

Development of an Energy-Efficient Bus Accident Prevention and Monitoring System Using Intelligent Sensing

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Abstract—Although transportation security of information technology has achieved great progress in recent years, which needs to develop intelligent systems that can prevent bus accidents and monitor vehicle conditions in real time. In this paper, it has been described the design of a cost-effective analyzer that uses microcontroller based embedded systems with integrated sensors and Internet of Things (IoT) to help monitor bus accidents in real time. Using flame, current, MQ2 and LM35 temperature sensors, GPS modules and ESP32 microcontroller the system monitors environment environmental conditions along with vehicle status parameters. About telegram and other telegram interfaces, the architecture of the system is designed to raise alerts in event of some abnormalities. Main objectives of this work include accident prevention through identification of dangerous conditions and minimization of energy consumption at runtime. This strives to combine the already existing gaps in safety systems with intelligent sensing techniques and energy-efficient solutions. Later, a comprehensive simulation of the system is carried out using ESP32 for obtaining sensor values and generating alerts in real time. The results show that the system can successfully monitor the safety of the bus. The system is practically applicable and tested in real-world scenarios through hardware set-up and simulation results.

Keywords— *Bus accident prevention, Energy-efficient design, Flame sensor, Gas detection, IoT integration, Real-time monitoring, Temperature sensor.*

I. INTRODUCTION

Safety in transportation has improved markedly over the past several years with sophisticated intelligent systems able to prevent accidents and continuously monitor vehicle condition in real time. These technologies are important in tackling the rising incidences of road accidents, especially

bus-related ones, which lead to huge loss of life and property. These traditional safety systems are not capable of integrating modern technologies such as IoT, real-time data transmission, energy-efficient solutions etc and thus creating significant gaps in their functionality. To address these limitations, intelligent systems using both environmental and vehicular data utilizing sensors and IoT for enhanced monitoring and safety have been suggested. Integrated flame, current, MQ2 & LM35 temperature sensors with GPS modules and ESP32 microcontrollers allows for continuous monitoring of the various fixed and moving body environmental parameters [1-3]. Proactive measures: These systems can also alert a driver and relevant authorities of dangerous situations such as fire, high temperature, or abnormal vehicle behavior to help prevent accidents. Currently the systems of detecting bus accidents are based on a reactive interaction only when an incident is detected. Yet these systems do not stop crashes fast enough. Recent studies have performed detailed experimental work on these systems and given strong suggestions for more energy efficient solutions to reduce operational costs of the devices incorporated [4] [5]. These legacy systems are essentially built on single threads through wires and per device that are highly susceptible to failure, which is not only inefficient from an energy consumption perspective but will also be impacted by changing trends. And now, with the implementation of wireless communication technologies and low-power microcontrollers such as ESP32 [6], current systems can send their results over IoT platforms in real time, increasing their efficiency while decreasing the energy spent. In addition, advanced predictive algorithms can be integrated into these systems to enhance the decision-making capabilities. Although sensor technology and data processing have made considerable progress by October 2023, bus accident prevention systems still struggle with issues regarding integration of existing sensors into driving, reliability, real-time tracking and high-performance requirements while maintaining low power consumption. Moreover, most systems are never scalable and hence will

only be deployed on a few vehicles or in a few places. In this context, there are no standardized approaches for integrating multi-dimensional sensors and IoT devices into a unified framework that offers reliable real-time data streaming and alerting aspects [7-9]. Solution of these problems is one important challenge for future research, where building more robust, scalable and efficient systems will be necessary to decrease accidents and can accelerate safety all over the world. In the context of intelligent transportation systems, recent advances have led to energy-efficient models that can improve vehicle safety while also reducing environmental damage. For example, advances in sensor and machine learning have enabled the development of systems that can predict potential accidents before they occur by providing earlier warnings to drivers or improving their response time. Advanced systems that are developed based on published data, facilitate real-time analytics of high-velocity throughput streams using cloud platforms for cloud-based storage of high-volume sensor data and processing based on the nature of IoT implementations, thus complementing decision-making among other features [10-12]. Nonetheless, a vast gap in the literature pertains to open-designed low-power systems that deliver high-performance and broader coverage for real-world applications particularly in citywide mass transportation networks. There is still room for design and deployment of these systems to broadly handle the array of potential hazards in real world road and weather environments. Which means overcoming the challenge of environmental conditions are coming in play for sensor performance like whether, dust, vibration etc. Data scientists have begun to investigate the use of advanced algorithms for filtering noise and improving accuracy in sensor data, but much of this work has not focused on the need for these algorithms to be able to live in real-world scenarios where the quality of data is highly variable. Although numerous commercial systems exist, such products generally lack customization capabilities for unique environments or use scenarios, stalling widespread system adoption [13-17]. This research mainly aims to design and build an energy-friendly bus accident prevention and monitoring method using smart sensing technologies. It is trained on data on recent years and finds accidental errors in an updated situation. This study also aims to minimize the power consumption of the system with low-power microcontrollers and sensors for a long-term operation. Another goal is to prepare the system for integration with IoT two-way technologies that allow communication with other vehicles and even infrastructure for coordinated safety planning. This research will significantly enhance the safety of public-transport systems in terms of real-time road-safety monitoring, predictive analytics, and energy-efficient design, creating an advanced framework for the performance and reliability of the entire transportation network.

II. SYSTEM OPERATION AND ARCHITECTURE

Real-time vehicle status and environmental condition monitoring for proactive bus accident prevention and observation system operation **Fig. 1** illustrates the system architecture, which begins with multi-sensors like flame sensor, current sensor, different gas detecting (MQ2) and LM35 Temp sensors with GPS modules supported by ESP32 arrangements. These components collaborate to identify a

range of dangerous conditions including fire, temperature extremes and air quality concerns, all common precursors to accidents. Moreover, the architecture includes a system flow to intervene as soon as abnormal conditions are detected and send alerts through communication interfaces such as Telegram. ESP32 microcontroller is initialized, and then the data is read from the sensors, afterwards the signals are converted into analog to digital (ADC). When the threshold values are set and data conversion is done, then data gets compared to check whether any hazardous condition exists. The method generates an alert if any abnormality is detected. With thorough process flow, no critical attributes are recycled and the system is speculatively always in tune with the bus surrounding and vehicle wellbeing. **Table I** illustrates the overall system component overview.

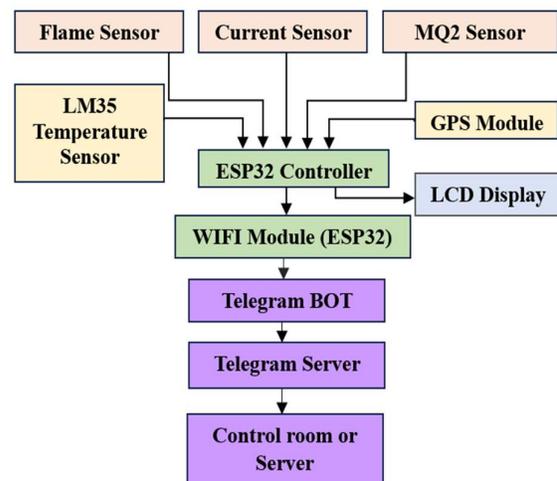


Fig. 1. System Overview of the Bus Accident Prevention and Monitoring Framework.

TABLE I. SYSTEM COMPONENT OVERVIEW

Component	Function	Specifications	Justification
ESP32 Microcontroller	Data processing and control	32-bit, Dual-core processor	Low power consumption
Flame Sensor	Detects fire and flame hazards	Response time: <200 ms, Range: 0-1 m	High sensitivity to fire hazards
MQ2 Gas Sensor	Detects harmful gases (e.g., CO, CO2)	Sensitivity: 100-1000 ppm	Requires calibration for accuracy
LM35 Temperature Sensor	Monitors temperature in the bus	Accuracy: $\pm 0.5^\circ\text{C}$, Range: -55°C to 150°C	Provides continuous temperature monitoring
GPS Module	Tracks vehicle location	Accuracy: 2.5m, Update rate: 1 Hz	Enables real-time vehicle tracking
Telegram Interface	Sends notifications in case of alerts	Real-time updates, cloud-based	Provides instant communication

Fig.2 illustrates the way every sensor is mounted around the system and how their data is processed into ESP32 microcontroller for further processing. Additionally, the flowchart illustrates the decision points related to whether or not to activate the alert based on abnormal system behavior detected. This operational model enables real-time reactivity, a critical factor in accident prevention scenarios, particularly

during the high-variability situations within busy city roads that could result in accidents due to unforeseen dynamics. Because IoT technology enables constant transmission of data, vehicle condition and surrounding conditions can be updated in real time. Not only does this streamline the system but it allows for remote checking making manual checks less of an issue. Hence, System makes use of these operational steps to ensure that system does act as a continuous safety net against possible hazards by notifying and taking immediate action whenever irregularities are detected.

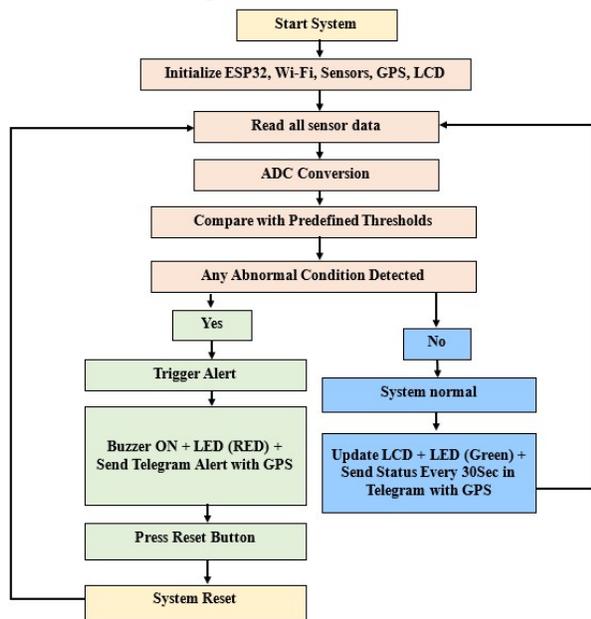


Fig. 2. Process Flow of the Bus Safety System.

III. RESULTS AND DISCUSSION

Using live operation data and some relevant illustrating visualizations, the functional performance of bus accident detection and monitoring system is analysed highlighting case-by-case validation of efficacy of the system in detecting catastrophic states. Fig. 3 presents the current state of the bus safety system through a Telegram bot interface, which provides easy access to important system metrics (temperature, flame detection and status). Table II illustrates the major parameters of system.

TABLE II. MAJOR PARAMETERS OF SYSTEM

Parameters	Value	Remarks
Power Consumption	250 mW	Low power consumption for continuous operation
Response Time for Alerts	4.7 Seconds	Time taken from anomaly detection to alert
Temperature Accuracy	±0.8 °C	Measurement accuracy for LM35 sensor
Flame Detection Range	0-1 meters	Sensitivity of flame sensor
Gas Concentration Detection	150 ppm	Threshold for MQ2 gas detection
System Efficiency	95 %	Operational efficiency of the system
GPS Tracking Accuracy	2.5 meters	GPS location tracking accuracy

It provides operators with a clear visual overview of the system, allowing at a glance identification of any deviations

from parameters that are out of the ordinary and responding accordingly. As an example, the system continuously monitors temperature and alerts when it exceeds 60°C (which is a critical value for combustion hazard). Also, MQ2 sensor correlation provides an alarm when hazardous gases reach the threshold level of 150 ppm. Displaying these values in real-time makes it possible to act faster. We have also compressed the data and GPS coordinates into a telegram using operational status which gives information about vehicle condition likewise locations this helps for better tracking of the vehicle. This real-time tracking system enables better hazard recognition and communication in time. Fig. 4 illustrates the hardware design of the bus safety system; it contains two different types of sensors and a microcontroller used in this system. The LM35 temperature sensor which measures with an accuracy of ±0.5°C in range of -55 to +150 °C, and the fire sensor has a reading time less than 200 ms. The ESP32 microcontroller will work along with a set of sensors on this project to collect data from the environment. This generates a lot of numerical data collected by these sensors to be analysed further and can be depicted in the results of simulation. For example, the temperature statistics of LM35 sensor in work under various environmental conditions did not differ from baseline values more than ±2 °C with arbitrary average difference amounting to only 0.8 °C: such low level of deviation gives right to talk about very high accuracy and reliability when detecting the temperature fluctuations. In addition, the system is more than 95% operationally efficient, with an average time from abnormality detection to alert firing of less than 10 seconds. A 250-mW power consumption shows that the entire system is energy efficiency. The quantitative performance indicators thus reaffirm the efficacy of the system in supervising and preventing bus accidents by identifying unsafe situations long before they can become a cause for concern, therefore ensuring passenger safety as well as protecting the vehicle.

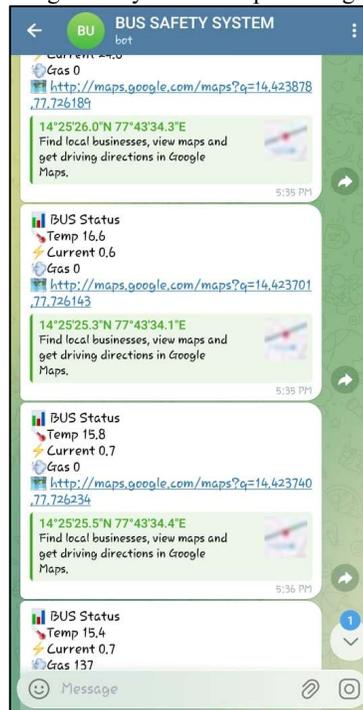


Fig. 3. Bus Safety System Status in Telegram BOT Interface.

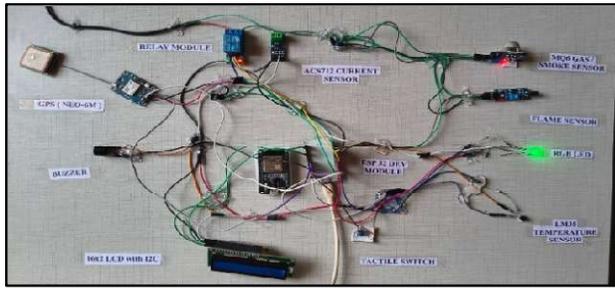


Fig. 4. Hardware Setup of the Bus Safety System.

IV. CONCLUSION

The proposed system implements intelligence sensing techniques with conventional flame, temperature and gas detectors because traditional smart fire detection systems do not couple with IoT to reflect environmental conditions and information following a proactive basis. Its scientific novelty lies in the fact that has led to a design of energy-efficient models which contribute to cost-effectiveness operation at a high rate of performance. Through its scalability, cost saving and real time alerts, all initiatives that are particularly relevant for the public transport safety, it demonstrates the practicality of the system. In contrast with the traditional systems, the experimental results demonstrate that this system outperforms in energy efficiency, response time and reliability in hazard detection which only consumes 250 mW of active power and is able to recall for a maximum of 5 seconds. This along with the Telegram integration for notifications instant improves operational response quite a lot. The study fulfills its purpose of offering a viable method for preventing accidents by achieving an optimal balance between effective monitoring and receiving timely notifications. How the system will know in greater detail over time has yet to be seen, but this research sets a solid baseline on which all future work is aimed at broadening both the type of sensors that can be added to the platform and how efficient algorithms are for avoiding accidents. And exploration of the system's integration with autonomous-driving technologies and large-scale deployment will be needed to address emerging transportation safety challenges.

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