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*Original Article*

# Smart Road Safety System Using YOLO-Based Object Detection and IoT Communication in Mountainous Terrains

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***Abstract -*** *Road grid lock in this high-speed world is a serious big issue due to road accidents and incorrect traffic lights. It is bad particularly in hilly areas, where poor visibility and tight turns make it even worse to have an accident. The proposed system offers an IoT-ambivalent prototype that should be introduced to improve safety on the roads in mountainous areas, and it should involve real-time object detection and alert signaling. The live video streams of the road conditions are recorded on two cameras, and the YOLO (You Only Look Once) model is used to process them to identify vehicles precisely and quickly. The processed data is stored and controlled on the Firebase real-time database that promises efficient data processing and communication. The Node MCU microcontroller is used to access the data that Firebase detects to turn on a pole-mounted red light to warn oncoming traffic about possible dangers. A solution to reducing accidents in dangerous hilly environments is to utilize the proposed architecture, which integrates YOLO-based detection and IoT-based communication with secure data transmission to provide a reliable and responsive solution to the problem.*

***Keywords -*** *Road Safety, Accident Detection, Intelligent Transportation System, Emergency Response, IoT Communication, Real-time Monitoring.*

## I. INTRODUCTION

The traditional means of road safety in hilly areas remains to be on warning signs, patrols, and speed limits. Although necessary, these techniques have a drawback in the fact that they cannot detect accidents in real-time and intervene proactively. Safety management is further complicated by the existence of sharp curves, steep slopes and unpredictable weather conditions. The surveillance cameras that are used in certain areas are limited in coverage and are inadequate to deal with the dynamic risks of hilly areas.

In order to address these hurdles, it will need a technology-based strategy. Road sensors can be installed to check the traffic, changes in road surface and the environment. This data could be sent in real time via IoT-enabled networks to be centralized and analyzed. Artificial intelligence (AI) algorithms provide predictive power by examining trends, making predictions based on possible hazards, and providing early warnings. This kind of system can warn drivers and authorities of landslides, fog or heavy rainfall and help to decrease accidents and respond quickly. The remaining section of this paper is stated as follows: section II describes the literature survey, section III provides the existing methods, section IV highlights the detailed operation of Object Detection, section V talks about results and discussions and section VI provides the conclusion.

## II. LITERATURE AND METHODS

A number of studies have led to the development of object detection algorithms, including early template-based algorithms and current classifier-based algorithms. These developments are briefly outlined below. Initial work on object detection was mainly based on template matching and basic part-based models. As machine learning improved, statistical classifiers, including Neural Networks, Support Vector Machines (SVM), Adaboost, and Bayes were developed, and detection performance improved greatly. These methods formed the basis of standard training, assessment and classification procedures that informed much of the later studies in this area.

Face detection was the most widely researched among other applications because it is a critical part of human-computer interaction. With time, studies were expanded to other areas including pedestrian detection, body parts (faces, hands, eyes) and vehicles (cars, airplanes) and animals, based on objects commonly found in real-life situations. This diversification allowed creating more generalized and robust detection methodologies. The majority of the early detection systems used the sliding window method, in which images were searched exhaustively at various scales and positions. Classifiers were used at every scale to classify image patches to detect the presence of objects, thus, providing a comprehensive detection of variations in size and position. Despite being efficient, this exhaustive search could be very complex to compute.

To overcome these shortcomings, other approaches were suggested such as bag-of-words models to refine object regions, patch sampling techniques that gave priority to probable areas of detection and key-point matching techniques. Although these methods helped lower the computational cost since they did not require exhaustive searches, they could not usually ensure that all object instances were detected.

NajiTaaib Said Al Wadhahi [1] implemented with the growing traffic risks by creating a two-stage system with IR sensors and Arduino Uno. During the detection stage, IR sensors detect accidents and GSM modules transmit alerts which include GPS-based locations. During the prevention stage, IR sensors alert drivers when their vehicles are too near to minimise the risks of collisions. To prove the effectiveness of the system, a prototype was created. The strategy shows a cost-efficient and viable way of improving road safety and reducing accidents.

Sayanee Nanda [2] presented an IoT-based solution to prevent and detect accidents, particularly in two-wheelers that have minimal safety features. They are detected with vibration sensors and accelerometers and send the details of accidents to emergency contacts and hospitals using GPS and GSM modules. The system also takes care of the secondary accidents by providing timely notification to various stakeholders. Monitoring of driver condition (e.g. drowsiness, instability) is used to prevent mishaps in advance. Also, RFID license verification limits the use of vehicles to licensed drivers and this increases safety.

Senthil Murugan [3] proposed an automated accident detection and prevention model of four-wheelers based on real-time vehicle tracking (RTVT). GPS and GSM modules provide the opportunity to determine the location correctly and send emergency messages promptly to the authorities. One of the contributions is the management of traffic with the use of RF receivers, which enable ambulances to switch the red color of traffic lights to green. This will greatly minimize the time wastage in emergency response and accessibility of ambulances to hospitals. The model focuses on reducing the number of casualties due to delayed medical attention.

S. Gowtham [4] identified different intelligent systems that are aimed at reducing the number of road accidents due to their real-time monitoring and control. Earlier works had the GSM and GPS used in the accident alert system, the alcohol sensors used in driver monitoring, the adaptive cruise control, used in speed regulation. Vibration and piezoelectric sensors were also used in research to detect the location of accidents automatically and report them in time. All of these studies point to the need to incorporate sensor-based automation to increase the safety of vehicles and decrease the number of accidents caused by human error.

Ancy John [5] proposed an embedded system based on Atmega328P controller to prevent and detect accidents. The system incorporates RF transmitters to control speed when vehicles enter predetermined areas. Alcohol, smoke, and eye sensors are used to reinforce safety by checking on the conditions of the drivers. Piezoelectric sensors are used to detect accidents and GPS and GSM modules are used to send location information to relatives and emergency services. The system offers an integrated system that integrates accident prevention, detection and quick emergency response.

Srihan Thokala [6] discussed about avoiding night time accidents due to low visibility. Image processing is used to identify pedestrians and animals within a 20-meter distance by the use of a machine learning model. The system uses camera-based input and algorithms to increase the accuracy of the system over traditional detection systems. It comes in handy especially in low-light driving situations to minimize risks. This method enhances the safety of the road to both humans and animals by using ML and vision methods.

Ashraf [7] presented the performance of the YOLOx model in vehicle detection under difficult weather conditions like rain, fog, and snow. The research compared detection accuracy and robustness with varying visibilities. Outcomes indicated that YOLOx was able to sustain stable performance with little accuracy degradation. This research contributes to the existence of YOLOx for real-time vehicle detection in unfavourable conditions.

Chandana [8] focused on object detection methods based on the use of YOLO and CNN models as they are more accurate and fast in detecting multiple objects. The article compared the performance of YOLO against the traditional CNN-based detectors based on their performance metrics. It emphasized the fact that YOLO is better suited to real time because of the single shot strategy. Future improvements towards the detection precision and computational efficiency were also discussed.

Diwan [9] conducted a comprehensive review of the YOLO object detector framework focusing on how it has developed over time with the main architectures and the way they have enhanced their performance. Some of the significant challenges that were discussed in the study included real time processing, occlusion, and the detection of small objects. It also examined benchmark sets that facilitate the training and assessment of YOLO.

Du [10] provided detailed analysis of the object detection methods based on CNN family and YOLO algorithms. This research paper compares the conventional CNN-based algorithms with the real-time detection ability of YOLO. It emphasizes the effectiveness of YOLO in terms of speed and accuracy.

Zhao [11] presented review of the object detection approaches that were developed using deep learning, and it shows how the development of these approaches evolved to the next level of the CNN architecture. The article defines the detection frameworks which can be divided into two-stage and single-stage frameworks and the strengths and limitations of these frameworks are analyzed. It also addresses benchmark datasets, evaluation metrics, and other important issues in real-life detection. The paper ends by providing an idea of the future research topics on how the accuracy and efficiency can be enhanced.

Devi [12] suggested how single-stage object detectors can be improved to detect pedestrians better in low-light and dark conditions. The research was aimed at optimization of feature extraction and illumination compensation to deal with low visibility conditions. The improvements in the experiment showed a greater detection accuracy than the conventional detectors. The strategy was effective in the real-time use of pedestrian safety of autonomous systems.

Jiang [13] suggested a better real-time object detector algorithm based on a better YOLOv4-tiny algorithm. The network was optimized to ensure that the accuracy of the detection is high, and the computational cost is low. It is also good in terms of balancing between speed and precision thus it is applicable to embedded and real time uses. The results of the experiment proved better operation than the classic YOLOv4-tiny model.

Li [14] introduced the improved version of YOLOv4 as ABYOLOv4 that detects human objects better. The model incorporates improved multi scale feature combination to reinforce detection efficiency on diverse object dimensions. It maximizes accuracy and recall particularly on multimedia visual scenes. Its results show high performance over the conventional YOLOv4 and other benchmark designs.

Gao [15] suggested an optimized YOLOv8 model to enhance the accuracy of object detection in Jiangnan classical private gardens. The research was aimed at the conservation of cultural heritage through proper identification of architectural and decorative features. The improved model had better detection accuracy and strength in the adverse environmental conditions. The study shows that deep learning is effective in preservation and visual recording of heritage.

## III. EXISTING METHODOLOGY

Accident prevention systems can also be enhanced by the addition of the best object detection models like YOLO (You Only Look Once). In contrast to two-stage detectors, YOLO is able to detect objects in the image in one pass, which guarantees the real-time detection of objects with high accuracy. It splits the input into grids, estimates bounding boxes with class probabilities and refines the results with non-max suppression. YOLO has been improved significantly with each version. YOLOv2 also added anchor boxes and multi-scale feature extraction, which improved its capability to detect objects of different sizes. YOLOv3 also enhanced the detection by using feature pyramid networks, more CNN architecture and optimized loss functions balancing classification and localization. These developments render YOLO very appropriate in real-time and safety-critical settings.

## IV. PROPOSED METHODOLOGY

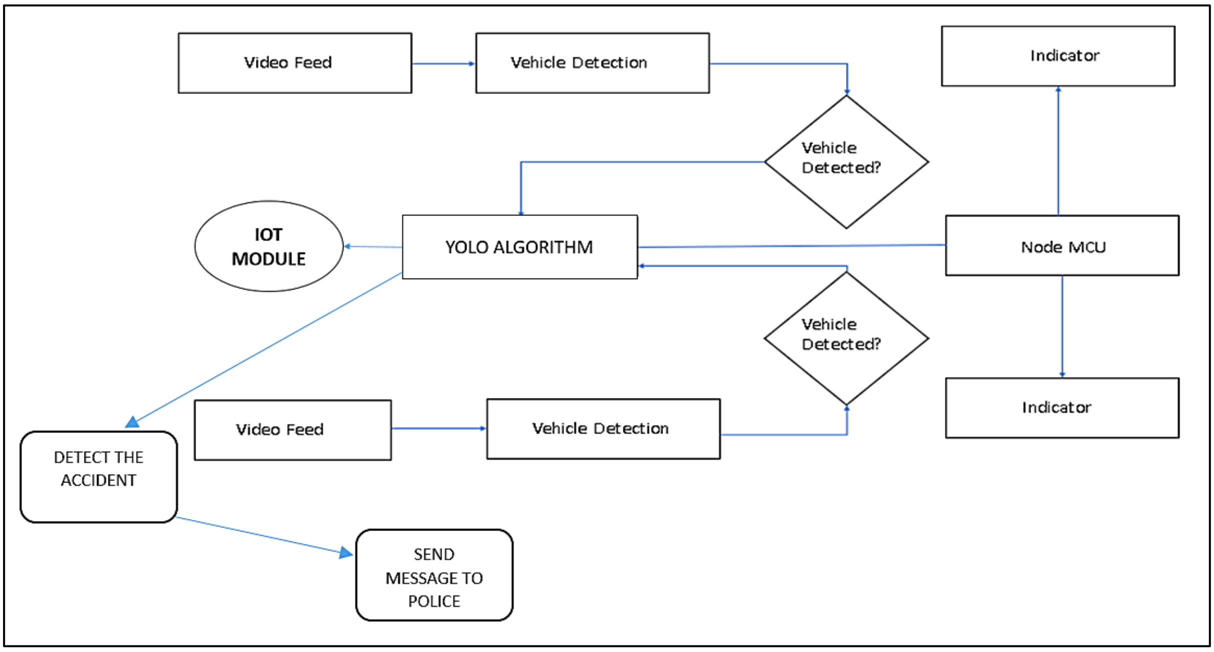


***Figure 1. Proposed Architecture***

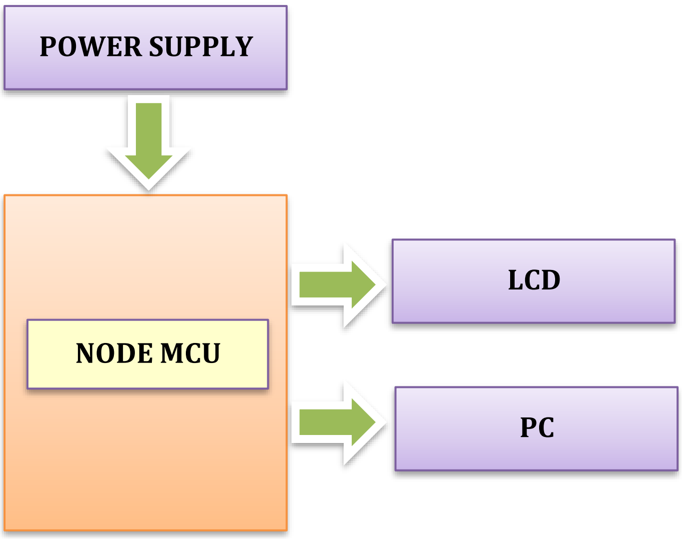


***Figure 2. Node MCU Architecture***

Node MCU microcontroller uses IoT-enabled communication with end-to-end encryption, which is secure and reliable in transferring data and protects against tampering. It is also efficient due to the integration of Google Firebase that enables real-time data to be uploaded and accessed easily.

The system is designed in terms of architecture into two large modules:

- **Object Detection Module**: This module uses YOLO to achieve effective and real-time recognition of objects. The cameras offer constant input and the YOLO model detects vehicles (toy cars in the prototype) with high precision, making sure that they are detected in time, which is crucial in difficult hilly conditions.
- **Node Module**: This element guarantees the incorporation of IoT by means of a Node MCU microcontroller. Once the detection results are uploaded to Firebase by YOLO, the Node module then recovers the information and translates it into a physical alert with a pole-mounted red light. This is a practical signalling system that gives a direct safety warning to oncoming traffic to fill the gap between digital detection and real-world communication.

These modules together form a strong, synergistic structure that can increase safety through the integration of real-time detection and responsive signalling. The proposed system is a comprehensive solution to the special safety issues of mountainous roads by combining the object detection system based on YOLO, secure communication in the IoT, and real-time data management.

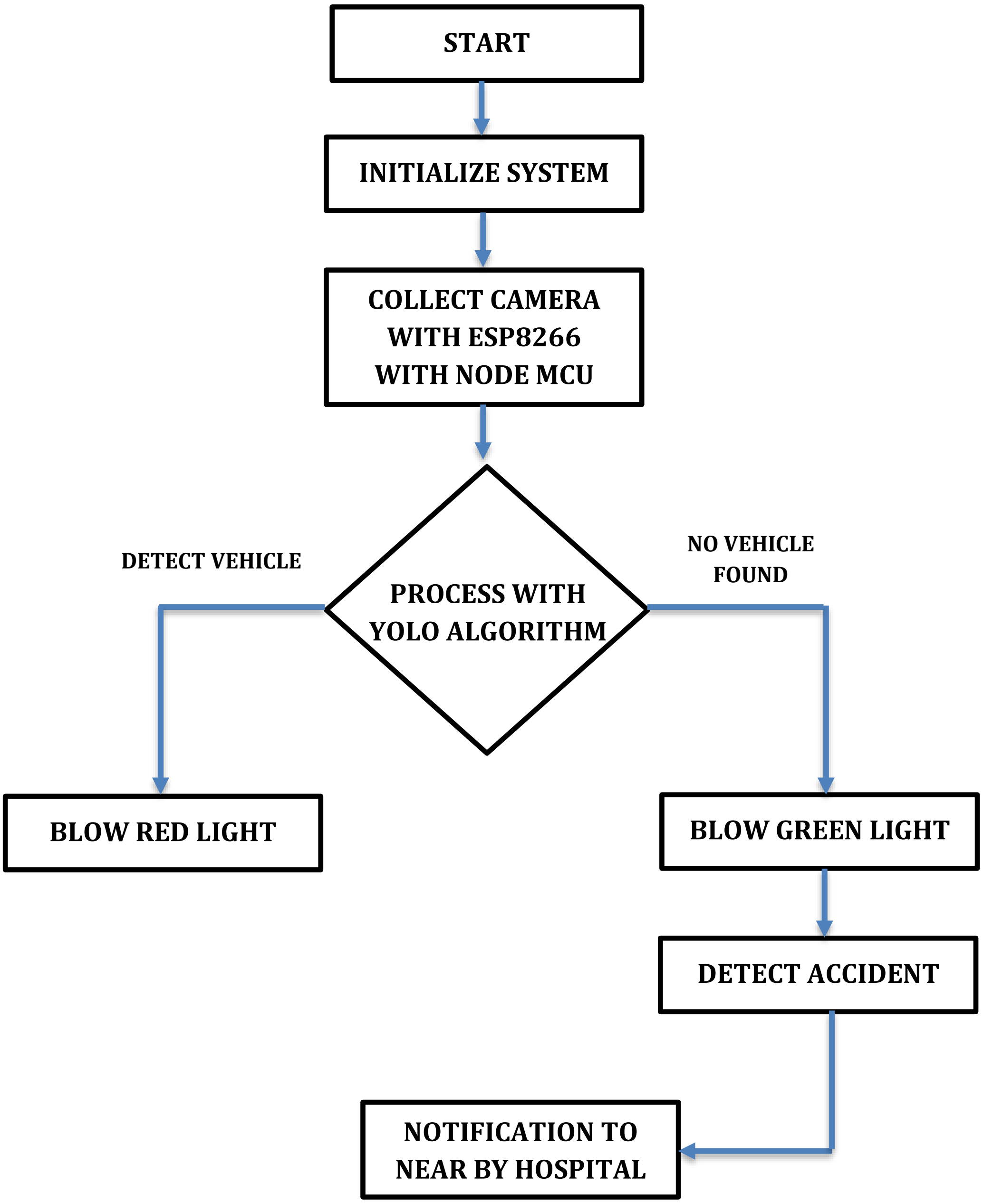


***Figure 3. Work Flow Chart***

The architecture diagram shown in Fig.3 demonstrates the systematic design of the proposed system that combines the detection of objects with the IoT-based communication to provide better safety in mountainous areas. It includes several modules that are interconnected and collaborate to provide real-time monitoring and signaling. The first step is to record video streams of the road environment in real time with cameras and process them with the YOLO (You Only Look Once) detection model to detect vehicles in each frame.

The information that has been processed is then optimized and sent to a cloud database like Firebase where it is stored and retrieved. This data is then accessed by an IoT module based on a Node MCU which translates it into a physical alert system, e.g. a signal light, to warn oncoming traffic about potential obstructions. The design is such that it provides a secure end-to-end communication, which provides a strong and comprehensive solution to accident prevention in complex terrains and hilly regions.

## V. RESULTS AND DISCUSSIONS

The created accident detection and prevention prototype was successfully implemented and tested in a simulated road setup. The proposed setup integrates the YOLO object detection model with IoT-based signaling components that are controlled by Node MCU controllers, sensors, and traffic lights are shown in Fig 4 and Fig 5. The system was meant to track moving vehicles in real time and initiate alerts for potential collisions, which would be beneficial for hilly or curvy roads.

When in the normal operating mode, the signal light was kept green to allow for vehicle flow. Upon detection by the YOLO module of a possible obstruction or accident, the processed data were sent immediately to Node MCU using Firebase cloud communication.

The controller then changed the traffic indicator to red as an alert to approaching vehicles of the identified risk. The LCD display also presented the live status of the system, facilitating monitoring and control.

The experimental testing substantiated that the IoT-based communication among detection and signaling units was reliable, secure, and speedy with no detectable delay. The integrated system successfully exhibited real-time detection, immediate response, and satisfactory alerting performance. In general, the prototype proved to be an efficient, low-cost, and scalable solution that can improve road safety through reduced reaction time and avoided accidents, particularly under adverse road or weather conditions.

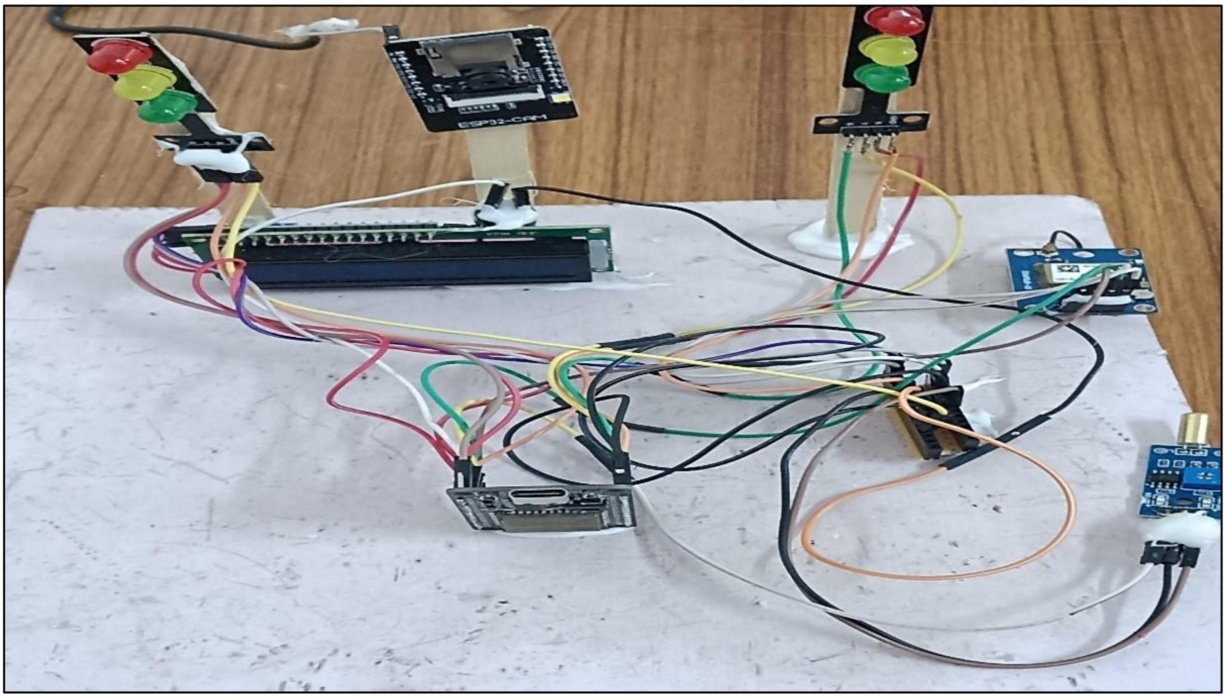


***Figure 4. Before Indicating Accident***

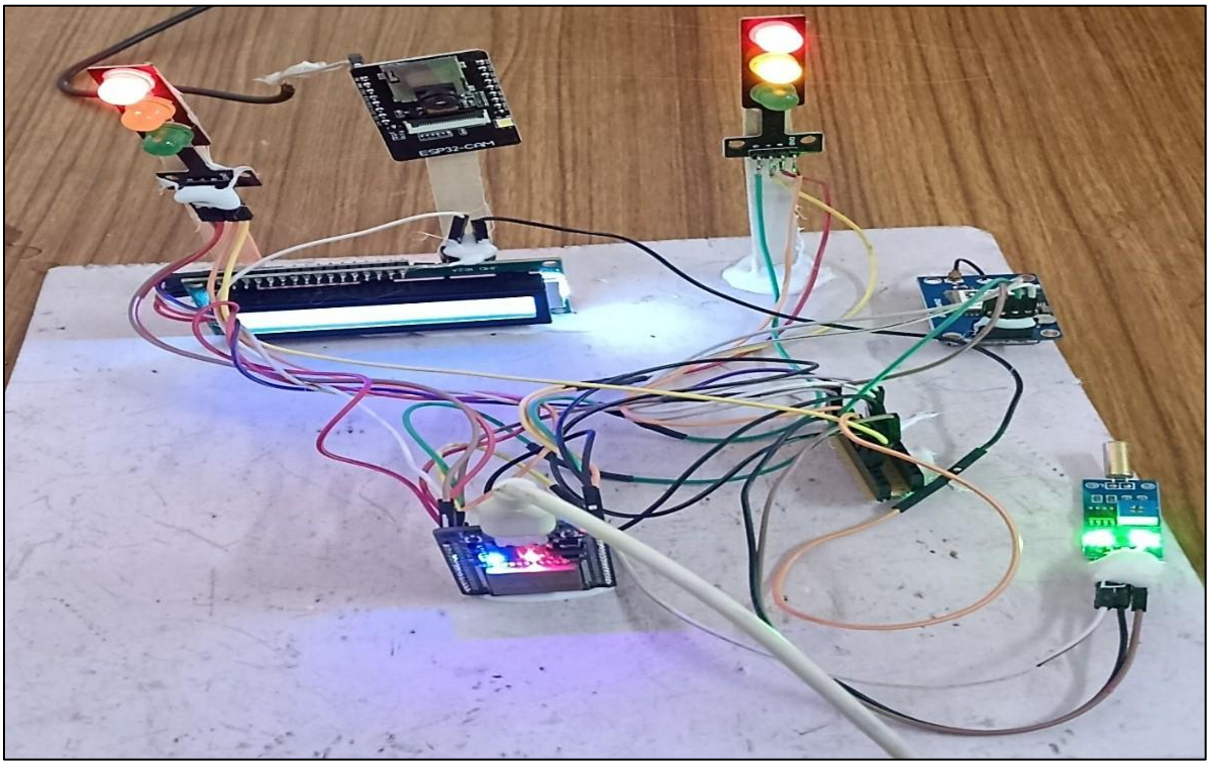

***Figure 5. After Indicating Accident***

## VI. CONCLUSION

The proposed system is a feasible and scalable approach towards enhancing road safety in hilly regions. It enables preventing accidents, detecting them, and reacting to the emergency on time by integrating object detection using YOLO with communication based on IoT. The versatility of the framework to be applied in real-world scenarios such as for traffic management in cities highlights its flexibility. Apart from its technical contribution, the system also serves a very critical social need, that of the reduction of deaths caused by accidents through the rapid communication with the emergency services.

### *A. Future Scope*

The future developments in object detection will have applications in wider domains such as autonomous driving, healthcare, AR/VR, and monitoring the environment. The future research will focus on accuracy, efficiency, and adaptability in dynamic environments and upholding ethical guidelines such as fairness and transparency.

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