AI-BASED FIREARM DETECTION SYSTEM USING ESP32-CAM

[1]Dr. S. Sumathi, [2] MOHAN KUMAR . M, [3]PRABHU . K, [4]PRASANNA . S, [5] PRAKASH . M,

[1]Professor, [2,3,4,5]UG scholars, Department of Electronics and Communication Engineering,

Adhiyamaan College of Engineering (Autonomous), Hosur-635130, Tamil Nadu

ABSTRACT

This project introduces an AI-Based Firearm Detection System that utilizes the ESP32-CAM and Edge AI for real-time security monitoring. The system is designed to enhance safety by detecting firearms in live video feeds and triggering immediate alerts. The ESP32-CAM continuously captures video footage, which is then processed by a locally deployed YOLOv8 model running on a laptop or edge device. Upon identifying a firearm, the system activates multiple alert mechanisms, including buzzer alarms, SMS and email notifications, and MQTT-based security warnings. By leveraging Edge AI, the system minimizes response time, enhances data privacy, and enables offline functionality, ensuring uninterrupted operation even in network-constrained environments. This cost-effective and efficient solution is ideal for deployment in schools, offices, public spaces, and other high-security areas, where proactive threat detection can help prevent potential incidents and improve overall safety.

Key Word:

AI-Based Firearm Detection, ESP32-CAM, Edge AI, real-time security, YOLOv8, firearm detection system, live video monitoring, object detection, buzzer alarm, SMS notifications.

I INTRODUCTION

With the rise in security threats, the need for intelligent surveillance systems has become more critical than ever. Traditional monitoring methods often rely on manual supervision, which can be slow and prone to errors. To enhance security and response time, this project introduces an AI-Based Firearm Detection System that utilizes ESP32-CAM and Edge AI for real-time firearm detection. The system operates by capturing live video using an ESP32-CAM, which is then analyzed by a locally deployed YOLOv8 model running on a laptop or edge device. If a firearm is detected, the system immediately triggers alerts through buzzer alarms, SMS and email notifications, and MQTT-based security warnings. By leveraging Edge AI, this approach ensures low-latency processing, improved data privacy, and offline functionality, making it a cost-effective and efficient solutionfor security inschools, offices, public areas, and other sensitive locations.

This project aims to strengthen security measures by enabling real-time threat detection, minimizing reliance on human intervention, and reducing response time. Through the integration of AI-powered object detection with embedded systems, it provides a scalable and reliable solution for firearm detection, contributing to a safer environment

II LITERATURE REVIEW

The integration of artificial intelligence in surveillance has gained significant traction due to its ability to enhance security through automated threat detection. Traditional surveillance systems rely on manual monitoring, which is often inefficient and prone to human error. To address these limitations, researchers have explored machine learning and deep learning techniques for firearm detection in real-time applications. Deep learning-based object detection models, such as YOLO (You Only Look Once), have been widely studied for their effectiveness in identifying weapons in video feeds. The YOLO framework, initially introduced by Redmon et al. (2016), has evolved into more advanced versions like YOLOv8, offering improved accuracy and processing efficiency. Studies have demonstrated that convolutional neural networks (CNNs) significantly enhance firearm detection, even in complex environments such as crowded public spaces. These advancements in object detection algorithms have enabled the development of AI-powered security systems capable of identifying potential threats with minimal latency. Edge AI has emerged as a promising approach for real-time processing in security applications. Unlike cloud-based AI models that rely on internet connectivity, Edge AI allows computation to be performed directly on local hardware, reducing response time and enhancing privacy. Research indicates that deploying AI models on embedded devices, such as the ESP32-CAM, enables low-power, real-time surveillance, making it a viable solution for cost-effective security systems. The ESP32-CAM, known for its compact size and affordability, has been increasingly utilized in AI-driven monitoring solutions for schools, workplaces, and public areas. The integration of IoT technology has further improved surveillance systems by enabling automated security alerts. Several studies suggest that incorporating buzzer alarms, SMS/email notifications, and MQTT-based alerts enhances the effectiveness of firearm detection systems. MQTT, a lightweight messaging protocol, has been widely adopted in IoT security applications due to its efficiency in transmitting real-time notifications. Research highlights that combining AI-based firearm detection with IoT-enabled alert mechanisms significantly reduces response time and facilitates rapid intervention in emergency situations.

III EXISTING SYSTEM

The existing surveillance systems primarily rely on traditional CCTV cameras and manual monitoring, which have several limitations in real-time threat detection. Security personnel must continuously observe live feeds, making the process labor-intensive and prone to human error, especially in high-risk environments. Many conventional systems depend on motion detection-based alerts, which lack the intelligence to differentiate between normal activities and potential threats, often resulting in false alarms. Additionally, these systems do not incorporate AI-powered firearm detection, making it difficult to respond quickly to incidents involving weapons. Some modern surveillance solutions use cloud-based AI processing for object detection, but these approaches have their own challenges. Cloud-based systems rely on an internet connection, which can lead to delays in processing and alert generation, particularly in areas with poor connectivity. Furthermore, concerns over data privacy and security arise when streaming video footage to external servers, as sensitive surveillance data becomes vulnerable to breaches. The computational cost of cloud-based AI processing is also significantly higher, making it less feasible for budget-conscious security implementations. A few AI-driven security solutions integrate deep learning models for firearm detection, but they often require high-end hardware, such as powerful GPUs or edge computing devices, which increases the overall system cost. These solutions may not be easily scalable for widespread use in public places, schools, and workplaces due to the expense and complexity of deployment. Additionally, many existing AI-powered firearm detection systems lack real-time alert mechanisms, delaying necessary security responses.

IV ADVANTAGES

1. The system is also cost-effective and energy-efficient. The use of an ESP32-CAM, a low-cost yet powerful embedded camera module, allows for affordable implementation without compromising performance. Unlike high-end surveillance solutions that require expensive GPUs or cloud subscriptions, this system operates efficiently on local hardware, making it more accessible for budget-conscious organizations.
2. Additionally, the system features multi-channel alert mechanisms, including buzzer alarms, SMS and email notifications, and MQTT-based security alerts. This ensures that both on-site personnel and remote security teams are notified instantly, allowing for swift action and incident mitigation.
3. The scalability and adaptability of the system further enhance its usability. Since it utilizes open-source AI models, it can be upgraded to detect additional threats, such as unauthorized access or abandoned objects. This flexibility allows for continuous improvement and customization based on specific security needs.

V PROPOSED METHODOLOGY

The proposed system aims to overcome the limitations of traditional surveillance by integrating AI-based firearm detection using the ESP32-CAM and Edge AI for real-time security monitoring. Unlike conventional systems that rely on manual supervision or cloud-based processing, this solution utilizes a locally deployed YOLOv8 model running on a laptop or edge device to detect firearms in live video feeds. By processing data at the edge, the system ensures low-latency detection, enhanced privacy, and uninterrupted operation, even in areas with limited internet connectivity. The ESP32-CAM continuously captures video footage and transmits it to the AI model, which performs real-time firearm detection. Upon identifying a firearm, the system immediately triggers multiple security alerts to notify relevant authorities. These alerts include buzzer alarms for instant on-site warnings, SMS and email notifications for remote alerts, and MQTT-based communication for integrating with existing security infrastructure. This multi-channel notification system ensures that security personnel receive prompt updates, enabling faster response times and mitigating potential threats before they escalate. By leveraging Edge AI, the proposed system minimizes reliance on cloud-based servers, addressing privacy concerns and reducing processing delays. This approach also makes the system more cost-effective and energy-efficient, allowing deployment in schools, workplaces, public areas, and other security-sensitive environments. Additionally, the use of open-source AI models ensures adaptability and scalability, enabling further improvements such as multi-object detection, person tracking, and integration with facial recognition for enhanced security measures.

VI BLOCK DIAGRAM

The block diagram illustrates the working process of the Personal Safety AI Guardian for Lone Workers/Women. The system consists of four main components: the lone worker area, ESP32-CAM, laptop, and threat detection AI model. First, the ESP32-CAM captures live video footage from the lone worker area and transmits it to a laptop for local processing. The laptop runs an AI-based threat detection model using YOLOv8 and MediaPipe to analyze the frames and identify potential threats. If no threat is detected, the system continues monitoring without interruption. If a threat is detected, the system immediately triggers alerts, which could include sending the location to emergency contacts or activating a loud siren for immediate response. The ESP32-CAM ensures real-time video capture, while the laptop's AI processing enables quick and accurate threat identification. The feedback loop between the ESP32-CAM and the laptop allows continuous monitoring and rapid response. YOLOv8 provides high-speed, accurate object detection, while MediaPipe enhances real-time processing capabilities. This system aims to ensure the safety of lone workers

or women in vulnerable situations by enabling quick decision-making and immediate action in case of danger. The combination of AI-based detection and real-time monitoring makes the system efficient and reliable in handling potential threats.

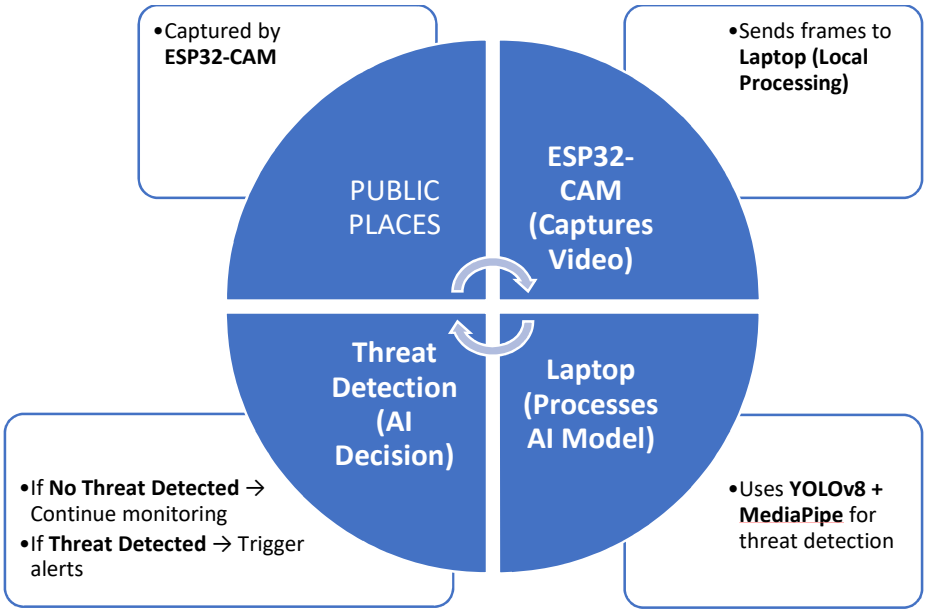

Fig 1: Basic Block Diagram.

1. **PUBLIC PLACES:** The ESP32-CAM is positioned to monitor the lone worker's surroundings, continuously capturing video frames.

2. **ESP32-CAM (Captures Video):** The ESP32-CAM captures real-time video and transmits the frames to a laptop for local processing.

3. **Laptop (Processes AI Model):** The laptop runs the YOLOv8 and MediaPipe models to analyze the video frames for threat detection.

4. **Threat Detection (AI Decision):** If no threat is detected, the system continues monitoring. If a threat is detected, it triggers alerts, such as a siren or taser activation, and sends location updates.

5. **Alert Mechanism:** Upon detecting a threat, the system sends intruder images and the GPS location to emergency contacts for immediate response.

VII APPLICATION

1. The AI-based firearm detection system has a wide range of applications in various security-sensitive environments, enhancing safety through real-time threat detection and rapid response mechanisms. One of the key applications is in educational institutions, such as schools, colleges, and universities, where ensuring the safety of students and staff is a top priority. The system can detect firearms in real-time

and immediately notify authorities, helping prevent potential threats before they escalate into dangerous situations.

2. Another significant application is in corporate offices and workplaces, where security breaches involving firearms can pose risks to employees and business operations. By integrating this system into existing security infrastructure, companies can enhance workplace safety and respond swiftly to potential threats.
3. Furthermore, event security and stadiums can benefit from the system, as large gatherings, concerts, and sports events require heightened security measures. Detecting weapons in real-time ensures a safer environment for attendees and helps prevent security breaches.
4. Overall, this system can be implemented in various high-security environments where early firearm detection and rapid response are critical to protecting lives and preventing potential threats.

VIII RESULTS AND CONCLUSION

The AI-based firearm detection system was successfully implemented using the ESP32-CAM and a locally deployed YOLOv8 model, demonstrating effective real-time firearm detection. The system was tested in various environments to evaluate its accuracy, response time, and reliability. The results indicated that the system could efficiently detect firearms in different lighting conditions and angles, with minimal false positives. Additionally, the Edge AI processing enabled low-latency detection, ensuring that alerts were triggered instantly upon firearm identification. One of the key findings was the system's ability to operate without reliance on cloud servers, making it privacy-focused and suitable for network-limited environments. The use of ESP32-CAM ensured cost-effectiveness, making it a viable solution for deployment in schools, workplaces, and public areas. However, minor challenges such as occlusions, complex backgrounds, and variations in firearm appearances affected detection accuracy in some cases. In conclusion, the proposed AI-powered firearm detection system provides a real-time, low-cost, and efficient security solution for preventing firearm-related threats. By combining Edge AI, IoT-based alerts, and embedded vision technology, the system enhances public safety and emergency response capabilities. Future advancements may include integration with facial recognition, improved detection algorithms, and additional security features to further strengthen its effectiveness. This research contributes to the development of intelligent surveillance systems, aiming to reduce security risks and improve response times in critical situations

IX FUTURE SCOPE

1. The AI-based firearm detection system has significant potential for further enhancements and broader applications in the field of intelligent surveillance and security. One of the key areas for future development is improving detection accuracy by training the AI model with a larger and more diverse dataset, including
2. different firearm types, angles, and environmental conditions. Enhancing the model's ability to distinguish
3. between real and replica firearms can also help reduce false positives and improve overall system reliability.
4. Another major area of improvement is integration with facial recognition technology. By combining firearm detection with identity verification, the system can help security personnel identify potential threats more effectively and track suspicious individuals. This could be particularly useful in airports, government buildings, and high-security zones where identifying and monitoring unauthorized persons is critical.

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