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IoT-based Black Box Monitoring for Vehicle Crash Data Analysis and Improving Safety

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Abstract

Road accidents are a significant global concern. This project proposes an Internet of Things (IoT)-based black box monitoring system for vehicles to enhance road safety through comprehensive crash data analysis. The system expands on traditional black boxes by incorporating various sensors (accelerometers, gyroscopes, GPS) and potentially in-cabin cameras (with privacy safeguards). This data offers a deeper understanding of crash dynamics, including impact severity, vehicle motion, and safety system deployment timing. The system works by continuously monitoring the vehicle's performance and the driver's behavior using various sensors. In the event of an accident, the system will automatically detect the impact force using the piezoelectric sensor, take a photo using the camera, record the vehicle's location using the GPS, and measure the speed using the DC motor as a wheel. The system will then send this data to the cloud using Blynk IoT, where it can be accessed by emergency services and other authorized personnel. The examination of the gathered data will be utilized to enhance forthcoming vehicle safety functionalities, including automated emergency braking and alerts for lane departure. Additionally, the system can optionally monitor driver behavior (with user consent) to identify risky habits and provide feedback for safer driving practices. This project has the potential to significantly improve road safety by providing valuable insights for developing safer vehicles and promoting better driving habits. Nevertheless, factors such as safeguarding data privacy, ensuring security, managing storage, and establishing industry-wide standardization must be dealt with for effective execution.

Keywords: IoT-based black box, vehicle crash data analysis, ESP32 microcontroller, GSP module, piezoelectric sensor, accelerometer sensor, Blynk IoT platform

INTRODUCTION

Traffic accidents are a major public health concern. Although traditional black boxes provide valuable post-crash information, they offer a limited perspective. This project introduces a next-generation black box system that leverages the power of the Internet of Things (IoT) to collect and analyze a broader range of crash data.

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By equipping vehicles with various sensors, such as accelerometers, gyroscopes, and GPS, the system goes beyond basic impact data. It captures details of vehicle motion before, during, and after a crash, providing a more comprehensive understanding of accident dynamics [1]. In addition, the system can incorporate in-cabin camera data (with strict privacy considerations) for even richer insights.

This project aims to utilize the data collected crash data for two key purposes:

1. *Enhancement of future vehicle safety features:* Analyzing crash patterns will enable engineers to identify contributing factors and develop

improved safety systems such as more responsive automatic emergency braking and advanced lane departure warnings.

2. *Improved driver behavior:* With user consent and clear privacy regulations in place, the system can monitor certain aspects of the driver's behavior. This data can be used to provide feedback on safer driving practices and potentially allow insurers to offer personalized premiums based on their driving habits.

This innovative IoT-based black box system has the potential to revolutionize crash data analysis and lead to significant improvements in road safety.

PROPOSED SYSTEM

The proposed system is designed such that the sensor device transmits data to the IoT, facilitated by the ESP32 chip with sensors, in case of an accident. The proposed framework employs an Arduino board for straightforward input/output access and seamless program execution. Various sensors, such as temperature, gas, speed, vibration, and GPS sensors, are connected to the Arduino board to accommodate diverse detection requirements.

Onboard Unit (OBU)

- Installed within the vehicle, the OBU serves as the data collection hub.
- It will house various sensors, including:
  - *Accelerometer:* Measures acceleration forces experienced during a crash.
  - *Gyroscope:* Tracks vehicle rotation and orientation during the accident.
  - *GPS:* Provides location data at the time of the crash.
  - *In-cabin camera (with driver's consent and privacy safeguards):* Captures video footage for a more comprehensive understanding of the accident (e.g., driver actions and external factors).

Cloud Platform

- A secure and scalable cloud-based server receives and stores crash data from OBUs installed on various vehicles.
- The platform offers functionalities like:
  - Data encryption for secure storage and transmission.
  - Data management for efficient organization and retrieval of crash data.
  - User authentication and access control for authorized personnel.

LITERATURE SURVEY

The evolution of vehicle black box systems through IoT technology represents a significant advancement in automotive safety and accident analyses. The integration of real-time data collection, advanced analytics, and intelligent decision-making capabilities has the potential to transform the investigation of accidents and the management of vehicle safety. Ongoing research and technological developments are expected to further enhance the effectiveness and reliability of these systems, leading to safer driving environments and more informed decision-making in accident scenarios, as shown in Table 1.

Table 1. Recent literature survey.

Title	Authors	Focus	Key findings
Car black box system for accident analysis using IoT	Charana PL, Parameshachari BD [2]	Prototype development	• Proposes an IoT-based black box system with various sensors for crash analysis, including accelerometers and GPS. • Emphasizes potential for improved data collection compared to traditional black boxes.
IoT-based smart black box system	Aishwarya Bhadale, Chetna Kalbhor, Rishikesh Khaladkar [3]	Design and development	• Presents a design for a cost-effective, IoT-based black box system with additional features for driver assistance (e.g., panic button). • Highlights the potential of IoT for black boxes beyond just crash data recording.

Title	Authors	Focus	Key findings
Implementing vehicle black box system by IoT-based approach	Sethuraman S, Santhanalakshmi S. [4]	Feasibility study	• Explores the feasibility of using IoT for vehicle black boxes, focusing on potential applications within Intelligent Transportation Systems (ITS). • Identifies limitations of traditional black boxes and the need for more comprehensive data collection.
Survey on vehicle black box	Advait Chandorkar, Omkar Phadke, Anuj Jain [5]	Existing black box systems	• Provides an overview of traditional black box functionalities and limitations. • Emphasizes the need for improved data collection capabilities for better crash analysis.
Intelligent vehicle black box using IoT	Anil Kumar, et al. [6]	Advanced features	• Discusses the use of various sensors in IoT-based black boxes, including accelerometers, gyroscopes, and breathalyzers (with privacy considerations). • Explores the potential for driver behavior monitoring alongside crash data collection.

BLOCK DIAGRAM

An alcohol sensor is designed to detect and measure the presence of alcohol in a person's breath, blood, or environment (Figure 1). It is commonly used in breathalyzers to determine the blood alcohol concentration (BAC) to ensure safety during driving and other activities. Sensors typically use chemical reactions or infrared technologies to detect alcohol levels [7].

HARDWARE REQUIREMENT

Microcontroller

The ESP32 microcontroller is a popular and versatile microcontroller unit (MCU) specifically designed for IoT applications. Here is a concise overview of its key features (Figure 2).

- *Microcontroller core:* The ESP32 utilizes a Tensilica Xtensa LX6 microprocessor core, which is known for its low power consumption and processing efficiency.
- *Integrated Wi-Fi and Bluetooth:* ESP32 offers built-in Wi-Fi and Bluetooth connectivity, eliminating the need for external modules and simplifying the board design for IoT projects.
- *Dual-mode Bluetooth:* ESP32 supports both classic Bluetooth and Bluetooth Low Energy (BLE) for various communication options with other devices.

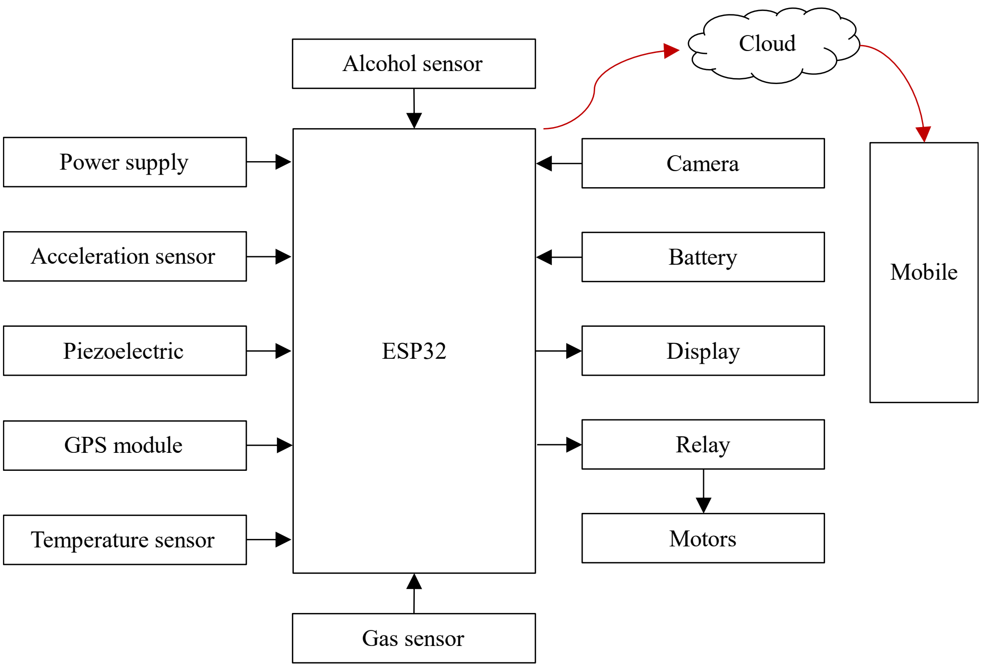

Figure 1. Block diagram of alcohol sensor.

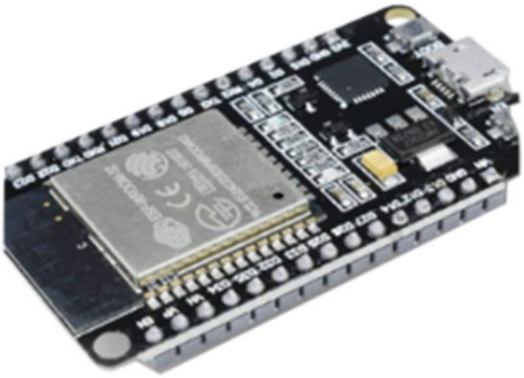

Figure 2. ESP32 microcontroller.

Piezoelectric Sensor

Piezoelectric sensors are transducers that convert mechanical stress or pressure into electrical signals (Figure 3). They work based on the piezoelectric effect, a property exhibited by certain materials, in which a mechanical strain applied to the material induces an electric charge.

- *Operating principle:* When a mechanical force is exerted on a piezoelectric material, its internal crystal structure changes, generating a voltage across the sensor. Conversely, applying an electric field to the sensor can cause slight deformation.

Temperature Sensor

A temperature sensor was used to measure the machine temperature (Figure 4). This can be used to detect faults, such as overheating bearings, windings, and oil [8].

Accelerometer/Gyroscope

An Inertial Measurement Unit (IMU) or Motion Processing Unit (MPU) sensor is instruments that gauge and communicate the specific force, angular velocity, and occasionally, the magnetic field encompassing an object, utilizing a mix of accelerometers, gyroscopes, and magnetometers [9]. It is commonly used in robotics, virtual reality systems, drones, and wearable devices for motion tracking and orientation sensing, as shown in Figure 5.

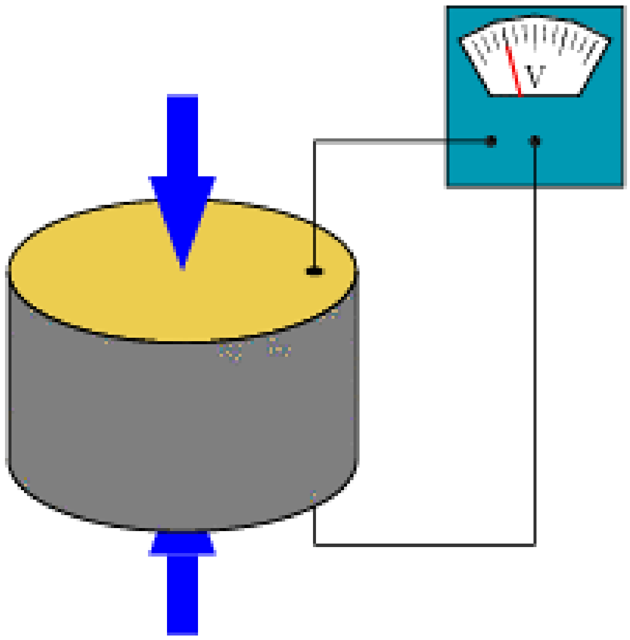

Figure 3. Piezoelectric sensor.

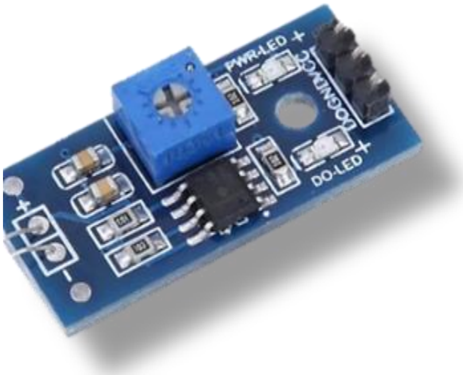

Figure 4. Temperature sensor.

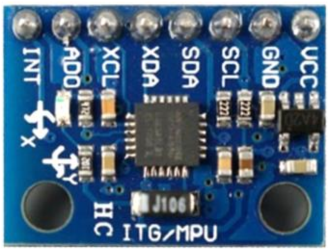

Figure 5. ITG/MPU.

Figure 6. MQ 2.

Gas Sensor

MQ-2 is an electrochemical gas sensor that is commonly used to detect the presence of alcohol vapor (Figure 6). Here is a concise overview of its functionalities relevant to the ESP32 project [10].

- *Target gas:* Primarily designed to detect ethanol (alcohol) vapor in air.
- *Electrochemical sensing:* The MQ-2 operates based on an electrochemical principle. When exposed to alcohol vapor, the conductivity of the sensor changed, allowing the ESP32 microcontroller to measure this change and infer the presence of alcohol.
- *Analog output:* The MQ-2 provides an analog voltage output that increases with the concentration of alcohol vapor it detects. ESP32's analog-to-digital converter (ADC) is required to convert this analog signal into a digital format for subsequent processing.

SOFTWARE DESCRIPTION

Embedded C

- *Resource-constrained environment:* Unlike desktop computers, microcontrollers possess restricted memory, processing capabilities, and storage capacity. Embedded C was optimized for these constraints, focusing on an efficient code that utilizes minimal resources.
- *Hardware interaction:* Embedded C provides functionalities for directly interacting with the hardware components of the microcontroller, such as sensors, actuators, timers, and communication interfaces. This allows the ESP32 to be programmed to control and read from these hardware components.
- *Focus on low-level programming:* Compared with high-level programming languages, Embedded C delves deeper into low-level operations. One might work with memory addresses, bit manipulation, and register programming to achieve precise control over the hardware.
- *Libraries and frameworks:* While Embedded C is a core language, various libraries and frameworks simplify the development of specific microcontrollers, such as the ESP32. These libraries offer pre-written functions for interacting with common hardware components and functionalities, thereby saving time and effort.

Embedded C equips you to program ESP32 to perform specific tasks by:

- *Reading sensor data:* Utilizing sensor interfaces to acquire data from sensors such as ADXL335 or MQ-3.
- *Controlling actuators:* Sending signals to control devices connected to the ESP32, potentially based on sensor readings.
- *Communicating with other devices:* This enables communication with other devices (e.g., sending data to a server) using protocols such as Wi-Fi or Bluetooth (built-in on the ESP32).

Arduino Software (IDE)

Here is a concise overview of the Arduino IDE (Integrated Development Environment) relevant to this project.

- *User-friendly platform:* The Arduino IDE offers a beginner-friendly interface for writing and uploading code to microcontrollers, including ESP32. It provides a text editor for code development, a compilation button to translate the code into machine-readable instructions, and an upload button to transfer the code to the ESP32 board.
- *Streamlined development:* The IDE simplifies development by offering pre-written code libraries. These libraries, accessible through the built-in library manager, contain functions for various sensors, actuators, and functionalities commonly used in electronic projects. While some libraries might be specifically designed for Arduino boards, there are also community-developed libraries that support ESP32.
- *Abstraction layer:* The Arduino IDE provides an abstraction layer. This implies that it functions as a mediator between the code and hardware of ESP32. Instead of writing complex, low-level code to directly control hardware components, the functions provided by Arduino libraries can be used to interact with sensors and actuators more intuitively. This simplifies development, especially for beginners.

RESULT

The proposed system is implemented and tested in a simulated environment. The results show that the system can accurately measure the impact force, vehicle speed, acceleration, and other parameters. The system can also autonomously issue alerts if an accident occurs, as shown in Figure 7. The system has the following advantages:

- It is low-cost and easy to implement.
- It uses a variety of sensors to collect comprehensive data on a vehicle's performance and environment.
- It can automatically send alerts to emergency services in the event of an accident.

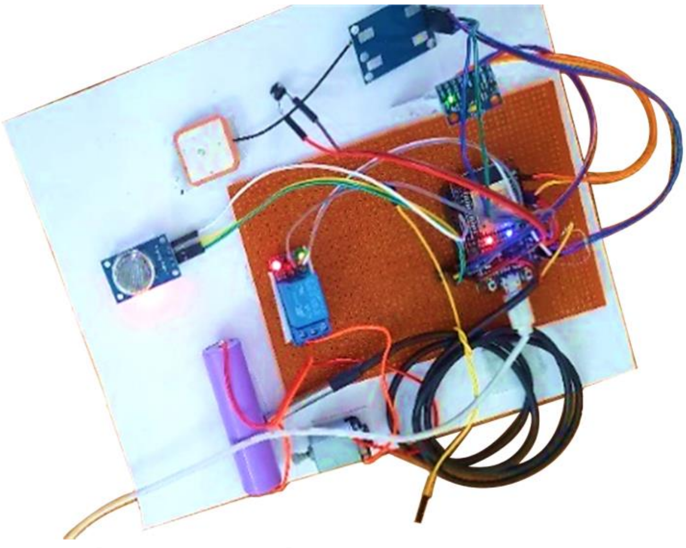

Figure 7. Accident occurrence device.

CONCLUSION

The IoT-based black box system is a valuable tool for improving vehicle safety and accident investigations. It can provide accurate and unbiased data regarding the circumstances of an accident, which can be used to identify the cause of an accident and prevent future accidents. The system is relatively inexpensive and easy to install, making it a viable option for all types of vehicles.

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