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Advancing Road Safety through Intelligent Vehicle Accident Detection and Reporting Enabled by IoT Innovation

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Abstract

Accidents frequently occur due to factors such as speeding, impaired driving, and night driving, often leaving passengers unable to seek timely help due to severe injuries, which can result in loss of life. To address this issue, a system has been developed for early accident detection and prompt rescue assistance. The system integrates Raspberry Pi and Arduino, with Raspberry Pi capturing images of passengers once vehicle doors are closed and detecting faces to estimate the number of passengers. Arduino collects data from a force-sensitive resistor (FSR) and a global positioning system (GPS), and assesses the severity and impact location of the accident. In the event of a collision, Arduino transmits the data to Raspberry Pi, which then captures immediate images and sends accident details, along with pre- and post-incident images, to the response center via email.

Keywords: Internet of Things (IoT), Raspberry Pi, Arduino, FSR, GPS, accident detection, emergency response, road safety, data analysis, intelligent system.

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1. Introduction

Road accidents are a persistent threat to human life, exacerbated by delays in emergency response, particularly in remote or isolated areas. Factors like speeding, impaired driving, and adverse weather conditions increase accident risks, further intensifying the need for timely intervention. The World Health Organization (WHO) reports that road traffic injuries are among the leading causes of death globally [1]. Traditional emergency systems struggle to bridge the gap between accident occurrence and assistance, particularly in isolated regions. This research introduces an IoT-based smart vehicle accident detection and reporting system, utilizing Raspberry Pi and Arduino microcontrollers. The proposed system addresses this critical gap by leveraging force-sensitive resistors (FSRs), GPS, and a Pi camera to detect accidents, assess severity, and transmit vital information to emergency services. This paper discusses the development of this system, which aims to reduce response times and save lives by enhancing road safety infrastructures.

2. Related work

Traditional accident detection systems have largely relied on outdated methodologies that depend on static traffic data, such as annual or hourly traffic volumes, limiting their effectiveness in real-time scenarios. In contrast, contemporary approaches, including the proposed Vehicle Accident Detection and Reporting System, leverage real-time information from various sources—such as GPS, force-sensitive resistive sensors, and cameras—to predict accident severity, estimate the number of passengers involved, and capture crucial pre- and post-accident imagery. Historically, accident detection methods depended heavily on manual reporting mechanisms, including driver calls, public reports, or aerial surveillance. These approaches often resulted in delays and inaccuracies, jeopardizing timely responses and potentially leading to fatalities.

Early automated systems that employed impact or airbag sensors combined with GPS technology for accident detection have laid the groundwork for advancements in this field [2]. Subsequent developments introduced accelerometers and GSM technology for enhanced collision detection and location transmission [3, 4, 5, 6]. More recently, smartphone-based systems have been explored, but their widespread adoption has been hampered by limitations related to false alarm filtering and the high costs associated with implementation. Although wireless accident detection systems have demonstrated effectiveness, they are often expensive to deploy due to the need for multiple road-mounted receivers [7, 8, 9].

The proposed system addresses the limitations of these earlier approaches by utilizing GPS data not only for accurate accident detection but also for the transmission of vital information regarding victims to emergency services through voice channels. This innovative methodology offers a more efficient and timely response to accidents, significantly improving the chances of passenger survival.

Recent literature has shown a growing trend toward integrating IoT technologies into accident detection systems, providing enhanced predictive analytics and data processing capabilities. However, gaps remain in the seamless integration of multiple data sources and the real-time processing of information, which are critical for effective emergency response. The motivation behind this research lies in addressing these gaps, aiming to develop a comprehensive solution that utilizes real-time data and advanced analytics to enhance the overall effectiveness of accident detection and response systems.

3. System Model

This section presents the design and implementation methodology for a novel smart vehicle accident detection and reporting system utilizing IoT technology. Previous research primarily focused on basic accident notification systems employing GSM and GPS for location-based alerts, lacking comprehensive accident details. The proposed system introduces a comprehensive approach encompassing immediate notification and detailed accident information. The key objective was to develop a cost-effective, high-performance solution. Force-sensitive resistors (FSRs) were selected as accident detection sensors due to their ease of installation and maintenance. The Arduino Uno and Raspberry Pi 3B+ were integrated to leverage Arduino's FSR compatibility and Raspberry Pi's Wi-Fi capabilities [10, 11]. A GPS-NEO 7M module and Pi Camera were incorporated for location determination and passenger image capture. Facial recognition on pre-accident images is employed by the Raspberry Pi to determine passenger count [12].

The system operates in four distinct phases: pre-accident passenger image capture, system integration, accident detection and data extraction, and post-accident image capture with subsequent emergency notification. Python code and OpenCV are utilized for facial recognition and image processing. Arduino and Raspberry Pi communicate via USB through Python-serial libraries. Upon accident occurrence, FSRs trigger data transmission to Arduino, which calculates impact data and forwards it to the Raspberry Pi. Post-accident images are captured, and accident details are emailed to the emergency response center using SMTP libraries. The system hardware comprises a prototype vehicle, Raspberry Pi, Pi Camera, Arduino Uno, FSRs, GPS module, pushbutton, and power converter. Software components include Tiny GPS++, Software Serial, SMTP, OpenCV, and PyFirmata libraries. Rigorous testing validated passenger image capture, FSR functionality, and GPS accuracy. The system demonstrated a 100% crash detection rate, precise location tracking, and accurate severity assessment, showcasing its potential to revolutionize road safety.

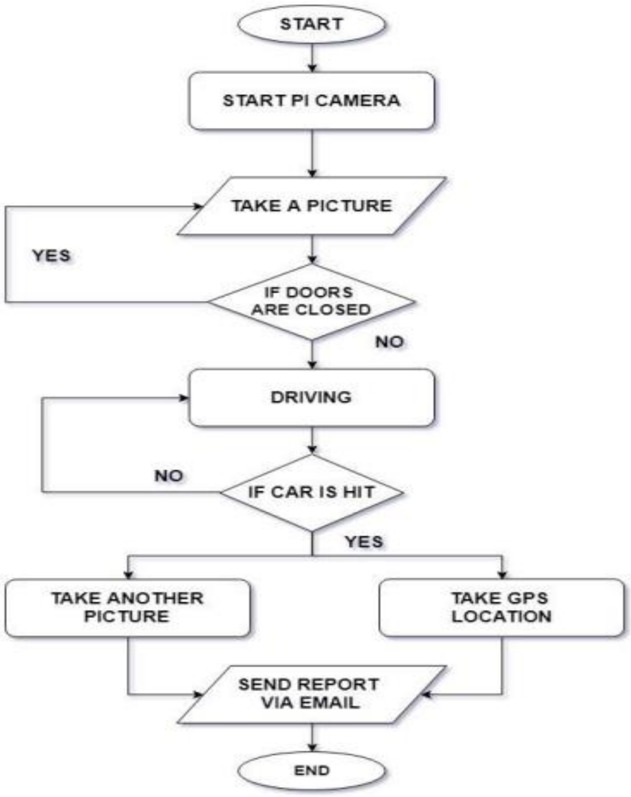

Figure 1 Methodology

Table 1 FSR Table

S.no	**FSR Output value**	**Severity of Accident**
1	≥1000	100%
2	≥675	>75%
3	≥450	>50%
4	≥225	>25%
5	≥100	<25%

4. Foundational Hardware and Components

To design a system that effectively addresses the objectives of this project, a combination of hardware and software components has been utilized. The foundation of the system is the Raspberry Pi, a compact computing platform developed by the Raspberry Pi Foundation to enhance computer science education, particularly in developing regions. Its versatility allows it to be applied in various innovative projects, including robotics, without the need for external devices like keyboards or mice. Complementing the Raspberry Pi is the Pi Camera, introduced in April 2016, which features an 8-megapixel Sony IMX219 sensor capable of capturing high-definition video and still images. This camera is compatible with all Raspberry Pi models and is controlled via a Python library, making it essential for on board passenger imaging.

The system also incorporates the Arduino UNO, an open-source microcontroller board based on the Microchip ATmega328P, equipped with 14 digital input/output pins and 6 analogue pins. This microcontroller is programmable through the Arduino Integrated Development Environment (IDE) via a USB Type B cable and can be powered by either USB or an external battery, accepting a voltage range between 7 and 20 volts. A key component for impact detection is the Force Sensitive Resistor (FSR), an electronic device that changes its resistance in response to applied pressure, thereby facilitating the detection of accidents.

For location tracking, the NEO-7M GPS module is integrated into the system, providing high-performance GPS capabilities with a compact ceramic antenna. This module allows for effective satellite searching and includes power and signal indicators for status monitoring. User interaction is enabled through a push button switch, a durable device that completes a circuit when pressed, allowing signal flow. To power the entire system, a 5V DC adapter is employed, designed as a high-quality switching power supply that regulates output voltage, accommodating an input range of AC 100-240V.

On the software side, the system operates using C++ and Python programming languages to execute essential functions such as email transmission, passenger image capture, and GPS operations. Several libraries have been installed on both the Raspberry Pi and Arduino, including TinyGPS++, which provides user-friendly methods for extracting data from GPS devices; SoftwareSerial, which enables serial communication on alternative GPIO pins of the Arduino; SMTP, the standard protocol for sending and receiving emails; OpenCV, an open-source computer vision library that facilitates machine perception; and PyFirmata, a library that enables Arduino control with a special Firmata sketch.

The project design utilizes various software tools, including the Arduino Integrated Development Environment (IDE), which supports writing and uploading code to Arduino-compatible boards, and is developed in Java. Additionally, Python IDLE, an integrated development environment designed for Python, offers a user-friendly interface suitable for beginners.

Lastly, RealVNC provides remote access capabilities, allowing the VNC Server and VNC Viewer to facilitate remote control of another computer's screen through the Virtual Network Computing protocol. This integrated approach ensures the development of a robust system capable of detecting accidents and providing timely assistance to affected passengers.

5. Results and Analysis

Extensive evaluations of the designed system have confirmed its high reliability and accuracy. The system consistently meets optimal performance metrics and delivers precise accident location data. To illustrate its capabilities, a series of comprehensive analyses and graphical representations generated using MATLAB are presented. These include:

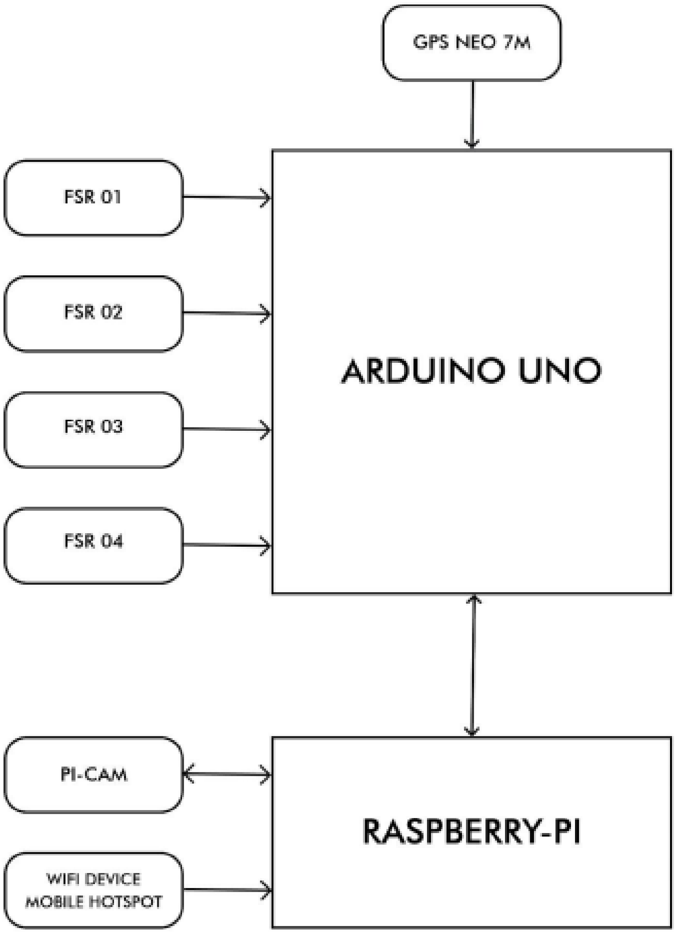

Figure 2: Flows

5.1 The Output1 Received on Email

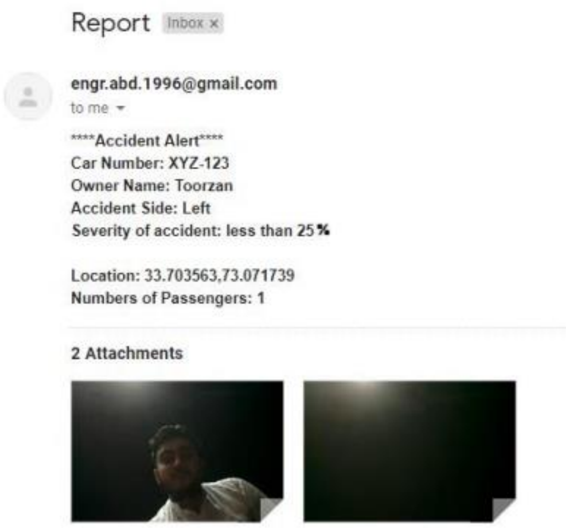

Figure 3 output 1

5.2 *Output Received on Google Map*

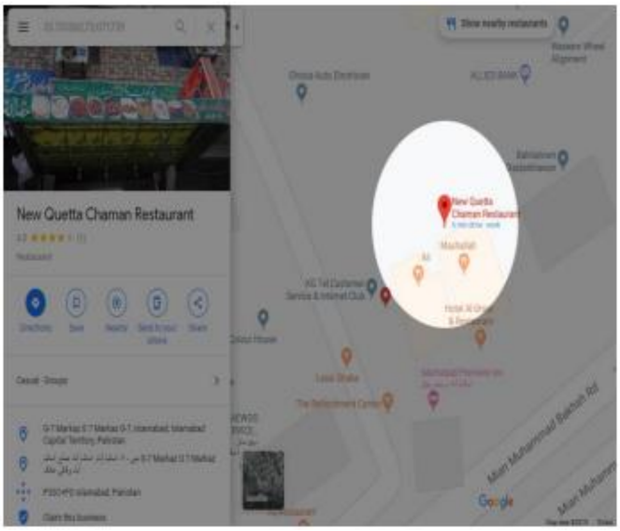

Figure 4 Location of the accident spot

5.3 Output Received on Google Map

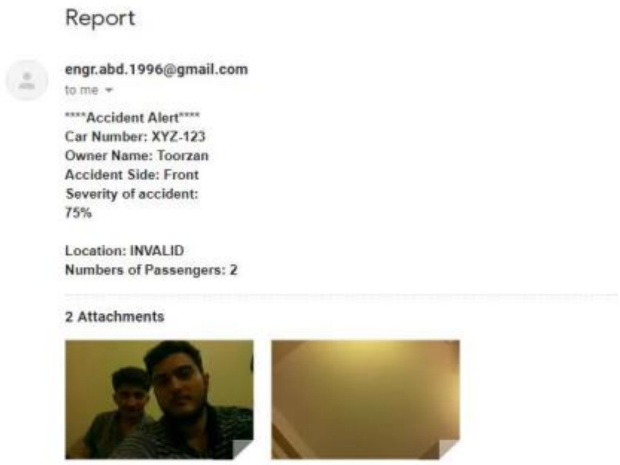

Figure 5 output2

5.4 Analysis of MATLAB Simulation Results

The findings are detailed through a series of comprehensive graphs generated using MATLAB. These graphical displays provide an extensive visual overview of the system's functionality and effectiveness. Each aspect of the system is analyzed in depth, with various graphical representations illustrating their practical implications. This collection of informative graphics underscores the robustness of the methodology and offers a thorough understanding of the advancements achieved in enhancing road safety. The following table 5.1 summarizes the key parameters used in the MATLAB simulations:

Table 2 Simulation parameters

Parameter	**Description**
Latitude actual	Array of actual latitude values for accident locations (e.g., [34.0522, 40.7128])
Longitude actual	Array of actual longitude values for accident locations (e.g., [-118.2437, -74.0060])
Latitude detected	Array of detected latitude values for accident locations (e.g., [34.0525, 40.7130])
Longitude detected	Array of detected longitude values for accident locations (e.g., [-118.2430, -74.0055])
Case labels	Labels for different accident cases (e.g., {'Case 1', 'Case 2'})
Email results	Array of detection accuracy percentages for each case (e.g., [100, 100, 100])
Time days	Array of time points for crash detection rates (e.g., [1, 2, 3, ...])
Detection rate	Array of crash detection rates (e.g., [72, 85, 92])
Highlight indices	Indices of points to highlight in the plot (e.g., [4, 6])
Impact Force	Array of impact force values (e.g., [150, 300, 450])
severity	Array of severity assessment values (e.g., [20, 40, 60])
Threshold High	Threshold value for high severity (e.g., 75)
Threshold Medium	Threshold value for medium severity (e.g., 50)
Actual Passengers	Array of actual number of passengers (e.g., [4, 3, 2])
Detected Passengers	Array of detected number of passengers (e.g., [4, 2, 3])
Response Times	Array of response times in seconds for email alerts (e.g., [10, 15, 8])
System Features	Names of system features (e.g., {'Crash Detection', 'Location Accuracy', 'Severity Assessment'})

5.4.1 Rate of Crash Detection Over Time

Figure 5.4.1 displays the dependability of system's crash detection ability over a predetermined time period. The x-axis of the graph represents time periods, such as days or weeks, while the y-axis displays the corresponding proportion of observed crashes. The consistency of this system's performance and its quick responsiveness to spotting incidents as they happen are highlighted by this graphic portrayal.

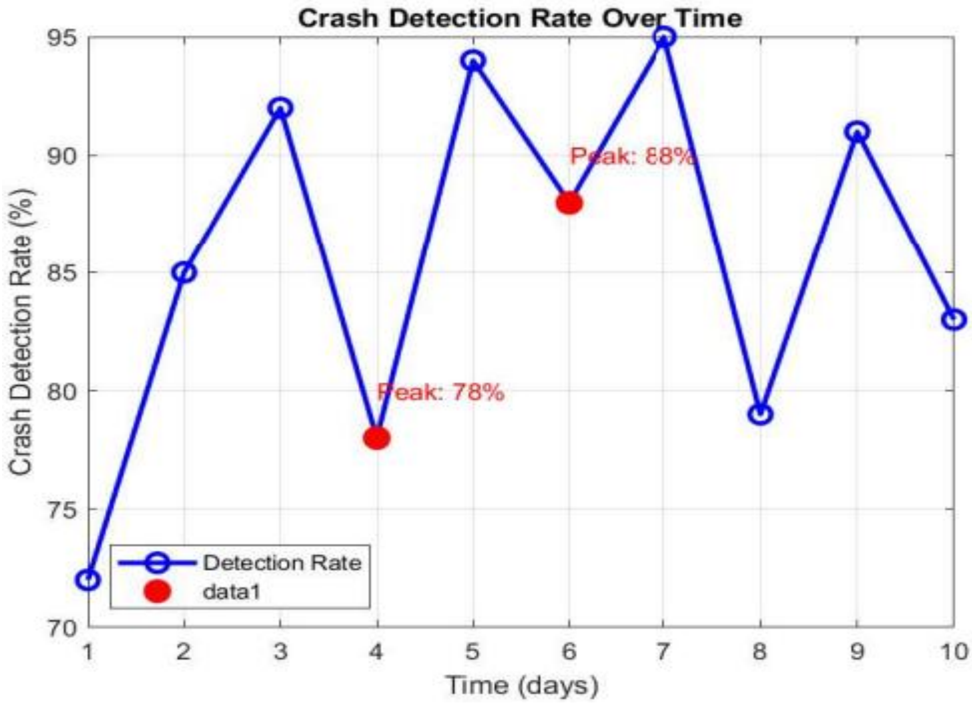

Figure 6 Detection rate

5.4.2 Impact in Comparison to Severity

A scatter plot showing the relationship between impact force and the seriousness of observed collisions is shown in Figure 5.4.2. Each data point on the plot represents a crash that has been discovered; its location plots impact force along the x-axis and severity evaluation along the y-axis. This graphic representation helps to comprehend probable outcomes under various impact scenarios by illuminating the link between impact force levels and the severity of accidents.

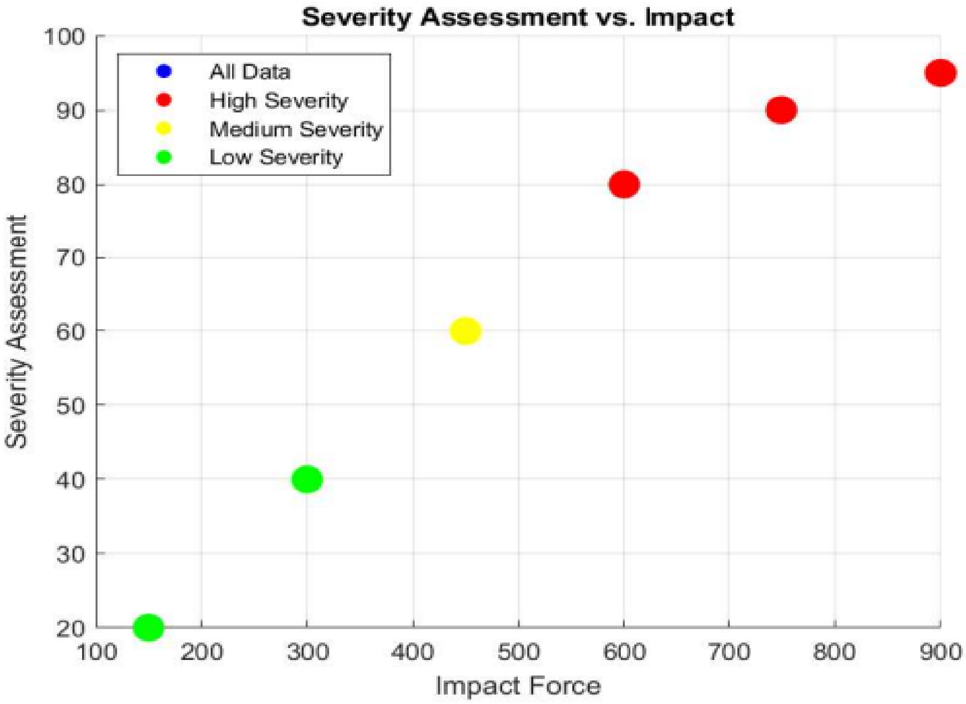

Figure 7 Severity Impact

5.4.3 Accuracy of Location

The accuracy of system's GPS data extraction is highlighted by a map visualization in Figure 5.4.3. The map shows red 'X' markings for system's identified sites and blue dots for real accident locations. It's crucial to remember that each pair of these marks refers to the exact same accident incident. You could see some overlap from time to time between the blue and red marks. This incident happens as a result of the intrinsic limits of GPS technology and other elements, which might cause slight fluctuations in coordinate precision. Consequently, while some identified red markers roughly coincide with genuine blue markers, exact overlap is not always attained. The degree of precision that technology achieves in locating accident locations is vital information that may be gained from this visual depiction.

5.4.4 Email Response Time

The "Email Response Time" in the Figure 5.4.4 graph illustrates how quickly the system can send email notifications to the response Centre once an accident is detected. The graph's bars represent individual accident cases, and the height of each bar represents the time in seconds it took for the system to send the warning for that accident instance. Faster response times are shown by shorter bars, whereas slightly delayed answers are indicated by longer bars. This graph offers important insights into the response time variance across several accident scenarios and gives a clear picture of how well this system works at informing authorities quickly.

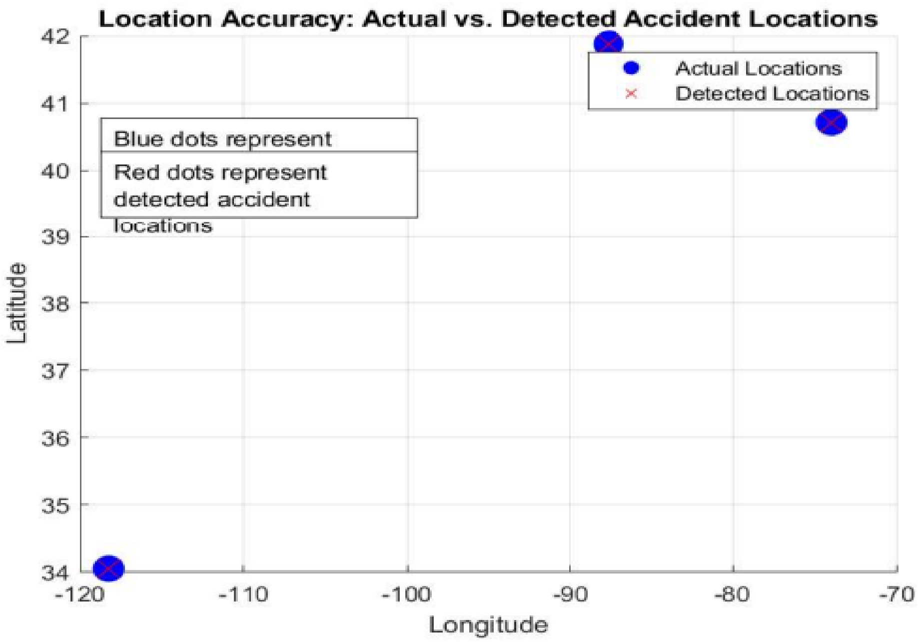

Figure 8 Accuracy of location

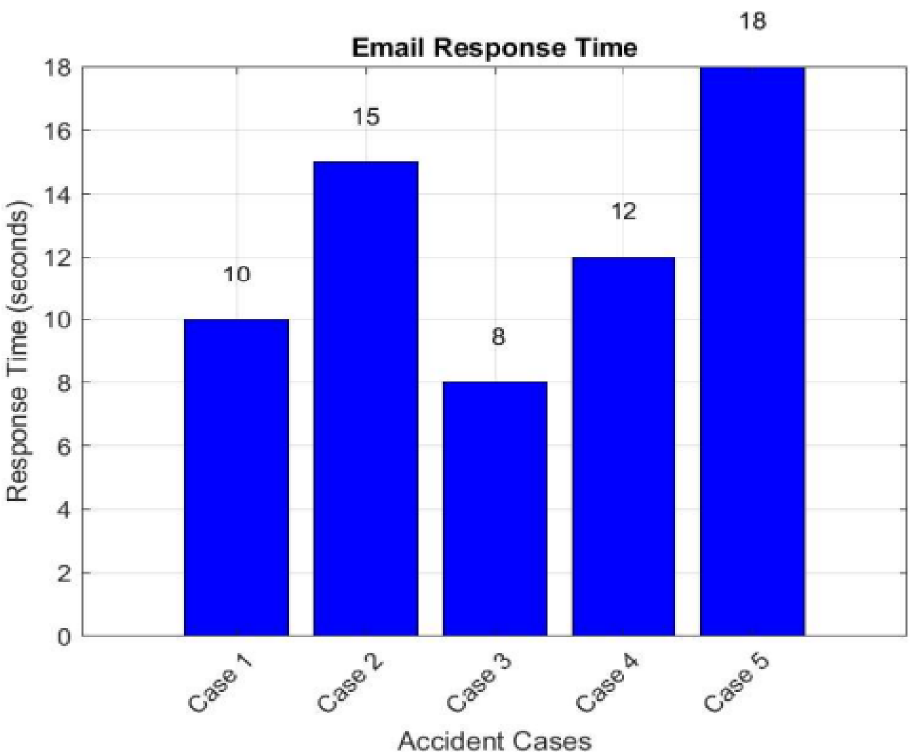

Figure 9 Email Response Time

6. Conclusion

This research demonstrates the potential of IoT technology in improving road safety through intelligent accident detection and reporting. By integrating sensors, image processing, and GPS into a cohesive system, the proposed solution enables faster and more informed emergency responses. The system's ability to accurately detect accidents and assess their severity has the potential to reduce accident-related fatalities significantly. However, challenges remain in terms of scalability and system robustness under different environmental conditions. Future research should explore these aspects and investigate the integration of advanced machine learning techniques to further improve detection accuracy and response times. The proposed system lays the groundwork for smarter, safer roads and more efficient emergency response infrastructures.

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