

DEPARTMENT OF ECE

EC3811 – "MICRO VISION KIT: AI-DRIVEN OBJECT DETECTION FOR IOT APPLICATIONS "

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OPTIMIZED EDGE COMPUTING FOR OBJECT DETECTION: ESP32-CAM WITH YOLO AND EDGE IMPULSE

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**ABSTRACT:**

AI on Edge refers to the deployment of artificial intelligence algorithms directly on edge devices, such as microcontrollers and microprocessors, enabling real-time data processing without relying on cloud servers. This approach significantly enhances efficiency by reducing latency, bandwidth usage, and operational costs while improving system performance. While cloud computing has traditionally been preferred for its scalability and ease of maintenance, recent advancements in embedded AI and hardware acceleration have made edge computing a powerful alternative. By processing data locally, edge AI brings intelligent decision-making closer to the source, enabling faster and more responsive systems.

Object recognition is a core discipline in computer vision and artificial intelligence, involving the identification and classification of objects within images or video streams. It allows machines to interpret and analyse visual data in a manner similar to human perception. While the terms object detection, object recognition, and image recognition are often used interchangeably, they serve the same fundamental purpose—enabling automated identification of visual elements.

In this project, we leverage the ESP32-CAM module to develop an AI-driven image recognition system capable of detecting and identifying various objects. Using the Edge Impulse platform, we train a custom deep learning model tailored to specific object categories. The trained model is then deployed onto the ESP32-CAM, enabling real-time inference directly on the device. The detection results are displayed on an OLED screen, offering an efficient, low-power, and cost-effective solution for real-time object classification. This implementation demonstrates the potential of AI-powered edge computing for diverse applications, including smart surveillance, agriculture, and industrial automation.

### **LITERATURE SURVEY:**

The field of real-time object detection and edge computing has evolved significantly with advancements in AI, IoT, and embedded systems. Several research works and technological developments contribute to the foundation of this project.

**1. OBJECT DETECTION USING DEEP LEARNING**

Various deep learning models like YOLO (You Only Look Once), SSD (Single Shot Detector), and Faster R-CNN have revolutionized object detection by providing high-speed and accurate real-time processing.  
 Studies show that YOLO is more efficient for low-power embedded systems due to its fast inference time and lightweight architecture.

*Reference:* Redmon, J., & Farhadi, A. (2016). "YOLO: Real-Time Object Detection." IEEE Conference on Computer Vision and Pattern Recognition.

**2. EDGE COMPUTING FOR AI-POWERED OBJECT DETECTION**

Traditional cloud-based object detection systems suffer from high latency and privacy concerns due to their dependency on internet connectivity.

Studies highlight that low-power AI accelerators like ESP32-CAM and Raspberry Pi are becoming viable solutions for real-time image processing.

*Reference:* Sathyanarayanan, M. (2017). "The Emergence of Edge Computing." IEEE Computer Society.

**3. ESP32-CAM FOR IMAGE PROCESSING & AI IMPLEMENTATION**

The ESP32-CAM is a low-cost Wi-Fi-enabled module with a built-in camera, widely used in IoT-based surveillance, smart agriculture, and industrial automation.  
 Recent research demonstrates the capability of deploying lightweight AI models on ESP32-CAM using frameworks like TensorFlow Lite and Edge Impulse.

*Reference:* Hu, W., & Gao, Y. (2021). "Deploying AI on Edge Devices: Case Study of ESP32-CAM for Object Detection." International Journal of Embedded Systems Research.

**4. EDGE IMPULSE FOR AI MODEL TRAINING AND DEPLOYMENT**

Edge Impulse provides an **automated, low-power AI model training and deployment platform** for embedded devices like ESP32-CAM.

*Reference:* Jain, S., & Patel, M. (2022). "Leveraging Edge Impulse for Embedded AI Applications." IoT and AI Research Journal.

**PROBLEM STATEMENT:**

**WHAT ISSUE ARE WE SOLVING?**  
Traditional object detection systems rely heavily on cloud computing, requiring continuous internet connectivity for processing images and videos. This leads to increased latency, security concerns, and high computational costs. There is a need for a low-power, real-time, and cost-effective alternative that can process data locally without relying on cloud infrastructure.

**WHY IS EDGE-BASED OBJECT DETECTION IMPORTANT?**

* **LOW LATENCY:** Reduces the delay in object recognition by processing data directly on the device.
* **OFFLINE FUNCTIONALITY:** Works efficiently without requiring an internet connection.
* **ENERGY EFFICIENCY:** Uses low-power AI models optimized for embedded hardware like ESP32-CAM.

**CHALLENGES WITH TRADITIONAL CLOUD-BASED OBJECT RECOGNITION:**

1. **HIGH LATENCY:** Cloud processing takes time, making real-time applications (like autonomous vehicles or security surveillance) inefficient.
2. **INTERNET DEPENDENCY:** AI models require an internet connection to send and receive data, making them unreliable in remote locations.
3. **COST & INFRASTRUCTURE:** Cloud services require expensive infrastructure and recurring costs for AI processing.
4. **DATA PRIVACY CONCERNS:** Cloud-based solutions may expose sensitive data to external networks, leading to security risks.

**SOLUTION**  
This project proposes an **optimized edge computing approach for object detection using ESP32-CAM, YOLO, and Edge Impulse.** By integrating lightweight AI models on **ESP32-CAM**, we enable **real-time, low-cost, and energy-efficient** object recognition without the need for cloud-based computation.

**EXISTING SYSTEM:**

In the traditional approach, object detection is primarily performed using cloud-based computing or high-power GPU-based systems. These methods involve:

* **Cloud-Based Object DETECTION:** Images are captured and sent to a remote server for processing. AI models running on the cloud analyse the images and return results.
* **HIGH POWER CONSUMPTION:** Devices require continuous internet connectivity and high computational resources, making them unsuitable for low-power IoT devices.
* **LATENCY ISSUES:** The delay in sending data to the cloud and receiving results makes real-time detection difficult.
* **SECURITY AND PRIVACY CONCERNS:** Since data is transmitted over the internet, there is a risk of data breaches and unauthorized access.
* **HARDWARE REQUIREMENTS EXPENSIVE:** Traditional object detection often relies on high-end GPUs or powerful processors, making it costly for real-world, large-scale applications.

**PROPOSED SYSTEM:**

To overcome the limitations of the existing system, we propose an Edge AI-based real-time object detection system using ESP32-CAM, YOLO, and Edge Impulse**.**

**KEY ENHANCEMENTS:**

**YOLO FOR FASTER DETECTION:** Utilizing the YOLO (You Only Look Once) algorithm, which is optimized for real-time and high-accuracy object detection**.**

**EDGE IMPULSE INTEGRATION:** A custom-trained AI model will be deployed on the ESP32-CAM, enabling recognition of specific objects of interest

**LOW POWER CONSUMPTION:** Designed for low-energy IoT devices, making it suitable for battery-operated systems.

**PRIVACY AND SECURITY:** Since data is processed locally, there is no risk of data leakage, making it ideal for smart surveillance, agriculture, and industrial applications.

**COST-EFFECTIVE SOLUTION:** Eliminates the need for expensive GPUs or cloud computing, making it an affordable AI-powered object detection system.

**CONCLUSION:**

This project successfully implements real-time, edge-based object detection using ESP32-CAM, YOLO, and Edge Impulse, eliminating the challenges of cloud dependency. By enabling low-latency, cost-effective, and energy-efficient AI processing, it enhances security, reliability, and scalability for IoT applications. The results demonstrate the potential of edge AI in smart surveillance, automation, and real-world deployments, paving the way for future advancements in embedded intelligence.