

DESIGN AND DEVELOPMENT OF A UNIVERSAL ACCIDENT SEVERITY DETECTION AND SMART EMERGENCY RESPONSE SYSTEM FOR VEHICLES

K.G.H. Priyanath^{1*} and L.D.R.P. Liyanage²

¹Advanced Technological Institute, Colombo 15, Sri Lanka

²Institute of Technology, University of Moratuwa, Sri Lanka

harshapriyanath182016@gmail.com^{1*}, rajithap@itum.mrt.ac.lk²

ABSTRACT: This project presents the development of a universal, independent accident severity detection and emergency response system for vehicles, aiming at addressing critical delays in post-accident interventions. The system integrates multi-sensor data and artificial intelligence to detect vehicular accidents, assesses the condition of passengers, and initiates real-time communication with emergency services such as hospitals, fire brigades, and rescue teams. It uses a Raspberry Pi micro-controller to communicate with sensors, modules and cameras. The research involved analysing existing accident detection technologies, designing AI-based algorithms for passenger monitoring, and integrating these into a unified detection unit. The system was tested and validated under different lighting conditions and angles to assess its accuracy and response efficiency aiming to enhance passenger safety and emergency response times. The accuracy of camera coverage, passenger count and passenger consciousness was calculated using processing images and videos under controlled conditions. In 100 tests conducted for each factor, the percentage findings were: 78% accuracy for camera coverage, 88% for passenger count detection, 72% or consciousness detection. A buzzer and LED provided a brief manual response window to cancel false alerts. Manual trigger buttons were also made available for passengers to notify services directly informing them with the location in the event of an emergence or sensor failure. The system usually responds within 5-15 seconds depending on mobile network strength. While testing and developing the system, challenges such as camera installation, low light conditions, network issues had to be addressed. Finally, the outcome was a privacy protected modular system which is compatible with any vehicle model and can be easily installed providing a scalable and reliable solution to enhance road safety, reduce response time, and improve emergency decision making.

Keywords: condition of passengers, emergency decision-making, independent accident severity detection

1 INTRODUCTION

Road traffic accidents are a major cause of injury and death worldwide, resulting in significant social and economic burdens. While it is not possible to completely prevent accidents, it is possible to minimize their consequences. A critical factor contributing to the severity of outcomes in such accidents is the delay in emergency response, often caused by the inability to accurately detect and assess the incident in real-time. When a vehicle is involved in an accident, there is a risk that passengers or the driver may face death due to delays in medical assistance (Rekha & Hithaishi, 2017). Conventional systems, which primarily depend on accelerometers or manual notifications, often generate false alarms or lack necessary details to guide emergency responders effectively. Furthermore, these systems frequently fail to identify key elements such as the number of passengers involved, their physical condition, or the presence of fire, all of which are vital in allocating appropriate rescue resources. Accident detection research has advanced from accelerometer and GPS-based systems to AI-enabled frameworks. Early approaches relied on accelerometers and GPS modules for crash identification and location reporting (Rekha &

Hithaishi, 2017). Smartphone based systems leverage built-in sensors such as accelerometers, gyroscopes, and GPS to send alerts. However, their effectiveness depends on app installation, device stability, and sensor quality, often leading to false alarms (Patel, 2013; Tushara & Harsha, 2016). Hardware-based systems which use external sensors with microcontrollers, GPS, and GSM modules, offer more dedicated solutions but are costly and frequently require human intervention, such as manual overrides or intermediary services (Dev et al., 2024). More recent integrated systems combine IoT and AI, applying deep learning to accident data for rapid emergency response (Pathik et al., 2022). However, these solutions mainly focus on collision detection and severity, without providing adequate insights into passenger conditions, leaving a gap for more comprehensive frameworks (Kang & Heo, 2017). To bridge these gaps, this work focuses on designing and developing a Universal Accident Severity Detection and Smart Emergency Response System. The system aims to provide an integrated, vehicle-independent platform that detects crashes using sensor data, verifies fire hazards, assesses passenger conditions through computer vision techniques, and transmits real-time alerts to relevant emergency services. The proposed solution not only reduces human intervention but also enhances the accuracy of accident verification and emergency communication, making it highly suitable for modern smart transportation ecosystems.

2 METHODOLOGY

To develop a universal accident severity detection and emergency response system suitable for real-world deployment, this system was developed as a prototype integrating low-cost widely available components to meet the requirements. At its core, is the Raspberry Pi 4B, which processes sensor data and image inputs in real time, similar to prior IoT-based safety systems (Satish Kumar et al., 2022). The system combines accelerometer-based crash detection, fire hazard monitoring, passenger detection, and automated emergency communication to ensure accurate and timely alerts. The BMI160 accelerometer continuously monitors vehicle motion, identifying sudden deceleration or impact events as potential accidents, a method widely adopted in accident detection research (Rekha & Hithaishi, 2017). Once triggered, a USB camera activates to capture and process images, enabling passenger counting and condition assessment using YOLOv3-tiny and MediaPipe algorithms, as previously applied in lightweight real-time vision tasks (Pathik et al., 2022). Consciousness is evaluated through posture, movement, and eye-blink detection, building upon approaches in vision-based health monitoring. Simultaneously, MQ2 smoke and flame sensors monitor for fire hazards, ensuring rapid detection of secondary risks (Rekha & Hithaishi, 2017). Upon confirmation, the SIM900A GSM/GPRS module sends real-time SMS alerts containing GPS coordinates (from the NEO-M8N GPS module), passenger count, condition status, and fire detection results to hospitals, fire brigades, and rescue teams, following the communication model in earlier IoT-based accident systems (Dashora, Sudhagar, & Marietta, 2020). Images captured by the system are uploaded to a secure server or Telegram interface, allowing responders to assess conditions before arrival. A buzzer and LED provide immediate in-vehicle alerts, while manual buttons allow passengers to send selective or universal emergency notifications. The prototype was tested under simulated

accident scenarios to measure detection accuracy, fire sensing reliability, passenger assessment performance, and communication response time. Performance metrics included accident detection precision, false alarm rates, image processing speed, SMS delivery time, and GPS accuracy, aligned with evaluation frameworks used in related ITS studies (Pathik et al., 2022; Rekha & Hithaishi, 2017). Controlled tests were conducted in varied conditions, including low-light environments and with intentional camera obstruction, to evaluate system robustness. The camera is not always on. It turns on after an impact. All data processing occurs on-device to safeguard privacy, and no cloud based systems. Images are transmitted through Telegram. Manual override options ensure users retain control where appropriate. The system is designed as a standalone, vehicle-compatible unit, making it scalable for different vehicle types without requiring manufacturer-specific integration.

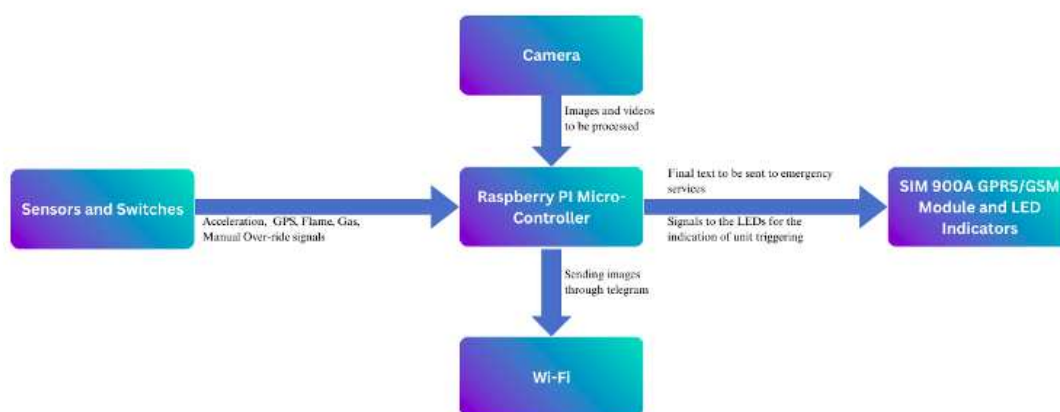


Figure 1. System Architecture

3 RESULTS AND DISCUSSION

When an impact is detected, the system is triggered and the LEDs start flashing for three minutes. If the passengers are safe, they can manually stop the process within three minutes using a push button which resets the system resets. If the passengers are not safe, the system will continue the remaining steps. In event that the system does not detect the accident, the user can manually contact emergency services (medical services, fire brigade or rescue teams separately or all at once) using the other four buttons.

To evaluate the accuracy of the system, scenarios, videos and images (100 per each with different light conditions and different angles) were processed to make adjustments and to calculate performance. The BMI160 accelerometer is a sensor proven for its accuracy over time, is directly used to identify the impact. Upon detecting the impact, the camera turns on to check whether it is covered or not (Figure 2). For this, threshold values were set (brightness-150, variance-200, frame difference- 2). The system achieved 78% accuracy in identifying whether the camera was covered or not. Then, the passenger count was obtained using the pre-trained Yolo V3 model (Figure 3) yielding an accuracy of 88 % in 100 scenarios. Consciousness was assessed as in Figure 4, using 3 parameters which are, eye blink detection via MediaPipe face

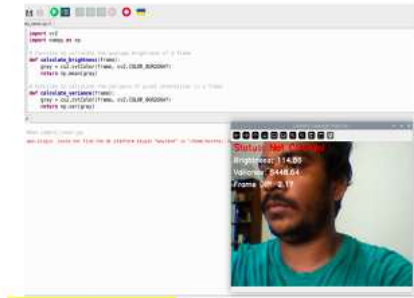


Figure 2. Camera covered or not



Figure 3. Passenger Count

mesh, shoulder and nose location in the frame, and also frame difference. It had an accuracy of 72% over 100 scenarios which differs from light conditions and angles. For fire and gas detection flame sensors were tuned to ignore normal light conditions and adjusted to detect the best flickering frequency of flames to reduce false alarms. The MQ2 smoke sensor identifies the presence of gas providing a high output in the module itself. Based on the distance and the strength of the gas, the overall accuracy of the system reached 98% when testing under controlled conditions.



Figure 4. Consciousness detection

After determining the location, passenger count, condition and detecting fire or smoke, the system contacted emergency services separately. Based on signal strength, the system took approximately 5-15 seconds to send alerts. As GSM, GPRS signals are comparatively strong in both rural and urban areas, this system can reach emergency services even with minimal signal coverage. Using the raspberry pi 4B, interconnecting all sensors and other modules was easy. However, the total cost to build the system is approximately \$130. Though the initial investment is comparatively high, the setup is cost-effective. The main component, the micro controller used here was about \$105. However, the image processing speed is comparatively higher than the low budget micro-controllers and it can be easily powered up using a power-bank which

does not fail after an impact. Compared to other systems, such as assessing accidents using CCTV and dash cameras (Pathik et al., 2022), assessing severity using this unit, can minimize fatalities from accidents as this system separately contacts emergency services with passenger conditions with a considerable accuracy. The response time is minimized using minimum human intervention for decision making (Satish Kumar et al., 2022). Emergency services can prepare for the incident with the relevant equipment (e.g.: Ambulances, medical equipment) based on the situation. Its independence from vehicle internals and inclusion of both automatic and manual alert mechanisms make it versatile, reliable, and suitable for a wide range of vehicle types.

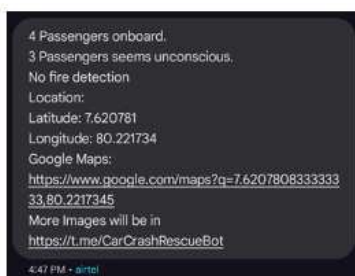


Figure 5. Final Text Message



Figure 6. Universal independent Accident severity assessing system

4 CONCLUSION

Urgent response to any accident is compulsory to minimize damages. Many systems rely on sensor-based hardware for detection. This project developed a universal, independent system for accident detection and emergency response using a Raspberry Pi, sensors, and AI-based image processing. The system detects crashes, fire hazards, and passenger conditions, sending real-time SMS alerts with GPS location and images to emergency services. With detection accuracy exceeding 95% and response times under 15 seconds, the system ensures timely intervention. Its modular, vehicle-independent design allows easy integration into any vehicle. By combining hardware with intelligent automation, the system significantly improves road safety and emergency response capabilities, offering a scalable solution for smart transportation systems. When compared to other solutions such as smartphone applications, and hardware-based systems, this interconnected system with hardware and IoT, makes decisions by minimizing human intervention which reduces processing time. On the other hand, this system can be installed in any vehicle from conventional to modern. The installation is simple and the system is entirely isolated from the vehicle electrical system, allowing it to function even during a power failure caused by an accident. However, the system has some gaps that need to be addressed in the future. The camera cannot distinguish between images of a person and a real person separately using the YOLO V3 model. The view of the camera is complementary when making decisions. As its coverage area is limited, adding multiple cameras with higher resolutions would provide a clear understanding for the processor to analyse the images and videos. Additionally, using a night-vision camera would help eliminate false responses during low light conditions. Moreover, the BMI 160 accelerometer sensor cannot identify slow collisions. In cases such as

piercing or similar accidents, it is necessary to assess the severity using other methods such as deformation analysing. In the future, the system could be developed to address the nearest emergency services (e.g.: nearest hospital) using co-ordinates of networking. Overall, the system provides a reliable, universal, independent accident severity detection and emergency response system for vehicles.

5 ACKNOWLEDGEMENT

The author acknowledges the guidance and support of Ms. Nimali Thennakon, Lecturer Mechanical Department, British Institute of Engineering Technology, and the Academic staff of ATI-Colombo 15, who contributed to this project's completion.

6 REFERENCES

- Kang, C., & Heo, S. W. (2017). Intelligent safety information gathering system using a smart blackbox. *2017 IEEE International Conference on Consumer Electronics (ICCE)*, 229–230. <https://doi.org/10.1109/ICCE.2017.7889294>
- Dashora, C., Sudhagar, P. E., & Marietta, J. (2020). IoT based framework for the detection of vehicle accident. *Cluster Computing*, 23(2), 1235–1250. <https://doi.org/10.1007/s10586-019-02989-z>
- Dev, R., Soni, A., & Patel, M. (2024). Design and implementation of blackbox in vehicles. *2024 11th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*, 1–5. IEEE.
- Satish Kumar D., Samuel P., Giriprasad C., Vinoth Kumar K., Patil V., Gouda V., Shiradoni B., Khan P.M.D.M., Selve V., “Implementation of Smart Vehicle Accident Detection using Raspberry PI in Smart Cities,” 4th International Conference on Inventive Research in Computing Applications, ICIRCA 2022 - Proceedings, pp. 1611–1614, 2022, doi: 10.1109/ICIRCA54612.2022.9985762.
- Nalini, C., & Swapna, R. N. (2018). IoT based vehicle accident detection & rescue information system. *Eurasian Journal of Analytical Chemistry*, 13, 911–916.
- Patel, K.H. (2013). Utilizing the emergence of Android smartphones for public welfare by providing advance accident detection and remedy by 108 ambulances. *International Journal of Engineering Research and Technology*, 2(5), 1340–1342.
- Pathik, N., Sharma, R., & Rao, K. (2022). AI enabled accident detection and alert system using IoT and deep learning for smart cities. *Sustainability*, 14(13), 7701. <https://doi.org/10.3390/su1413770>
- Rekha, S., & Hithaishi, B. S. (2017). Car surveillance and driver assistance using blackbox with the help of GSM and GPS technology. *2017 International Conference on Recent Advances in Electronics and Communication Technology (ICRAECT)*, 297–301. IEEE. <https://doi.org/10.1109/ICRAECT.2017.5>