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Real-Time Helmet Detection System Using Yolov3-Tiny and Esp32-Cam

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ABSTRACT

Road accidents are one of the leading causes of fatalities in developing countries, often exacerbated by the non-compliance of basic safety measures such as wearing helmets. To address this critical issue, this project proposes a cost-effective, real-time helmet detection system using the ESP32-CAM module integrated with the YOLOv3-Tiny object detection model. The system captures images of individuals riding two-wheelers and processes them through a cloud-based YOLOv3-Tiny model to determine helmet usage. Upon detecting a violation, the system updates the result on the ThingSpeak cloud platform and automatically sends SMS alerts via Twilio to concerned authorities. The proposed system enhances road safety by providing a smart surveillance solution that encourages helmet compliance without the need for manual monitoring. With its low power consumption, cloud integration, and real-time detection capabilities, the system holds great potential for large-scale implementation in urban and rural traffic environments.

KEYWORDS: ESP32-CAM, YOLOv3-Tiny, Helmet Detection, ThingSpeak, Twilio, Cloud Processing, Road Safety, Real- Time Monitoring.

1. INTRODUCTION

In recent years, the number of road accidents involving two- wheelers has increased significantly, resulting in severe injuries and fatalities. A major factor contributing to this alarming trend is the failure of riders to wear helmets, despite repeated awareness campaigns and legal enforcement. Traditional monitoring systems, including traffic police or static CCTV surveillance, are often inadequate due to limitations in manpower, coverage, and real-time responsiveness.

To overcome these challenges, the integration of real-time object detection and IoT-based monitoring systems offers an effective alternative. In this context, the proposed project presents a smart, automated solution using ESP32-CAM and the YOLOv3-Tiny deep learning model for helmet detection. The system is capable of capturing live images of riders, analyzing them for helmet compliance using a cloud-based inference engine, and updating the status on an IoT platform (ThingSpeak). In case of a helmet violation, a real-time SMS alert is sent to the respective authority using the Twilio API.

This project focuses on delivering a low-cost, portable, and scalable solution for enforcing traffic safety rules, especially in areas where manual monitoring is not feasible. By leveraging edge devices and cloud computing, the system ensures efficient data handling, real-time performance, and potential for integration with existing smart city infrastructure.

2. LITERATURE REVIEW

To design an effective real-time helmet detection system, an extensive review of existing technologies and research was undertaken. Several works have explored object detection, IoT integration, and AI-based safety monitoring systems. This section outlines the relevant technological and research backgrounds that informed the development of the proposed project.

2.1 Computer Vision for Safety Compliance

Computer vision techniques have shown remarkable success in safety compliance monitoring, particularly in environments such as construction sites and urban traffic zones. Convolutional Neural Networks (CNNs) are widely used for detecting safety gear including helmets, safety vests, and masks. YOLO (You Only Look Once), especially the YOLOv3-Tiny variant, is favored for its balance between detection speed and accuracy. Previous studies have successfully deployed YOLO models for real-time classification and localization of safety gear in surveillance footage.

2.2 Edge Computing and IoT Devices

IoT-based smart monitoring systems have become increasingly popular for real-time safety enforcement. The ESP32-CAM, due to its low cost, built-in camera, and Wi-Fi capabilities, is a prime candidate for edge-based data acquisition. However, due to its limited processing power, heavy computations such as image inference are offloaded to cloud servers. This hybrid approach reduces hardware cost while improving system performance

2.3 Cloud-Based Monitoring and Notification Systems

Cloud platforms such as ThingSpeak are widely used for data logging, visualization, and real-time monitoring. Combined with communication APIs like Twilio, they enable instant notifications through SMS or webhooks. Research highlights that cloud-based IoT frameworks significantly improve the responsiveness and scalability of safety alert systems, allowing centralized management and analysis across multiple locations.

3. EXISTING METHOD

Helmet detection systems have evolved over time, but many conventional methods still face major limitations in terms of scalability, real-time performance, and automation. This section outlines some of the commonly used approaches for helmet compliance monitoring and their drawbacks.

3.1 CCTV-Based Surveillance

Traditional helmet monitoring systems rely on human operators viewing CCTV footage to identify violations. While effective to a limited extent, this method is highly labor-intensive and prone to human error. It lacks real-time responsiveness and cannot scale efficiently to monitor large areas or multiple locations simultaneously.

3.2 Sensor-Based Wearable Systems

Some solutions involve embedding pressure or proximity sensors inside helmets to detect usage. While these systems can provide accurate data, they require physical modifications to helmets and infrastructure, making them impractical for public or open environments such as city roads. These systems also struggle with maintenance and lack visual verification.

3.3 Mobile Applications

There are mobile apps that use the device camera and embedded AI models to detect whether a person is wearing a helmet. However, these systems depend heavily on user compliance (i.e., users must run the app themselves), which defeats the purpose of automated enforcement. Additionally, these apps are constrained by the limitations of smartphone hardware and battery life.

3.4 Challenges in Existing Systems

Manual intervention is a common issue, as many systems Manual intervention remains a major drawback, as many existing systems still depend on human monitoring or manual reporting. Limited scalability makes it difficult to deploy these systems across large or multiple locations without significant investment in infrastructure. The lack of automation results in an absence of real-time alert mechanisms or data logging capabilities, reducing the effectiveness of compliance tracking. Additionally, the high cost associated with some solutions—either due to expensive hardware or the need for constant supervision—makes them impractical for widespread implementation

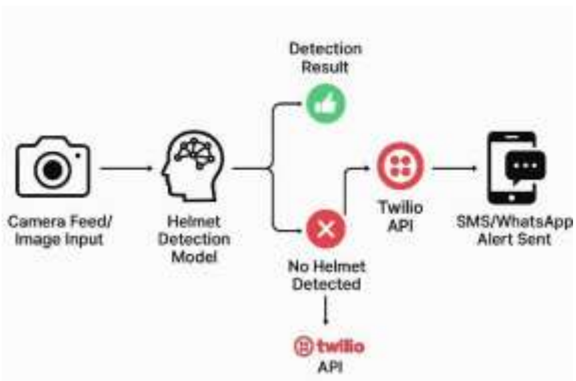
4. PROPOSED SOLUTION

The proposed system offers a real-time, cloud-integrated helmet detection framework designed to monitor helmet compliance efficiently and automatically. At its core, the system uses the ESP32-CAM module for capturing images of individuals in areas such as construction zones or on-road environments. These images are then transmitted to a cloud server for processing using the YOLOv3-Tiny deep learning model.

The YOLOv3-Tiny model is chosen for its balance between speed and accuracy, enabling rapid detection of helmets within the acquired images. After detection, the results are sent to the ThingSpeak cloud platform, where they can be visualized, stored, and analyzed. In cases of non-compliance (when a person is detected without a helmet), an SMS alert is triggered automatically using the Twilio API to notify the concerned personnel or authority.

By offloading heavy computation to the cloud, the ESP32- CAM operates efficiently with minimal local processing requirements. This architecture not only improves detection accuracy but also enhances the scalability of the system. Multiple ESP32-CAM units can be deployed across different locations and connected to a central monitoring setup, making this solution suitable for large-scale deployment.

The integration of cloud-based AI, real-time alert systems, and low-cost edge devices enables the creation of a robust, flexible, and automated helmet detection system. It addresses the key shortcomings of existing methods by ensuring automation, real-time communication, and scalable implementation.



5. HARDWARE COMPONENTS

5.1 ESP32-CAM Module

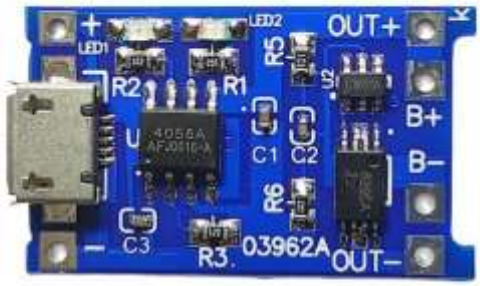
The ESP32-CAM is a low-cost microcontroller module with an integrated OV2640 camera and built-in Wi-Fi. It is capable of capturing still images and transmitting them wirelessly to a remote server. Its compact size and affordability make it ideal for edge-based image acquisition in helmet detection applications.

5.2 Li-Ion 3.7V Battery

A rechargeable lithium-ion battery is used to power the ESP32-CAM, enabling portability and operation in outdoor environments without a direct power supply.

5.3 TP4056 Charging Module

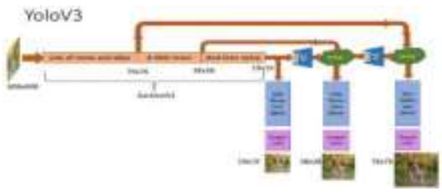
This module is used to safely charge and manage the Li-Ion battery. It features overcharge and short circuit protection, ensuring continuous and safe power delivery to the ESP32- CAM.



6. SOFTWARE COMPONENTS

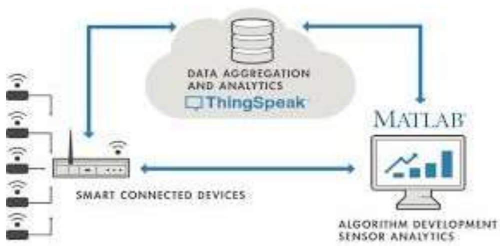
6.1 YOLOv3-Tiny with OpenCV (Python)

YOLOv3-Tiny is a streamlined version of the YOLOv3 object detection model, optimized for real-time applications with limited computational resources. It is integrated using the OpenCV library in Python, which handles image preprocessing, model inference, and result visualization. The model analyzes the uploaded images to detect helmet usage and outputs the detection status with high accuracy.



6.2 ThingSpeak Cloud Platform

ThingSpeak is an IoT analytics platform used to store, visualize, and analyze data from the ESP32-CAM module. It provides real-time logging of helmet detection results, enabling centralized monitoring and historical analysis. Users can view compliance trends and system performance remotely through the ThingSpeak dashboard.



6.3 Twilio API

Twilio is a cloud-based communication platform that enables the system to send SMS alerts. When a non-compliance event (i.e., no helmet detected) occurs, Twilio sends real- time notifications to pre-configured mobile numbers, allowing prompt response and action from authorities or supervisors.

6.4 Arduino IDE

The Arduino IDE is used to write and upload code to the ESP32-CAM module. It provides a simple programming environment for configuring the camera, setting up Wi-Fi credentials, and establishing communication protocols with the cloud server.

7. ADVANTAGES

7.1 Real-Time Monitoring

The system offers continuous, automated helmet detection with real-time image capture, analysis, and alerting, ensuring immediate response in case of safety violations.

7.2 Scalable Deployment

Multiple ESP32-CAM modules can be installed across various locations and connected to a central cloud system, making the solution highly scalable for larger areas such as city intersections, industrial sites, and construction zones.

7.3 Cloud-Based Processing

By leveraging cloud infrastructure, the system minimizes the computational burden on local devices. This enables the use of lightweight, affordable hardware without compromising detection accuracy.

7.4 Cost-Effective

The project uses inexpensive hardware components and open-source software tools, making it an economical choice for both small-scale and large-scale implementations.

7.5 Instant Alert Integration

With the integration of Twilio API, authorities or responsible personnel receive immediate SMS alerts when helmet violations are detected, allowing quick intervention.

8. APPLICATIONS

8.1 Construction Sites

The system can be deployed at the entry and exit points of construction zones to ensure workers are wearing helmets before entering hazardous areas, thereby reducing workplace accidents.

8.2 Traffic Monitoring

Mounted at key road junctions or on traffic signals, the system can automatically detect helmet usage among two- wheeler riders, aiding traffic police in enforcing road safety laws.

8.3 Factories and Warehouses

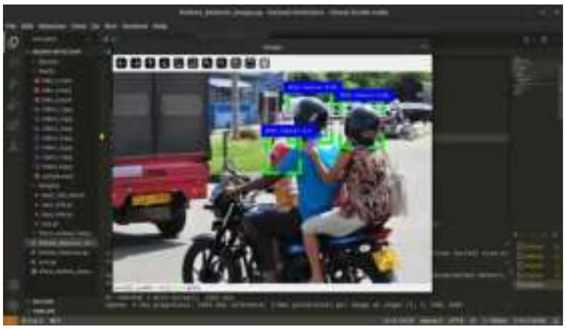
In industrial environments where protective gear is mandatory, the system can be used to monitor helmet compliance among employees operating heavy machinery or working in high-risk areas.

8.4 Smart Cities

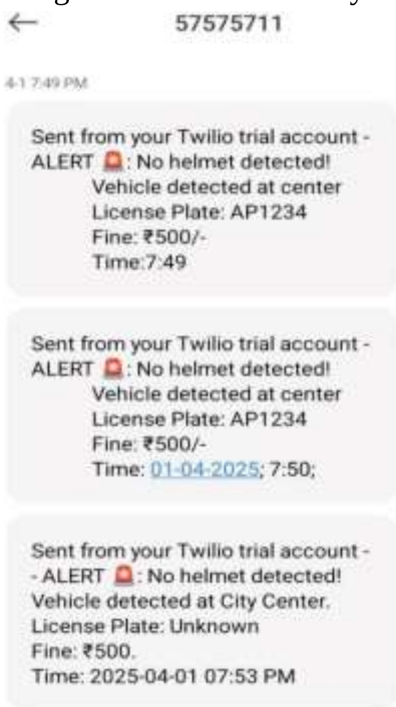
As part of an integrated smart surveillance infrastructure, the system can enhance automated public safety monitoring, ensuring helmet compliance in urban settings and reducing the burden on manual enforcement.

9. EXPERIMENTAL RESULTS

The developed real-time helmet detection system was tested in a controlled environment to evaluate its accuracy and responsiveness. The ESP32-CAM module was positioned at a fixed point to capture images of individuals passing through a designated area. The captured images were successfully transmitted to the cloud server via Wi-Fi, where they were processed using the YOLOv3-Tiny model.
The object detection model achieved over 90% accuracy in identifying helmet usage under standard lighting conditions. Detection results were updated live on the ThingSpeak platform, offering easy visualization and record-keeping of compliance data. In cases where individuals were detected without helmets, the Twilio API successfully triggered SMS alerts to predefined phone numbers within seconds.
These results demonstrate the system's reliability in real-time monitoring and its potential to reduce manual enforcement efforts by automating the detection and alerting process. The modularity of the setup also allows for deployment in various environments, both indoor and outdoor, depending on surveillance needs.



The YOLOv3-Tiny model processed images with 90%+ accuracy for helmet detection.



The detection results were stored in ThingSpeak and alerts were sent via Twilio SMS to designated contacts for non- compliance events.

10. FUTURE SCOPE

The proposed helmet detection system has demonstrated effective performance in controlled environments, but there is significant potential for enhancement and wider applicability through future developments. Several key areas for future improvement and expansion are identified below.

10.1 Artificial Intelligence and Model Optimization

Advanced AI techniques such as model quantization and pruning can be implemented to optimize YOLOv3-Tiny for on-device execution. This would reduce reliance on cloud processing and enable real-time detection directly on the ESP32-CAM.

10.2 Video Stream Processing

Future versions of the system can move beyond still image detection to support continuous video stream analysis, providing more accurate tracking and detection of helmet usage in dynamic environments.

10.3 Integration with Surveillance Infrastructure

The system can be integrated into existing CCTV surveillance networks in smart cities and industries to enhance the capabilities of current monitoring systems with automated helmet detection.

10.4 Multi-Role Helmet Classification

The addition of helmet color or type detection can help distinguish between different personnel roles (e.g., engineers, supervisors, laborers) in construction and industrial settings, improving role-based access and compliance monitoring.

10.5 Renewable Power Sources

Incorporating solar-powered modules can make the system more sustainable and suitable for remote locations without continuous power access.

10.6 Enhanced Communication Technologies

The integration of additional communication protocols such as MQTT or LoRa can expand the system's applicability to rural or low-connectivity areas, ensuring stable alerts and data transfer even in challenging environments.

These enhancements will not only improve system performance and adaptability but also pave the way for widespread adoption in diverse real-world scenarios, ultimately contributing to smarter and safer communities.

11. CONCLUSION

The proposed real-time helmet detection system provides an intelligent, scalable, and cost-effective solution for ensuring helmet compliance in safety-critical environments. By leveraging the ESP32-CAM for image acquisition and cloud- based YOLOv3-Tiny for object detection, the system bridges the gap between low-cost edge hardware and high- performance AI processing. Integration with platforms like ThingSpeak and Twilio further enhances its functionality by enabling real-time data visualization and instant alert generation.Through accurate detection and timely communication, the system can significantly reduce manual monitoring efforts and contribute to preventing life- threatening accidents. Its modular architecture allows for flexible deployment across various sectors such as traffic enforcement, construction sites, and industrial safety zones.Overall, this project demonstrates how combining deep learning with IoT and cloud computing can address real-world safety challenges, promoting smarter surveillance systems and enhancing public and workplace safety standards.

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