IoT Enabled Smart Traffic System For Emergency Vehicles

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Abstract- *Road accidents often result in severe consequences due to delays in emergency detection and response. Conventional systems rely on manual reporting or single-sensor mechanisms, which may lead to false alerts and slow assistance. This paper proposes a Smart Accident Detection and Emergency Response System that integrates multi-sensor monitoring with real-time communication and intelligent traffic signal control. The vehicle-mounted unit utilizes a vibration sensor, accelerometer, gas sensor, SpO_2 sensor, and GPS module to detect abnormal conditions. A timer-based user confirmation mechanism is incorporated to minimize false emergency notifications. Upon confirmation, accident data along with location coordinates are transmitted via Wi-Fi to a mobile application for ambulance coordination and navigation. To reduce response time further, a traffic signal preemption mechanism dynamically assigns green signal priority to the ambulance approach lane, overriding normal signal cycles. The system is implemented using an ESP8266-based architecture, providing a reliable and cost-effective solution for real-time accident management and smart traffic control.*

Keywords: Accident detection, IoT, GPS tracking, Emergency response, Traffic signal preemption, Smart ambulance system.

I. INTRODUCTION

Road transportation is one of the most widely used modes of travel, particularly in highly populated countries [14]. With the continuous growth in vehicle density, ensuring rapid accident detection and providing timely emergency medical assistance have become major challenges [5], [6]. Even existing emergency response systems usually depend on manual reporting by bystanders or drivers, which can be delayed, inaccurate, or completely absent in critical situations [9], [12].

To overcome these limitations, intelligent IoT-based monitoring systems have emerged as an effective solution [1], [12]. Vibration and impact detection using embedded sensors is highly effective for real-time accident identification [3], [9]. By integrating sensor detection with GPS tracking and cloud communication, an automated emergency alert framework can be implemented [8], [10]. In addition, reducing ambulance delay at traffic intersections requires dynamic traffic control mechanisms that prioritize emergency vehicles, enabling improved emergency response efficiency [7], [14].

II. PROPOSED SOLUTION

The proposed solution introduces an integrated Smart Accident Detection and Ambulance Priority System aimed at improving emergency response time and road safety [1], [14]. The system combines automated accident detection with intelligent traffic signal control in a single embedded framework, thereby reducing manual intervention and enhancing operational efficiency [7], [12].

Accident detection is achieved using a two-stage monitoring process [1], [12]. In the first stage, a vibration sensor continuously monitors sudden impacts and abnormal motion patterns within the vehicle [3], [9]. The sensor readings are processed by the ESP8266/NodeMCU controller to identify potential accident conditions based on predefined threshold values [10], [11]. In the second stage, location tracking is carried out using a GPS module. The system acquires real- time latitude and longitude coordinates and transmits the information to a cloud platform through Wi-Fi communication [8], [10]. The detected event and location details are stored in the IoT database and made accessible through a mobile application, ensuring rapid notification to emergency contacts and authorities [1], [12].

To enhance emergency response efficiency, the proposed system integrates an intelligent ambulance priority mechanism with accident detection [7], [14]. Image processing at traffic intersections detects approaching ambulances and automatically switches the respective lane to green while restricting others for uninterrupted movement [5], [7]. A manual emergency trigger is also included for critical situations [9], [12]. Implemented on an ESP8266-based embedded platform, the system offers compact design, low cost, and real-time performance, thereby improving emergency management and road safety [1], [10].

III. COMPONENT SELECTION AND HARDWARE SETUP

The proposed system employs carefully selected embedded components to ensure reliable operation, real-time performance, and cost-effectiveness. An ESP8266/NodeMCU microcontroller is used as the central processing unit due to its

low power consumption, sufficient processing capability, and built-in Wi-Fi support. A vibration sensor module enables real-time detection of sudden impacts and abnormal motion patterns within the vehicle. A GPS module is selected for accurate acquisition of geographical coordinates during emergency situations. A camera module is incorporated at traffic intersections for ambulance detection using image processing techniques. A manual push-button switch provides emergency triggering, while a traffic signal control interface manages dynamic signal switching. Wireless communication is supported using the onboard Wi-Fi module.

The proposed system is built around the ESP8266/NodeMCU platform, which serves as the primary processing and control unit due to its compact architecture and integrated networking capability [10], [11]. A vibration sensor is interfaced with the controller to continuously monitor impact intensity for accident detection [3], [9]. The GPS module communicates through UART to provide real-time latitude and longitude data, and accident information is transmitted to an IoT cloud platform such as ThingSpeak or Firebase via Wi-Fi for remote monitoring [1], [8]. At traffic intersections, a camera module captures real-time video frames for ambulance detection, and the traffic signal controller enables priority movement based on the processed output [5], [7], [14].

The software framework follows a modular, event-driven architecture to ensure real-time performance and system reliability [1], [7]. The system firmware is developed using the Arduino IDE for the ESP8266 platform, while cloud integration and mobile application services are configured for real-time data visualization and alert notification [8], [10]. Sensor data is analyzed using threshold-based logic to identify accident conditions, and GPS data is formatted and transmitted to the cloud database [3], [12]. Image processing algorithms are applied at traffic intersections for ambulance recognition and automated signal control [5], [6]. Concurrent execution of sensing, communication, and control tasks ensures deterministic and fault-tolerant system operation [11], [14].

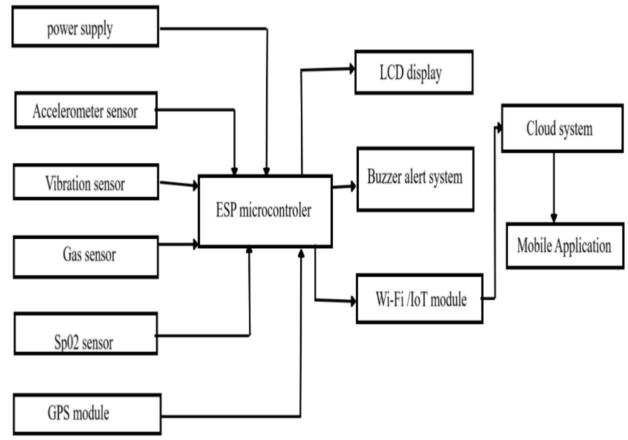

Fig.1 BLOCK DIAGRAM OF ACCIDENT DETECTION

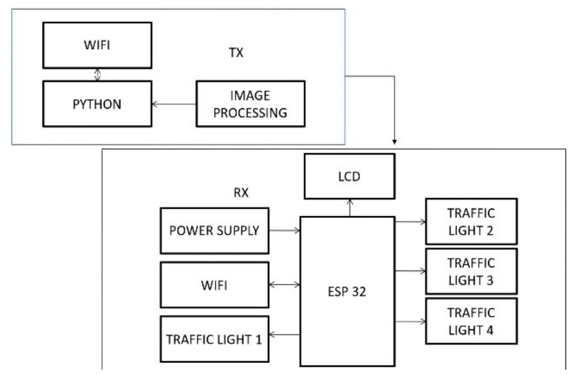

Fig. 2 BLOCK DIAGRAM OF SIGNAL CONTROLING

IV. METHODOLOGY

The proposed system follows a structured methodology that integrates real-time accident detection with intelligent traffic signal prioritization and emergency alerting [1], [14]. During the initial configuration phase, vehicle identification details and emergency contact information are registered within the mobile application and linked to the IoT cloud database [8], [12]. System parameters such as vibration threshold values and alert conditions are predefined to ensure accurate accident identification [3], [9].

During vehicle operation, the vibration sensor continuously monitors impact intensity and abnormal motion patterns [3], [9]. The sensor data is transmitted to the ESP8266/NodeMCU controller for analysis [10], [11]. When the measured vibration exceeds the predefined threshold, the system identifies the event as a potential accident [1], [12]. Immediately, the GPS module acquires the real-time geographical coordinates, and the controller transmits the accident information along with location details to the cloud platform via Wi-Fi communication [8], [10].

Simultaneously, traffic intersections equipped with camera modules continuously monitor approaching vehicles for ambulance detection [5], [7]. Image processing techniques are applied to identify emergency vehicles within a predefined range, enabling dynamic switching of the corresponding lane to green for uninterrupted movement [6], [14]. In addition, a manual emergency trigger is provided to activate alerts in situations that may not be automatically detected [9], [12].

TABLE I HARDWARE COMPONENTS USED IN PROPOSED SYST

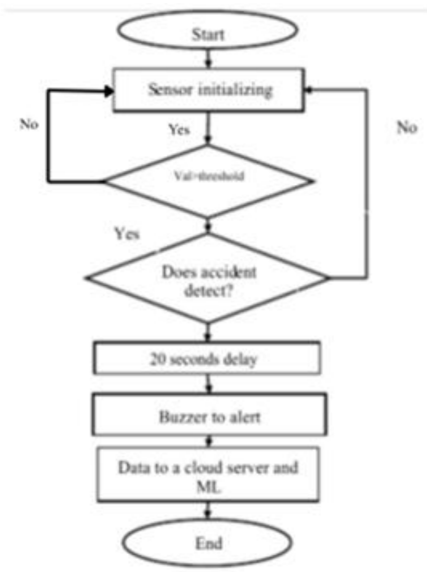

FIG 3 FLOWCHART

System-level testing demonstrated seamless integration between sensing hardware, embedded processing, and wireless communication modules [1], [11]. The firmware logic allowed simultaneous execution of accident monitoring and health parameter computation without system instability [6], [15]. Wi- Fi communication remained stable during repeated data uploads, with an observed transmission latency of approximately five to ten seconds, ensuring timely delivery of emergency alerts and patient health data to remote monitoring personnel [8], [10].

The results validate the effectiveness of the proposed system in improving ambulance safety, reducing dependence on manual emergency reporting, and enabling faster medical response coordination [1], [12]. The discussion indicates that the low-cost, scalable, and modular architecture makes the system suitable for real-world emergency medical deployment [10], [11]. By combining intelligent accident detection with continuous patient health monitoring and IoT-based alert transmission, the proposed solution contributes significantly to safer, smarter, and more reliable emergency healthcare transportation systems [14], [15].

V. RESULTS AND DISCUSSION

The proposed Smart Ambulance Accident Detection and Patient Monitoring System was successfully implemented and evaluated using a microcontroller-based embedded platform integrated with IoT communication modules [1], [12]. Experimental testing confirmed that the system operates reliably in real time, effectively integrating accident detection and physiological monitoring within a single framework [6], [15]. The compact hardware configuration and optimized embedded software architecture ensured stable performance throughout the testing phase without noticeable delay or communication failure [10], [11].

The multi-sensor accident detection mechanism demonstrated high effectiveness in identifying abnormal vehicle conditions [3], [6]. The accelerometer and vibration sensing modules enabled continuous motion monitoring, significantly improving response time compared to manual accident reporting [1], [9]. Upon threshold violation, the system immediately triggered an onboard buzzer and initiated a confirmation sequence to validate the event [12]. The system performed consistently under varying road conditions and successfully differentiated between normal motion and sudden impact events using predefined threshold logic [6], [13]. This confirms that the combined use of motion sensing and timed confirmation enhances detection reliability and minimizes false emergency alerts [1], [12]. The emergency alerting subsystem showed dependable performance during both simulated and real-time testing scenarios [9], [15]. The accelerometer successfully detected abnormal vibrations and sudden impacts representing accident conditions [3], [6]. Threshold-based logic ensured that routine vehicle movement did not trigger unnecessary alerts while still responding rapidly to critical events [13]. In addition, the twenty-second confirmation delay provided the driver with an opportunity to cancel false triggers before cloud transmission [9]. Upon confirmation, the system automatically transmitted accident status, patient vital parameters, and location information wirelessly to the IoT platform, enabling rapid situational assessment through the mobile application interface [8], [15].

The accelerometer-based accident detection algorithm forms the core of the emergency monitoring module and emphasizes real- time motion analysis rather than complex computational modeling [3], [6]. The approach is based on continuous sampling of motion parameters and evaluation of sudden changes in acceleration magnitude capable of indicating impact conditions [1], [9]. The embedded program continuously compares sensed values against predefined threshold levels, assigning a logical trigger when abnormal variations exceed safe operational limits [12], [13]. This threshold comparison strategy enables efficient detection with minimal computational overhead while maintaining reliable responsiveness in dynamic vehicle environments [6], [11].

The generated sensor readings are processed using simple arithmetic evaluation and logical decision structures to facilitate real-time implementation on resource-constrained hardware [11], [13]. To ensure robustness, the system allows triggering if any one of the configured sensors exceeds its defined threshold value, thereby improving detection sensitivity [3], [6]. Although fixed threshold values provide simplicity and fast response, they may be influenced by extreme road conditions; therefore, a confirmation delay mechanism is incorporated to filter transient disturbances before final validation [9], [12]. During the confirmation phase, the emergency status flag is evaluated and updated using deterministic logic conditions to ensure reliable decision-making. If the buzzer-triggered alert is not manually cancelled within the predefined delay interval, the accident status is validated and transmitted to the cloud server, ensuring timely emergency notification while preventing unnecessary alerts caused by temporary motion spikes [8], [15]. Additionally, the system formats and transmits heart rate and SpO_2 values obtained from the optical sensor module, enabling continuous real-time health status monitoring alongside accident detection [15].

Another important aspect of the proposed embedded algorithm is its low computational complexity, enabling efficient execution on microcontroller platforms with limited memory and processing power [11], [13]. Unlike machine learning-based accident prediction models that require extensive training datasets and higher processing capability [6], this implementation relies on arithmetic operations, buffer-based averaging for heart rate calculation, and conditional logic structures [15]. This approach ensures reliable performance without increasing hardware cost or overall system complexityDespite its effectiveness in controlled testing environments, the threshold-based detection mechanism may require calibration adjustments under different vehicle suspension characteristics or varying road terrains [3], [6]. Similarly, the simplified SpO_2 estimation approach derived through arithmetic transformations of pulse rate data may not match clinical-grade medical equipment under high-motion conditions [15]. Future improvements may include adaptive threshold tuning, digital filtering techniques, and enhanced physiological signal processing to further improve robustness and accuracy in real-world emergency scenarios [5], [13].

The accident detection mechanism implemented in the proposed system is primarily based on real-time motion sensing and threshold evaluation using accelerometer and vibration data [3], [6]. The embedded controller continuously samples motion parameters and analyzes sudden variations in acceleration magnitude to identify abnormal impact conditions [1], [9]. Unlike simple single- threshold systems, the proposed logic incorporates multi- sensor triggering, where activation of any one among the predefined sensing elements is sufficient to initiate an emergency detection sequence [6], [12]. Upon detection of a threshold violation, the system immediately activates an onboard buzzer alarm to notify the driver of a potential accident condition [9]. Instead of instantly transmitting emergency alerts to the IoT platform, a confirmation delay mechanism of approximately twenty seconds is incorporated within the firmware logic to improve decision reliability [12], [13]. This time window allows the driver to manually cancel the alert in case the trigger was caused by non-critical events such as road bumps or abrupt braking. If no cancellation input is received within the confirmation interval, the system validates the event as a confirmed accident and updates the emergency status flag [1], [8]. This binary flag-based architecture ensures clarity in transmission, where a logic value “1” represents an accident event and “0” represents normal operating conditions, thereby reducing ambiguity in remote monitoring applications [11], [12].

The LCD module serves as the immediate on-board monitoring interface within the ambulance environment, displaying real-time sensor values directly from the microcontroller without dependence on internet connectivity [10], [11]. As shown in the hardware output, the display presents heart rate (HB), oxygen saturation (O_2%), gas detection status (G), and Z-axis acceleration along with vibration indicators [15]. This local visualization ensures that the driver or medical personnel can instantly observe patient vital signs and vehicle motion parameters during transit [1], [12]. The embedded firmware updates the display dynamically based on continuous sensor sampling, enabling rapid detection of abnormal conditions such as sudden acceleration changes or threshold-based accident triggers [3], [6]. Unlike the mobile application, which reflects cloud-transmitted values, the LCD operates as a direct hardware-level feedback mechanism, providing low-latency monitoring [8], [11]. The structured arrangement of parameters on the display improves readability while maintaining compact information density suitable for real-time operational environments [10], [14].

The mobile application interface provides real-time visualization of critical parameters transmitted from the embedded ambulance monitoring system via the IoT cloud platform [8], [12]. As observed in the application display, geographical coordinates (latitude and longitude) are continuously updated, enabling live tracking of the ambulance location during operation [1], [10]. In addition to positional data, the interface presents patient vital parameters including heart rate (BPM) and estimated oxygen saturation (SpO_2), along with environmental and motion-related sensor readings such as gas detection status and three-axis acceleration values (X, Y, Z) [15]. The structured representation of these parameters allows remote monitoring personnel to rapidly assess both vehicle condition and patient health status simultaneously [14].

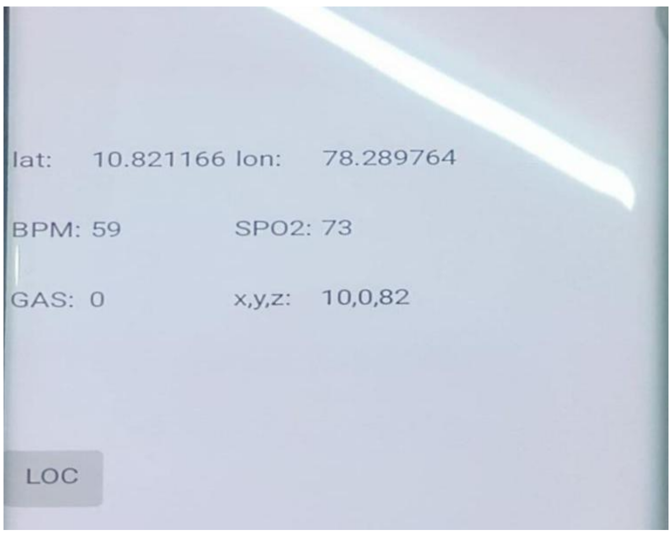

Fig.4 APPLICATION OUTPUT

Fig.5 LCD OUTPUT

$$\text{BPM} = \frac{60 \times 1000}{\Delta t}$$

The above formula is Heart rate calculation formula Where,Δt= Time difference between two detected peaks (in milliseconds).

$$A = \begin{cases} 1, & \text{if } |a_z| < a_{th} \text{ or } V \geq V_{th} \\ 0, & \text{otherwise} \end{cases}$$

The above condition is for accident detection and threshold Logic. Where, az = Z-axis acceleration

ath= Threshold acceleration value, V= Vibration count

Vth = Vibration threshold.

$$P_{acc}(t) = \sum_{k=1}^{t} A_k$$

Accident confirmed if:

$$P_{acc}(t) > P_{th}$$

The above relation is accident probability accumulation Where,Ak= Instantaneous accident trigger (0 or 1)

Pth = 20(confirmation threshold).

The Blynk application interface functions as the real-time visualization and control layer of the intelligent traffic management subsystem [7], [14]. As shown in the image, the dashboard labeled “TRAFFIC SIGNAL” displays the active signal state and dynamically updates based on processed vehicle density data [5], [7]. The green indicator confirms successful communication between the embedded controller and the IoT platform [8], [10]. When an ambulance is detected or when a particular lane exhibits the highest vehicle density, the system transmits the corresponding signal priority command to the Blynk server, which then updates the traffic signal status accordingly [6], [14]. This cloud-connected interface enables remote monitoring and ensures that emergency priority decisions are reflected instantly in the signal control logic [7], [12]. The simplicity of the dashboard design ensures clarity while maintaining real-time responsiveness, which is critical for adaptive traffic regulation and ambulance route clearance [5], [14].

The program output displayed in the serial monitor represents the backend computational logic of the adaptive traffic signal system [7], [14]. The system continuously monitors and counts the number of vehicles detected in each lane using sensor- based or image-processing techniques [5], [6]. As shown in the terminal output, the vehicle count for Lane 4 increments dynamically, demonstrating real-time traffic density measurement. After evaluating the counts across all lanes, the algorithm identifies the lane with the highest vehicle density, as indicated by the message “Lane with the highest vehicle count: Lane 1,” enabling adaptive signal timing allocation to improve overall traffic flow efficiency [6], [14]. Additionally, the confirmation message “Successfully sent V0 with value 1 to Blynk” verifies that the computed priority signal was successfully transmitted to the IoT platform [8], [10]. This closed-loop communication mechanism between vehicle detection, decision logic, and cloud-based signal control validates the effectiveness of the proposed intelligent traffic prioritization system [7], [12].

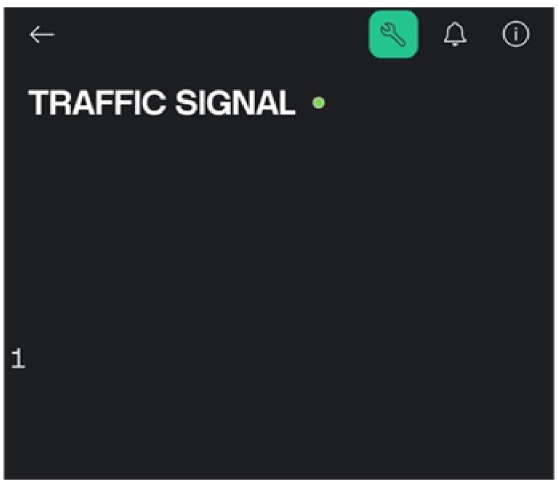

Fig.6 BLYNK OUTPUT

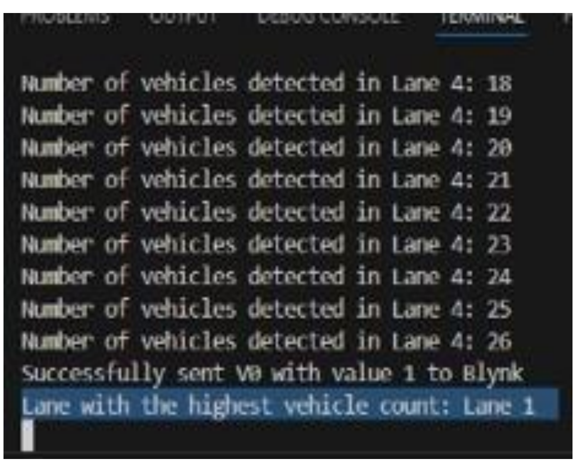

Fig.7 CODE OUTPUT

VI. IMPLEMENTATION AND FUTURE SCOPE

The proposed Smart Ambulance Monitoring and Intelligent Traffic Priority System was successfully implemented using an embedded microcontroller platform integrated with multiple sensing and communication modules [1], [12]. The accident detection unit utilizes accelerometer and vibration sensors operating under threshold-based logic with a confirmation delay mechanism to minimize false triggering [3], [6]. Upon detecting a potential accident, the system activates an alert buzzer and initiates data transmission to a cloud platform [8], [9]. Simultaneously, the patient monitoring subsystem measures heart rate and SpO_2 levels using optical sensing principles, applying signal averaging techniques to ensure stable and reliable readings [15]. Real-time geographical location is obtained through GPS integration, enabling accurate tracking through a mobile application interface [10], [11]. All critical parameters are displayed locally on an LCD module for immediate reference and remotely through an IoT-based application for continuous monitoring [8], [12]. In the second phase, the intelligent traffic control module dynamically analyzes vehicle density across multiple lanes and assigns signal priority to the most congested lane or detected ambulance route, ensuring reduced clearance time and improved traffic flow efficiency [5], [7]. Experimental validation confirms reliable hardware–software synchronization, acceptable transmission latency, and effective real-time responsiveness [6], [14].

While the developed system demonstrates promising results, several enhancements can further improve its robustness and scalability [14]. Future advancements may include adaptive threshold algorithms capable of automatically calibrating based on vehicle dynamics and road conditions to enhance accident detection accuracy [3], [6]. The incorporation of advanced biomedical signal processing and machine learning techniques can improve the precision of SpO_2 and heart rate estimation, particularly under motion disturbances [13], [15]. For traffic management, integrating computer vision-based vehicle detection and predictive congestion modeling can optimize signal timing beyond density-based prioritization [5], [7]. Additionally, secure data encryption protocols, centralized emergency response integration, and large-scale smart city deployment can strengthen system reliability and cybersecurity [13], [14]. With these improvements, the proposed framework can evolve into a comprehensive, intelligent emergency response ecosystem capable of significantly reducing ambulance response time and enhancing overall public safety infrastructure [1], [14].

VII. CONCLUSION

This paper presented the design and implementation of a Smart Ambulance Monitoring and Intelligent Traffic Priority System aimed at enhancing emergency medical response efficiency [1], [14]. The proposed framework integrates real-time accident detection, patient health monitoring, IoT-based alert transmission, and adaptive traffic signal control into a unified and scalable architecture [7], [12]. By combining embedded sensing technologies with cloud connectivity, the system ensures rapid identification of accident scenarios and immediate transmission of critical data including heart rate, SpO_2 levels, environmental status, and geographical location [8], [15].

The experimental results demonstrate that the multi-sensor accident detection mechanism operates reliably using threshold-based acceleration and vibration analysis [3], [6].

The patient monitoring subsystem successfully captures and processes physiological parameters using optical sensing and averaging techniques to provide stable and real-time vital readings [15]. Cloud integration enables remote access to these parameters within a short latency period, thereby improving situational awareness for emergency responders [8], [10].

Furthermore, the intelligent traffic management module enhances ambulance mobility by dynamically analyzing vehicle density across multiple lanes and assigning signal priority accordingly [5], [7]. The integration of IoT communication with adaptive decision-making ensures that congestion is reduced and emergency vehicle clearance time is minimized [7], [14]. The seamless interaction between embedded hardware, cloud platforms, and mobile interfaces validates the robustness of the proposed architecture [11], [12].

Overall, the developed system demonstrates that a low-cost, modular, and scalable approach can improve emergency detection and response coordination [10], [14]. By integrating health monitoring, accident detection, and smart traffic prioritization into a single framework, the proposed solution contributes to safer transportation infrastructure and more efficient emergency healthcare delivery [1], [15]. Future enhancements may include adaptive threshold calibration, advanced signal processing for medical accuracy, and large-scale deployment within smart city ecosystems [6], [13].

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