timely warnings to drivers and reducing the likelihood of accidents. This project demonstrates the potential for cost-effective and scalable technologies to address critical challenges in transportation safety, paving the way for future advancements in intelligent vehicle systems.

The system's design and implementation demonstrate the successful use of modern technologies and sensor fusion to address a real-world problem. The ESP32 microcontroller processes the sensor data efficiently, while the Raspberry Pi provides a platform for real-time video processing and display. This multi-layered approach significantly enhances situational awareness, making the system a valuable tool for ensuring road safety in foggy conditions.

Future improvements could include the incorporation of machine learning models for more precise detection and advanced obstacle classification, making the system even more adaptable and responsive to diverse environmental challenges. Moreover, the system's scalability means it can be deployed in various vehicles, contributing to broader safety standards in harsh driving conditions.

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