LEVERAGING IOT AND COMPUTER VISION FOR ACCIDENT DETECTION AND REAL-TIME EMERGENCY RESPONSE OPTIMIZATION FOR MUNICIPALITY OF IMUS

Undergraduate Thesis
Submitted to the Faculty of the
Department of Computer Studies
Cavite State University - Imus Campus
City of Imus, Cavite

In partial fulfillment
of the requirements for the degree
Bachelor of Science in Computer Science

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January 2025

CHAPTER 1

INTRODUCTION

Background of the Study

In recent years, the integration of Internet of Things (IoT) and computer vision technologies has revolutionized urban safety and emergency response systems. The uncontrollable growth of road accidents and increasing urban population have emphasized the critical need for smart solutions in emergency management (Li et al., 2024). In the Philippines, particularly in developing cities like Imus, Cavite, traffic accidents remain a significant public health and safety concern, with delayed emergency response times contributing to increased fatality rates.

The concept of smart cities has evolved to incorporate real-time monitoring and response systems, where IoT sensors and computer vision algorithms work together to detect and respond to emergency situations (Anwar et al., 2023). IoT technology is revolutionizing vehicle safety by enabling automatic accident detection and rapid rescue responses. This innovative system takes advantage of interconnected devices to quickly identify and respond to road incidents, potentially reducing fatalities and mitigating accident impacts (HashStudioz, 2023). Computer vision technologies, particularly deep learning models, have demonstrated remarkable accuracy in identifying traffic accidents through surveillance footage, with success rates exceeding 95% in controlled environments (Branch-Bedoya et al., 2021).

In the context of Imus Municipality, the increasing urbanization and vehicle density have created unique challenges for emergency response teams. Traditional emergency response systems, which rely heavily on human reporting and manual dispatch, often result in delayed response times and inefficient resource allocation. The implementation of IoT-based sensors throughout the city's major intersections, coupled with advanced computer vision algorithms, presents a promising solution to these challenges (Angus et al., 2022).

Recent studies have shown that integrated IoT and computer vision systems can not only detect accidents but also predict potential high-risk scenarios through pattern recognition and machine learning algorithms. A pilot project in India demonstrated a significant reduction in emergency response times after implementing such a system. The system used IoT devices to detect accidents and automatically alert emergency services, which helped save lives by minimizing delays in rescue operations (Baz et al., 2022). These systems can analyze various restrictions such as traffic flow patterns, weather conditions, and historical accident data to optimize emergency response routes and resource allocation (Abdel-Hamid et al., 2023).

The success of similar implementations in developing cities has demonstrated the feasibility and effectiveness of such systems. It sets the foundation for exploring how similar technologies can be adapted and implemented in Imus Municipality to enhance public safety and emergency response capabilities. The system aims to design, develop, and evaluate an integrated emergency response and public safety communication system for Imus Municipality that can use digital technologies to enhance real-time incident monitoring, rapid emergency coordination, and operational efficiency of local public safety departments.

Statement of the Problem

The study aimed to identify and solve specific questions related to the following factors:

1. Manual accident reporting causes significant delays in emergency response times, endangering lives due to the lack of automated detection systems.
2. Emergency teams lack real-time accident scene information and verification, preventing proper resource allocation before arrival.
3. Absence of data-driven decision-making to automate accident detection for real-time emergency response.

Objectives of the Study

The primary objective of this study is to develop a system that leverages IoT and computer vision to enhance accident detection and real-time emergency response optimization for the Municipality of Imus. The study aims to achieve the following specific objectives:

1. To enhance emergency response processes by providing timely and accurate accident information to first responders and relevant authorities.
2. To establish a scalable framework that can be implemented to support new technological advancements in the city.
3. To design, develop, and implement an automated system to quickly notify the local government unit’s emergency response team when an accident is detected.

Time and Place of the Study

The study started in November 2024 until present at Cavite State University - Imus Campus located at Land Transportation Office (LTO) Compound at Emilio Aguinaldo Highway, Imus City, Cavite. The concept of the study was formulated through a series of brainstorming activities, and the researchers started to gather relevant studies and literature by searching online and at the university library.

Scope and Limitation of the Study

The study develops a system for improving accident detection and more effective real-time emergency response in Imus City by utilizing IoT and computer vision technology. This includes integrating IoT devices such as sensors (sound and speed radar) and Closed-Circuit Television (CCTV) cameras for real-time monitoring and data gathering as well as analysis using computer vision algorithms on video feeds for accurate accident detection. The system will initially cover some strategic areas in Imus City, especially major intersections, highways, and accident-prone ones. Thus, its features would include automatic identification of vehicle type (bicycle, motorcycle, tricycle, e-bike, jeepney, van, bus, truck, private vehicle car), real-time notification alerts to relevant authorities and machine learning to reduce response times. Videos of accidents will be sourced online to be used for testing, training, and validation.

The research, however, has a number of limitations. The effectiveness of the system relies heavily on the availability and reliability of existing infrastructure like internet connectivity, power supply, and road surveillance equipment. There are also constraints concerning technology, like how much the current computer vision models can detect accidents, especially for those that are rather complex or ambiguous. Environmental conditions may also have an effect. Current geographical coverage remains confined to a localized area because a city-wide implementation will need additional resources and upgrades.

Also, compliance with data privacy laws such as that of the Philippine Data Privacy Act could spell possible restrictions on data gathering and sharing. Success also hinges upon the data on the level of readiness and cooperation of emergency services, where manual inefficiencies could stand in the way of efficiency goals. Finally, funding availability will influence the project's scale, particularly for the acquisition and maintenance of IoT devices and software development.

Definition of Terms

The following terms defined were used in this study:

AIoT (Artificial Intelligence of Things) - The integration of artificial intelligence capabilities into IoT devices, enabling them to analyze data and make autonomous decisions.

Computer Vision - A field of AI that enables computers to understand and process visual information from digital images or videos.

DeepSORT - A tracking algorithm that follows multiple objects across video frames while maintaining their unique identities using deep learning features.

Geographic Information System (GIS) - A computer system that captures, stores, analyzes, and displays geographic data to understand spatial patterns and relationships.

Internet of Emergency Services - A specialized IoT system that connects emergency responders, services, and management systems to improve emergency response coordination and efficiency.

IoT (Internet of Things) - A network of physical devices embedded with sensors and software that connect and share data with other devices over the Internet.

LiFi (Light Fidelity) - A wireless communication technology that uses LED light to transmit data between devices, similar to WiFi but using light waves instead of radio waves.

Machine Learning - It is a subdomain of artificial intelligence (AI) which continuously improves based on the data that it consumes and it will be used to make the deciphering process more efficient.

ResNet/InceptionResNet - Deep learning architectures designed for image recognition that use skip connections (ResNet) and multi-scale processing (Inception) to improve accuracy in computer vision tasks.

YOLO (You Only Look Once) - A family of deep learning models for real-time object detection that processes images in a single pass to identify and locate multiple objects simultaneously, known for its speed and accuracy.

Theoretical Framework of the Study

The combination of Internet of Things (IoT) and computer vision technologies presents a valuable opportunity for improving accident detection and accelerating emergency response times. In the Municipality of Imus, the swift growth of urban areas and rising vehicle traffic require creative strategies to guarantee public safety and effective emergency services. This framework seeks to utilize these technologies to establish a strong system that can identify accidents in real-time and manage efficient emergency responses.

The Internet of Things (IoT) encompasses the connectivity of tangible devices like sensors and cameras via the Internet, allowing them to gather and share data. This technology plays a vital role in providing real-time monitoring and data gathering across different settings, delivering ongoing surveillance and swift alerts that can greatly minimize reaction times during emergencies. Computer vision allows machines to understand and make decisions based on visual information from their surroundings. By implementing computer vision algorithms, the system can effectively recognize accidents, assess traffic flows, and identify irregularities, thereby improving the precision and dependability of accident detection and facilitating quick and suitable reactions.

Real-time data processing is crucial for making timely decisions and responses. This requires the use of algorithms and computational models to assess data as it is gathered, ensuring that emergency services are promptly alerted to incidents and enabling quick deployment and coordination. Developments in computing power and data analytics are pivotal in efficiently managing large amounts of data. Optimizing emergency response involves the tactical planning and allocation of resources to guarantee the fastest and most effective reaction to emergencies. By incorporating real-time data from IoT devices and computer vision technologies, emergency response teams can enhance their operations, leading to reduced response times and better overall effectiveness in managing emergencies.

The proposed framework for utilizing IoT and computer vision consists of several crucial elements. Accident detection employs IoT devices like cameras and sensors to continuously monitor roadways and identify accidents in real-time.

Computer vision techniques examine visual data to accurately recognize accident scenes. Data transmission involves implementing secure and efficient systems to communicate accident details to emergency response teams, utilizing wireless communication technologies and cloud computing to safeguard sensitive information and ensure dependable communication channels. Emergency response coordination establishes a centralized system to manage responses, leveraging real-time data to enhance the dispatch of emergency vehicles and efficiently allocate resources. Ongoing evaluation and enhancement of the system guarantee its effectiveness and relevance, with regular reviews and updates to integrate the latest technological innovations and best practices.

CHAPTER 2

REVIEW OF RELATED LITERATURE/STUDIES

This shows the related literature or studies for using IoT and computer vision in detecting accidents in Imus City to explain and identify the methods and practices employed to build the proposed application.

A Real-Time Computer Vision-Based Approach to Detection and Classification of Traffic Incidents

Road accidents still remain a formidable public safety challenge in various nations, and advances in computer vision and artificial intelligence technology have been used to tackle such challenges. The investigation by Basheer Ahmed et al. (2023) into robust frameworks using computer vision techniques for traffic incident detection and classification focuses on a system that incorporates YOLOv5. It is a state-of-the-art object-detection algorithm, whereas DeepSORT does real-time vehicle tracking. Together, they achieve a high average mean precision (mAP) of 99.2% while recognizing and tracking vehicles from dynamic traffic environments. The paper also presents a severity classification model using YOLOv5 for estimating the seriousness of accidents which achieves a mean average precision (mAP) of 83.3% in such evaluations. A fire post-collision detection model was developed with the ResNet152 algorithm with a successfully achieved efficacy of 98.9%. The models are presented as a complete framework aimed at reducing the response time and improving emergency management systems by using parallel computing techniques.

This study is thematically reviewed to point out the emphasis on real-time processing and computer vision for incident detection, as well as fully automated notifying systems. The framework includes five phases: vehicle detection, accident severity classification, fire detection, alert generation, and model integration. With this scheme, any incident could be detected on time, classified correctly, and reported promptly to the appropriate emergency services. Advanced algorithms such as

YOLOv5 for object detection and ResNet152 for fire detection have been used showing that the study focuses on high accuracy as well as reliability. In addition, the parallel computing architecture allows the system to operate in real time with minimal delays in the emergency response.

However, it is also noteworthy to mention some limitations of the study. The study is mainly directed toward large city smart infrastructures ignoring the smaller municipalities like Imus. It does not discuss the very unique challenges posed by mixed traffic conditions typical to most smaller municipalities, which include the different road users like tricycles and public utility vehicles, less other road users like pedestrians. Although the study relies on existing CCTV infrastructure for accident detection, it lacks integration into IoT sensors to enable real-time data collection for enhanced accuracy. Furthermore, the reliance on state-of-the-art computing hardware, such as parallel processing, is likely to inhibit scalability under resource-constrained conditions.

All this makes a way towards calling for a more localized and adaptable approach. The proposed title is aimed at targeting this. The proposed system will leverage the existing CCTV infrastructure of Imus and equip it with computer vision algorithms that can detect accident events and determine appropriate emergency responses that would trigger an ambulance or fire truck deployment. Unlike this study, the proposed system shall be scalable, economical, and customized to the local traffic pattern for this feasible solution for Imus. The addition of IoT sensors and predictive analytics would also allow further enhancement in accident detection abilities and, wherever possible, allow proactive safety measures for this localized approach.

AcciSense – A Real-Time Accident Detection and Emergency Response System

The AcciSense has been carried out by Shah et al. (2024) as a solution in highway accident management. The system is used to detect highway accidents in real time by YOLO-based machine learning simply through high-end hardware such as radar sensors, LiDAR, and high-resolution cameras. It also uses data-driven decision-making tools that rely on location tracking through GPS for more accurate and immediate emergency response. What makes this system stand out is its automatic emergency response system, which instantly dispatches an ambulance and notifies a hospital. It would address the gap between the detection of accidents and medical assistance, revolutionizing how accidents will be responded to on the highways.

Although AcciSense provides an incredible technology framework, its dependence on costly hardware may raise challenges in scaling up and cost, especially in low-budget municipalities. The application of integrated IoT and machine learning indeed presents an innovative idea in the research field and will serve as a benchmark for developing accident detection systems for urban and suburban environments, such as Imus. It clearly showed how real-time data analysis optimizes emergency response and can save lives.

From Sensors to Safety: Internet of Emergency Services (IoES) for Emergency Response and Disaster Management

How emergencies are defined and managed has been redefined by including IoT devices at the heart of action. The study by Damaševičius et al. (2023) investigates the Internet of Emergency Services (IoES), a framework for improving emergency responses through real-time data collection and analysis involved in IoT-enabled coordination of emergency services. Based on the application of sensors, it monitors the condition of the environment and infrastructure, and uses communication networks for data transmission, while the latter is used for the purposes of process and decision-making by all units involved. This comprehensive approach aims to enhance public safety by enabling rapid responses and minimizing the impacts of emergencies. Some of the main contributions include a taxonomy of IoES components like devices, communication protocols, and data analytics frameworks, which emphasize their joint contribution to the improvement of emergency services.

This research depicts how IoES adopts different types of technologies for emergencies such as using Internet-of-Things Sensors for real-time updates on environmental hazards while Geographic Information System (GIS) is being used to complement the amount of spatial data visualization for responders. Other features include low-latency data processing through edge computing and the use of machine learning models for predicting emergency purposes. While the importance of all these technologies is well underscored by the study, they concern general large-scale applications more than site-specific applications.

The research thus demonstrates significant strength in deriving modular-scalable IoES frameworks, while its major limitations are also evident. While the implementation of IoT and GIS multiplies situational awareness, the study does not dwell much on certain computer vision methods for analyzing visual data, including accident and fire detection. Likewise, it does not suggest an established framework for the real-time classification of accidents and automated dispatching of emergencies, thereby creating a gap in its immediate applicability. Additionally, it could be depicted that the framework fails to address localized contexts concerning its application, given its reliance upon the general. Such as these in Imus-by particular reference to the traffic patterns, the areas where accidents frequently occur, and the challenges posed by the low resources of the municipality. Most importantly, this study needs to validate its data collection through an empirical approach in a real-world scene to prove the tool's effectiveness.

These gaps are significant in understanding the proposed thesis. The computer vision algorithms will be combined with the existing CCTV infrastructure of the municipality to detect accidents and automate emergency response processes. Part of this localized section enables the address of unique traffic conditions, such as tricycles and pedestrians. In addition, the proposed critical IoT sensors and predictive analytics for proactive interventions may fill a lot of the missing specifications with the IoES framework. Empirical validation through real-world testing in Imus ensures the system's practicality and reliability, thus establishing a scalable and adaptable model for other municipalities.

AI Enabled Accident Detection and Alert System Using IoT and Deep Learning for Smart Cities

The integration of IoT with deep learning in accident detection systems has proven useful for improving transportation safety, especially in urban environments. The system Pathik et al., (2022) developed combines IoT devices such as Raspberry Pi and deep learning models like ResNet, and InceptionResNetV2 to identify accidents in real-time. The system's sensors measure impact force, location, and speed; data is then transmitted to a cloud-based platform where AI models can validate the occurrence of accidents. The validated information on accident occurrence sends alerts to emergency services, ensuring faster response time. Their system recorded an accuracy of 98%, signifying the promising nature of AI and IoT in building responsive safety frameworks. Indicating the capacity of data-driven technology to cut down fatalities from accidents by minimizing the time taken for emergency response. However, the methodology of the study is heavily based on sensors and devices such as Raspberry Pi that are installed in every vehicle which would have a problem in terms of building costs and adoption, especially among older vehicles with no match on recent technological compatibility.

Another shortcoming of the system is that it would not work well in a severe crash situation since sensors and cameras mounted inside the vehicle will most likely get damaged and would result in delayed response or incomplete accident detection.

Furthermore, privacy issues arise as the system continuously follows the automobile and processes sensitive data. Moreover, data analysis is done through cloud computing which adds to the problem of possible latencies experienced in areas with inconsistent internet connectivity, thus preventing the timely response to emergencies.

Challenges related to cost adoption, system vulnerability during severe accidents, and privacy concerns are issues that the study "Leveraging IoT and Computer Vision for Accident Detection and Real-Time Emergency Response Optimization for the Municipality of Imus" aims to overcome. The use of existing CCTV infrastructure already owned by the municipality enables such a solution to reduce costs, alleviate privacy concerns, and make use of existing resources to improve emergency response efficiencies, which is theoretically practical and scalable for applications specific to Imus.

Artificial Intelligence of Things for Smart Cities: Advanced Solutions for Enhancing Transportation Safety

Accident detection and safety measures in transportation are made possible through IoT and AI. The study by Jagatheesaperumal et al. (2024) suggested an AIoT-based infrastructure for transportation safety enhancement through smart city mechanisms where ultrasonic sensors for avoiding obstacles or other vehicles on the road, eye-blink sensors to watch the driver ensure proper alertness and prevent accidents resulting from drowsy driving, alcohol sensors for measuring the extent of alcohol breath, and Li-Fi technology for faster inter-vehicle communication are integrated. This significantly encourages the use of sensor technologies embedded in vehicles for continuous monitoring by the system of driver behaviors and environmental conditions, so that a responsive system of accident detection could be adopted. Even though their study dwells much on vehicle-based solutions, much consideration has always left great potential in infrastructure-based solutions, which would include roadside cameras to detect accidents and monitor hazardous conditions.

Real-time accident detection is possible with embedded sensors, however, their entire study is based on vehicle-mounted technology that is probably not applicable to older automobiles or in areas with less technological adoption. Further, the study puts emphasis on the IoT sensor networks or data-driven systems, unlike computer vision methodologies, which analyze a video feed for real-time processing. It limits its application to environments where such analysis could have optimized traffic monitoring and accident detection. Although this study concentrates on accident detection, it doesn't cut across predictive analytics for accident prevention or real-time emergency response systems for efficient dispatching.

The proposed thesis precisely addresses these gaps and opportunities by utilizing existing CCTV infrastructure to process video feeds through computer vision algorithms. It aims to make it independent of vehicle-mounted sensors and to create infrastructure-based cost-effective and scalable systems tailored to local traffic conditions. These are mixed-use roads with tricycles, public vehicles, and pedestrians, ensuring context-sensitive technology application. An emergency response system with predictive analytics makes transportation safety proactive compared to former measures, which were reactive approaches.

REFERENCES

Abdel-Hamid, Y., Hefny, H. A., & Sayed, A. (2023). Artificial intelligence-based traffic flow prediction: a comprehensive review. Journal of Electrical Systems and Information Technology, 10(13), 13. Retrieved from https://jesit.springeropen.com/articles/10.1186/s43067-023-00081-6

Ahmed, M. I. B., Zaghdoud, R., Ahmed, M. S., Sendi, R., Alsharif, S., Alabdulkarim, J., Albin Saad, B. A., Alsabt, R., Rahman, A., & Krishnasamy, G. (2023). A real-time computer vision-based approach to detection and classification of traffic incidents. Big Data and Cognitive Computing, 7(1), 22. Retrieved from https://doi.org/10.3390/bdcc7010022

Angus, A., Duan, Z., Kostić, Z., Raychaudhuri, D., Seskar, I., Yang, Z., & Zussman, G. (2022). Smart City Intersections: Intelligence Nodes for Future Metropolises. Columbia University, Rensselaer Polytechnic Institute, and Winlab, Rutgers. Retrieved from https://arxiv.org/pdf/2205.01686

Anwar, S. M., Li, J., Mahmood, T., Nadeem, L., Rehman, A., Saba, T., & Ullah, A. (2023). Smart cities: The role of Internet of Things and machine learning in realizing a data-centric smart environment. Complex & Intelligent Systems, 10(4), 1607-1637. Retrieved from https://link.springer.com/article/10.1007/s40747-023-01175-4

Baz, M., Gupta, R. K., Masud, M., Pathik, N., Sahu, Y., & Sharma, A. (2022). AI Enabled Accident Detection and Alert System Using IoT and Deep Learning for Smart Cities. Sustainability, 14(13), 7701. Retrieved from https://www.mdpi.com/2071-1050/14/13/7701

Branch-Bedoya, J., Robles-Serrano, S., & Sanchez-Torres, G. (2021). Automatic Detection of Traffic Accidents from Video Using Deep Learning Techniques. Computers, 10(11), 148. Retrieved from https://www.mdpi.com/2073-431X/10/11/148

Damaševičius, R., Bacanin, N., & Misra, S. (2023). From sensors to safety: Internet of emergency services (IoES) for emergency response and disaster management. Journal of Sensor and Actuator Networks, 12(3), 41. Retrieved from https://doi.org/10.3390/jsan12030041

HashStudioz. (2023). IoT Based Automatic Vehicle Accident Detection and Rescue System. Retrieved from https://hashstudioz.com/blog/iot-based-automatic-vehicle-accident-detection-and-rescue-system/

Jagatheesaperumal, S. K., Bibri, S. E., Huang, J., Rajapandian, J., & Parthiban, B. (2024). Artificial intelligence of things for smart cities: Advanced solutions for transportation safety. Computational Urban Science, 4(10). Retrieved from https://doi.org/10.1007/s43762-024-00120-6

Li, H., Nagel, J., Sun, L., & Yang, S. (2024). Convergence of AI and Urban Emergency Responses: Emerging Pathway toward Resilient and Equitable Communities. Applied Sciences, 14(17), 7949. Retrieved from https://doi.org/10.3390/app14177949

Pathik, N., Gupta, R. K., Sahu, Y., Sharma, A., Masud, M., & Baz, M. (2022). AI Enabled Accident Detection and Alert System Using IoT and Deep Learning for Smart Cities. Sustainability, 14(13), 7701. Retrieved from https://doi.org/10.3390/su14137701

Shah, Y., Patil, R., Shah, P., & Nemade, M. (2024). AcciSense – A Real-Time Accident Detection and Emergency Response System. International Journal of Computer Science and Mobile Computing, 13(5), 47-53. Retrieved from https://doi.org/10.47760/ijcsmc.2024.v13i05.004