

An IoT-Integrated Accident Detection and Emergency Alert System Using Deep Learning and Gesture Recognition

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ABSTRACT

Road accidents are a leading cause of death, and in order to lower the number of fatalities, immediate alertness and action are necessary. In order to provide real-time monitoring and emergency support, the research proposes an IoT-enabled AI-Based Accident Detection and Women Safety Monitoring System that combines deep learning, computer vision, and IoT communication technologies. The algorithm analysis motion patterns to automatically identify accidents and employs a YOLO-based object detection model to detect crashes. In order to recognize emergency signals and allow people to ask for assistance in emergency situations a gesture recognition module that uses hand sign detection is integrated. When an accident or gesture is detected, the system captures footage of the incident, uses Internet of Things modules to obtain GPS-based location information, and automatically notifies emergency services via SMS or email. An web interface is developed for recording and monitoring instances. Via efficient automated emergency response systems, research findings demonstrate high reliability and accuracy under a wide range of situations involving significantly reducing response times and enhancing road safety.

Keywords: Road safety, computer vision, YOLO, gesture recognition, deep learning, IoT, accident detection, and emergency alert systems

I. INTRODUCTION

Road accidents persist in to be one of the world's most prevalent causes of injuries and fatalities, raising major issues for transportation and public safety. Minimizing the severity of injuries and improving survival rates depend heavily on quick accident detection along with immediate communication with emergency services [1][13]. In addition to advanced sensor-based systems installed in roadside infrastructure, conventional accident detection approaches mostly rely on manual reporting by drivers, eyewitnesses, or traffic authorities [9][11]. Nevertheless, in complex traffic settings, these approaches frequently experience lower reliability, restricted coverage, high operating costs, and a delayed response [3][7]. Recent developments in computer vision and artificial intelligence (AI) have made possible the ability for developers to develop intelligent and computerized accident detection systems that can monitor and analyse data in real time [1][15]. Deep learning models, specifically Convolutional Neural Networks (CNNs), are used by AI-based systems for analysing visual data obtained from surveillance systems. When it comes to identifying cars, pedestrians, and unusual traffic incidents from video streams, object identification frameworks like YOLO have proven to be very effective. These systems may accurately

determine accidents without constant human supervision by analyzing motion patterns, object interactions, and collision scenarios [7][13].

Modern intelligent safety systems use additional technologies like gesture recognition, geolocation services, and automated alarm mechanisms in addition to accident detection. Through the use of frameworks such as MediaPipe, gesture recognition algorithms allow people in trouble to convey emergency messages using predefined hand gestures. Additionally, the system can pinpoint the exact location of an occurrence and translate it into a human-readable address according to the combination of reverse geocoding algorithms and the Global Positioning System (GPS). This information can be shared with emergency responders through communication channels such as Short Message Service (SMS) and email notifications [5][6][8].

AI-based accident detection systems offer several advantages over traditional methods, including real-time monitoring, improved detection accuracy, continuous large-scale surveillance, and faster emergency response. Additionally, these systems include data logging and analytics, which enable the identification of accident-prone areas and enhance traffic control strategies [2][7].

Encouraged by these developments, this study suggests an AI-driven accident detection system which integrates location-based services, computer vision, deep learning, and gesture recognition for highly efficient automated accident detection. In order to improve overall road safety and speed up reaction times, the proposed system seeks to detect accidents in real time, provide instant alerts, and give emergency personnel precise navigational data [12][13][14].

II. LITERATURE REVIEW

Alsayaydeh et al.'s low-cost Arduino/accelerometer–GPS–GSM devices provide a "vital lifeline" in early reaction by detecting severe impacts and sending SMS with GPS coordinates to emergency contacts and services [14]. Similar to this, Siri et al. employ a vibration sensor in conjunction with GSM/GPS to identify accidents and send location for quick rescue, particularly in faraway regions [8].

While pointing out issues with false positives, cybersecurity, resource consumption, and privacy, smartphone-based systems (Reddy et al.) use onboard sensors to automatically detect crashes, retrieve GPS, and call or SMS emergency numbers and contacts [4].

In order to determine the severity of an accident and notify friends and neighbouring medical facilities of its exact position, Gomathy et al. integrate an accelerometer and heartbeat sensor with GSM/GPS and an Android app [6].

An Internet of Things (IoT)-based smart accident detection server architecture is proposed by Babu et al. In-car sensors transmit speed, GPS, and accelerometer data via wireless networks; a central server uses machine learning (ML) to detect accidents and then notifies EMS, police, family, and even uses satellite links when cellular coverage is inadequate [7].

In order to achieve ~98% accuracy with ensemble transfer learning, Pathik et al. combine an IoT in-vehicle kit (force, pressure, g-force, speed, and position) with a cloud deep-learning model. Once the DL module verifies a collision, local hospitals, police, and mechanics are automatically contacted [15].

MEMS/vibration sensors operate in Bhaskar and Anitha's Raspberry-Pi-based system; when a threshold is exceeded, GPS data are read, and registered emergency contacts receive an SMS with accident details and precise position [3].

In order to lessen traffic and enhance public safety, Bandara et al. suggest a multi-modal urban safety system that makes use of CCTV, IoT-enabled drones, ML, and LoRa communication for real-time

accident detection, post-accident fire detection, criminal monitoring, and adaptive traffic-light regulation [5].

The deficiencies of current accident detection methods emphasize the need for a more intelligent and effective solution. The suggested solution combines deep learning and artificial intelligence methods for real-time accident detection and analysis in order to overcome these difficulties. To improve system response in emergency scenarios, it integrates gesture-based emergency signalling with object detection. To guarantee prompt communication with emergency services, the system also integrates location monitoring and automated alarm creation. The goals of this integrated approach are to increase overall traffic safety, decrease response times, and improve detection accuracy.

III. PROPOSED SYSTEM

The proposed system presents an AI-Based Accident Detection and Emergency Alert System that can autonomously detect accidents, monitor road surroundings in real time, and alert emergency services without the need for human interaction. To increase road safety and speed up response times in emergency situations, the system combines cutting-edge deep learning methods, computer vision, gesture recognition, and communication technologies [1], [8]. The system's workflow, which is depicted in Fig. 1, is made up of several interconnected modules that work together to efficiently and dependably carry out continuous monitoring, accident detection, location identification, and alert notification.

The system uses a deep learning model based on the YOLO (You Only Look Once) architecture for object detection, which is renowned for its quick and precise detection capabilities [1], [13]. The model creates bounding boxes around various vehicle types, such as cars, buses, trucks, and motorbikes, after processing each frame. The technology can effectively locate and identify items in intricate traffic situations according to this detecting method. In order to discover abnormal behaviours, recognized vehicles are also followed over successive frames and their motion patterns are analysed.

Analysing vehicle movement patterns, including speed, direction, and relative distance between vehicles, is a crucial function of the accident detection module. The system detects anomalous behaviours, such as unexpected accidents, violent interruptions or aberrant trajectories that would point to an accident, by continuously monitoring the above traits [3], [12]. When the system detects such an event, it records the timestamp of the occurrence, classifies it as a possible accident, and records the associated frame as evidence. This automated detection system guarantees quicker event identification and does away with the need for manual monitoring.

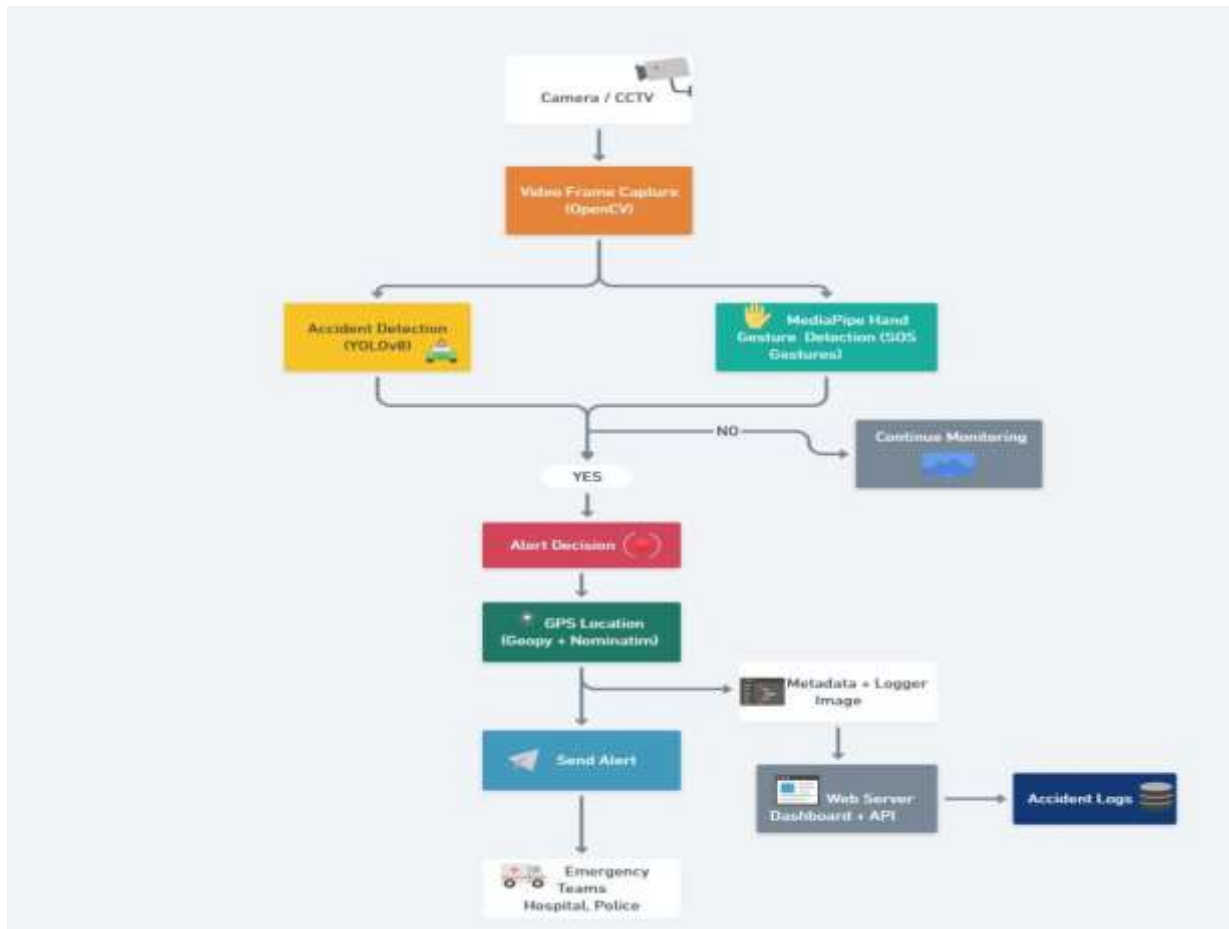


Fig.1 Workflow of the Proposed System

The system includes a gesture recognition module in addition to accident detection to improve personal safety, especially in situations of emergency where people might not be able to speak. MediaPipe, which identifies hand landmarks and examines the spatial relationships between finger joints to identify predetermined movements, is used to create this module [6], [14]. The system keeps an eye out for certain hand motions that are perceived as distress signals, such as an open palm, closed fist, or "V" sign. Even in the absence of a vehicles crash, the system adds an extra degree of security by activating an alert mechanism when it detects a legitimate gesture with enough confidence.

Additionally, as shown in Fig. 2, the suggested system incorporates an enhanced YOLO-based detection architecture that improves the standard model's performance [8], [15]. This design has cutting-edge elements including a Global Attention Mechanism (GAM) to enhance feature representation, C2f modules for effective feature propagation, and Spatial Pyramid Pooling Fast (SPPF) for multi-scale feature extraction. Additionally, information from many layers is combined using feature fusion techniques like concatenation and up sampling, which enhances detection accuracy in difficult situations including occlusion, uneven lighting, and crowded traffic areas.

When an accident or emergency gesture is detected, the system triggers the decision and alert module, which verifies the event before sending out notifications. The system then uses GPS-based services to retrieve the incident's geographical coordinates and uses Geopy and Nominatim reverse geocoding techniques to convert them into a human-readable address [4], [9]. In addition to location data, the system

takes a picture of the incident and logs the precise moment it occurred, making sure that all pertinent information is available for emergency response.

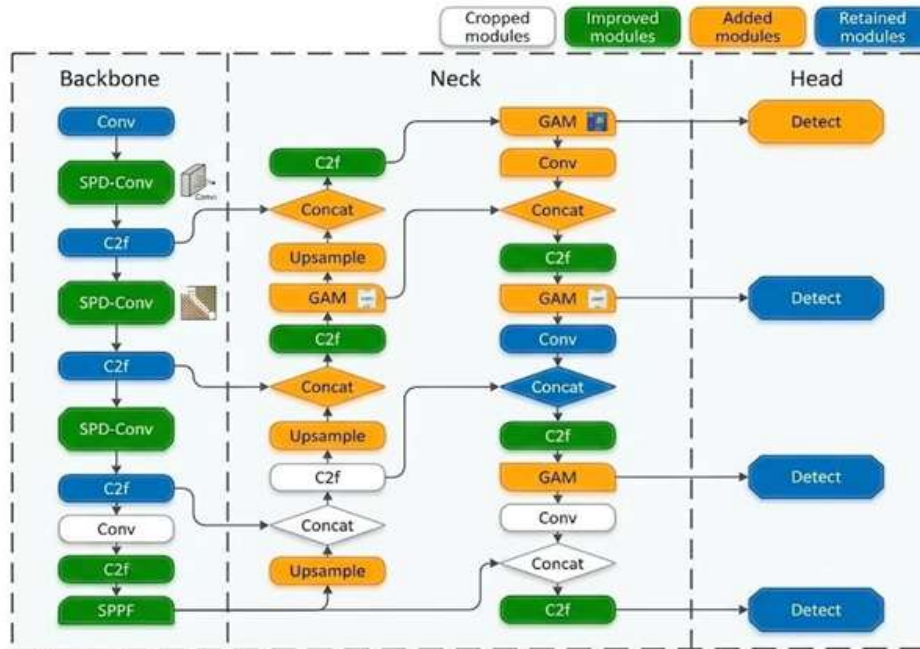


Fig. 2: Improved YOLO-Based Accident Detection Architecture

The system creates and transmits warnings to pre-specified contacts, such as hospitals, law enforcement, and emergency responders, after gathering the required data. Communication methods like email and SMS are used to send notifications, guaranteeing dependable and prompt delivery [2], [7]. Responders are able to promptly evaluate the issue and take necessary action since the alert message usually include the timing of the occurrence, location data with a map link, and the taken image.

The system has a web-based interface created with Flask to make data administration and monitoring easier. A real-time dashboard that shows identified occurrences, taken pictures, and matching geographical maps is provided by this interface. In order to facilitate future analysis, system assessment, and record maintenance, all detected events are kept in a centralized database [10], [11]. Additionally, system scalability and performance enhancement are supported by this data logging feature.

As seen in Fig. 3 the Architectural design of the proposed system starts with video acquisition and frame extraction, then moves on to vehicle recognition using the YOLO model and motion analysis for accident detection. Concurrently, the system uses MediaPipe to keep an eye out for emergency hand movements. The alert decision module is activated, location data is retrieved, alerts are generated, and event data is stored in the database when the system detects an accident or gesture. This automated, ongoing procedure guarantees effective monitoring and quick emergency action.



Fig. 3: Architectural design of the Proposed System

In conclusion, the suggested system creates an intelligent and automated accident detection framework by fusing artificial intelligence, deep learning, and communication technologies [1], [8]. The system offers a dependable and effective way to improve road safety and emergency response mechanisms by combining real-time object identification, gesture-based emergency signalling, and rapid warning generating.

IV. RESULTS AND DISCUSSION

Several specifications are used to evaluate the accuracy, efficiency, and dependability of the proposed AI-Based Accident Detection and Emergency Alert System in real-time settings [1], [12]. When evaluated on several traffic datasets with both normal and accident circumstances, the system shows good accident detection and gesture recognition skills.

One important metric for assessing system performance is accident detection accuracy. The suggested system detects automobiles and analyses their movement patterns using a deep learning model based on the YOLO architecture [13], [15]. The system detects anomalous occurrences including collisions, abrupt pauses, and aberrant motion trajectories by evaluating video frames in real time. The system achieves excellent detection accuracy, demonstrating its capacity to accurately differentiate between accident situations and typical traffic circumstances, according to experimental assessment. When compared to co-

ventional monitoring systems, deep learning greatly enhances detection performance. The efficiency of the gesture recognition module in recognizing emergency hand signals is also assessed. The system uses MediaPipe to identify hand landmarks and categorize motions according to pre-established patterns [6], [11]. According to experimental findings, the system operates consistently in a variety of settings, including variable illumination conditions, hand orientations, and motion speeds. Accurate gesture recognition and prompt alarm activation are made possible by the use of preprocessing methods, which further improves detection robustness.

The benefits of the suggested method are demonstrated by a comparison with conventional monitoring methods. Conventional solutions frequently have restricted scalability and delayed responses since they mostly rely on manual observation or simple sensor-based detection [3], [9]. On the other hand, the suggested solution uses deep learning and real-time video processing to automate emergency response and accident detection. It offers increased precision, quicker detection, and the capacity to keep an eye on several areas at once without constant human interaction.

The system has certain drawbacks despite its excellent performance. The accuracy of detection can be impacted by environmental variables such as occlusions, bad lighting, and bad weather. Furthermore, the system depends on reliable internet access to convey alerts and needs enough computing power for real-time processing [7], [12]. Nevertheless, these difficulties can be overcome with additional system improvements and optimization. The real-time accident detection interface of the suggested system is shown in Fig. 4, where accurate GPS-based position data is shown with discovered accident frames. The interface maps the accident site for simple identification and offers visual proof of the event. Authorities and consumers can rapidly comprehend the situation thanks to this real-time representation. The efficiency of emergency response is improved by the use of location tracking. The system has the capacity to dynamically monitor and present occurrences.



Fig. 4: Live Accident Detection System Interface with GPS Location

The accident log interface, where all identified accidents are methodically documented and archived, is seen in Fig. 5. For every mishap, the interface keeps track of photos, timestamps, and position information. Future analysis is supported and effective data management is made possible by this logging technique. It also aids in long-term system performance monitoring. The recorded data may be utilized to carry out more study and enhance detection models.

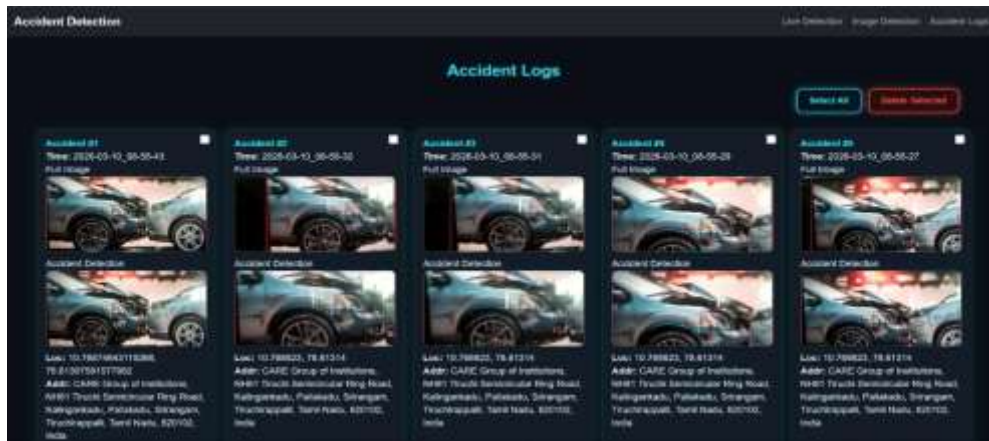


Fig. 5: Accident Detection Log Interface with Recorded Events

A thorough depiction of a detected accident, complete with mapped position data and visual evidence, is shown in Fig. 6. The interface offers a thorough depiction of the event, enabling viewers to assess the accident's severity and precise location. Emergency responders may make prompt, well-informed judgments with the help of this comprehensive depiction. Situational awareness is improved when location mapping and picture data are combined. Overall, the experimental findings show that the suggested system is effective, dependable, and capable of enhancing traffic safety through precise accident identification and prompt emergency alerts.



Fig.6: Detailed View of Detected Accident with Location Information

V. CONCLUSION

The suggested AI-Based Accident Detection and Women Safety Monitoring System offers a clever and automated way to improve emergency response systems and traffic safety. The system successfully detects accident occurrences and emergency circumstances in real time by using deep learning models like MediaPipe for gesture recognition and YOLO for vehicle identification [1], [8]. Incorporating location monitoring and automatic alert production guarantees that vital information is swiftly conveyed to emergency services, decreasing response time and increasing the likelihood of timely aid.

The system effectively integrates communication technologies, gesture-based emergency signalling, and accident detection into a single framework. The system outperforms conventional monitoring techniques and delivers excellent accuracy and reliability, according to experimental data [3], [13]. Additionally, the capacity to retain and analyse event data facilitates ongoing system enhancement and advances intelligent

traffic monitoring research.

In conclusion, the proposed system represents a scalable and effective method for accident detection and personal safety monitoring, marking a substantial improvement in AI-based safety solutions.

VI. FUTURE ENHANCEMENTS

Even if the suggested method performs well, there are a number of improvements that might be made to increase its usefulness and flexibility in practical settings. The use of multi-camera systems and sensor fusion methods, which can improve coverage and decrease blind spots in intricate traffic situations, is one possible enhancement [7], [8]. The accuracy and dependability of detection may be further increased by combining camera data with other inputs like GPS and car sensors.

Extending the training dataset to incorporate a variety of traffic situations, weather fluctuations, and uncommon accident scenarios is another significant improvement. This will decrease false detections and enhance the deep learning models' capacity for generalization. The system may be deployed on edge devices and made appropriate for low-resource contexts by optimizing the model design for lightweight processing.

By allowing a greater variety of emergency gestures and integrating temporal motion analysis, the gesture recognition module may be significantly enhanced. This will increase the system's capacity to identify intricate human behaviours and boost its response in dire circumstances. Additionally, including real-time APIs and mobile applications can give consumers immediate access to safety features and speed up connection with emergency services [4], [11].

In order to overcome issues with ongoing video monitoring, future research may also concentrate on putting privacy-preserving strategies like data anonymization and safe cloud storage into practice. The system may develop into a more reliable, scalable, and intelligent solution for emergency response, public safety, and accident detection applications by implementing these improvements.

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