ECO TRACK: AI- AND IOT-POWERED E-WASTE SEGREGATION AND AWARENESS FOR SUSTAINABLE RECYCLING

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Introduction:
Fast-paced advancements and shorter product lifecycles lead to a large amount of electronic waste being created. Since harmful substances in electronics can contaminate soil and water, mishandling old and broken electronics can cause serious environmental harm. At present, manually sorting small electronic parts is time-consuming, not very effective, and often leads to errors. In recent years, deep learning and IoT technologies have been widely used for automation and real-time monitoring. The project aims to create and implement a real-time e-waste segregation prototype that combines ESP32-driven mechanical actuation for sorting and classification with YOLOv8-based item recognition. A hybrid AI–IoT framework that improves accuracy and minimises user interaction is used in the system's architecture to sort small electronic components.

Objectives:
1. **Automate Component Segregation:** To design and implement a system capable of classifying and sorting six specific types of e-waste with high precision.
2. **Ensure Hazard Safety:** To integrate a hazard detection protocol that identifies dangerous items and segregates them into a dedicated hazardous waste compartment to minimize human exposure to toxic substances.
3. **Optimize Low-Cost Architecture:** To demonstrate the feasibility of using affordable, off-the-shelf hardware combined with external processing to achieve industrial-level accuracy without expensive industrial computing units.
4. **Achieve High Detection Accuracy:** To train and deploy a YOLOv8-M deep learning model achieving a mean Average Precision of at least 0.8.

Methodology:
The project execution is divided into two main phases: hardware fabrication and software integration, ensuring seamless coordination between object detection and physical sorting.

1. **Hardware Fabrication & Design:**
The mechanical setup consists of a custom-built conveyor system designed for stability, modularity, and low-cost implementation. A base platform of dimensions 60 cm × 27 cm × 10 cm was constructed using high-density thermocol and reinforced cardboard, providing a lightweight yet rigid structure. The conveyor mechanism (14.5 cm × 27 cm × 10 cm) was developed using wooden supports with drilled shafts (4.5

cm diameter) fitted with bearings (2 cm inner diameter) to enable smooth, low-friction rotation. The actuation system includes a 28BYJ48 stepper motor to drive the conveyor and control object positioning. A cylindrical sorting bin divided into four 90° compartments—plastic, hazardous, metals, and non-e-waste—was designed. An MG995 servo motor is mounted at the base of the bin to rotate it precisely based on classification outputs.

2. **Software & System Integration:**
   A custom dataset consisting of 3000 training, 600 validation, and 200 test images was prepared using Roboflow. The YOLOv8-M model was trained on Google Colab (T4 GPU) with a learning rate of 0.01 over 100 epochs, chosen for its balance between accuracy and computational efficiency. For real-time operation, a Streamlit-based interface was developed to handle image capture, inference, and visualization. Due to hardware limitations, model inference is performed on a laptop.
3. **Operational Workflow:**
   The system operates in three phases. First, the ESP32 activates the stepper motor to move the object into the camera's view. Next, the system pauses, and the mobile camera captures the frame, which is processed by the YOLOv8 model to generate class labels. Finally, the classification result is transmitted via Wi-Fi to the ESP32, which rotates the servo motor.

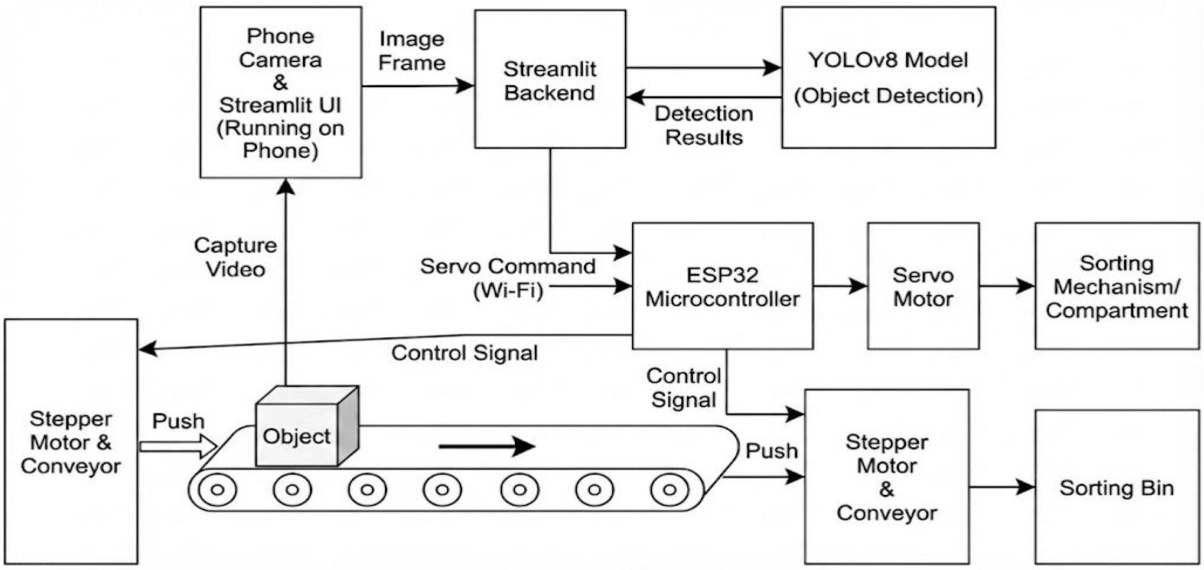

Figure 1: System Architecture

Result and Conclusion:

1. The proposed Eco-Track system successfully demonstrated the feasibility of integrating AI and IoT for automated e-waste component segregation. The YOLOv8-based detection model achieved a mean Average Precision (mAP) of 0.834 and an overall precision of approximately 0.91, indicating reliable performance under controlled laboratory conditions. The system was capable of processing image frames at a rate of 2–3 FPS with an average inference latency of 350–500 ms, which was sufficient for real-time operation in a prototype conveyor setup.
2. The hardware integration using ESP32, stepper motor, and servo motor enabled accurate physical sorting with an actuation response time of around 170 ms. The system effectively classified components such as ICs, LEDs, capacitors, transistors, dry cells, and pendrives into predefined categories including hazardous, plastic, metal, and non-e-waste. Among these, dry cells and ICs showed the highest

detection accuracy, while pendrives exhibited comparatively lower recall due to dataset limitations and higher variability.
3. In conclusion, the project proves that AI-driven vision systems combined with IoT-based actuation can significantly improve the efficiency, safety, and accuracy of e-waste segregation.

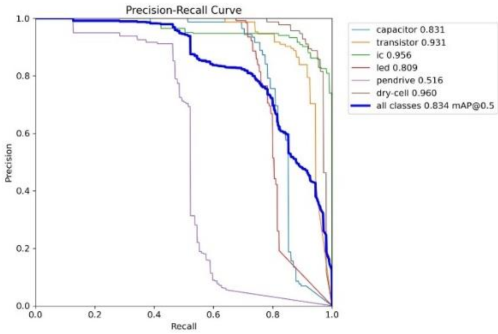

Figure 2: Precision Recall Curve

Figure 3: Project Setup

The Eco-Track project demonstrates a practical approach to automating e-waste segregation using AI and IoT technologies. By integrating YOLOv8-based object detection with ESP32-controlled actuation, the system reduces manual effort and improves sorting accuracy. This has strong relevance in industries such as recycling, waste management, and environmental monitoring, where efficient handling of hazardous materials is critical. In real-world applications, this system can be deployed in recycling plants to assist workers, reduce exposure to harmful components, and increase processing speed. This project involved the development of a **physical working prototype** rather than a simulation or theoretical study.

References:

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Future Scope:

The future scope of this project includes:

1. Expand dataset with more e-waste types and real-world variations and scalability
2. Improve accuracy for complex and similar-looking components
3. Enable edge deployment, industry grade sensors and increase processing speed