

AI Driven e-Waste Segregation Using Robotic Hand

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ABSTRACT: Electronic devices are rapidly gaining popularity and maturing in social life, contributing to an unprecedented accumulation of electronic waste (e-waste) with serious environmental and health implications. Proper recycling and safe disposal of e-waste require efficient segregation. In this paper, the performance of an efficient an AI-based e-waste separation system through a robotic hand was optimized. The camera acquires images of the e-waste items and processes them using YOLOv5. A microcontroller directs a robotic claw to pick up objects and place them into the appropriate boxes based on their classification. The system is evaluated across three key metrics: detection accuracy, sorting time, and overall efficiency. The experimental results show that the system performs with high accuracy while significantly reducing the need for manual labour. Compared to conventional manual sorting methods, the automated approach proves to be quicker, safer, and more dependable.

The paper also addresses the current limitations of the system and outlines potential improvements. Ultimately, the findings highlight how the integration of artificial intelligence and robotics can offer a viable and practical solution for managing e-waste in an automated setting. The rapid growth of electronic technology and the decreasing lifespan of electronic devices have caused a significant rise in electronic waste (e-waste).

KEYWORDS: YOLOv5, Automation, Smart waste system, Environmental protection, YOLOv5

I. INTRODUCTION

The fast development of electronics over the past years has facilitated life and made it easier. Nonetheless, it has also contributed to a high level of electronic waste (e-waste). With the advent of new technologies, older devices are being phased out rapidly, leaving many electronic devices discarded. The increase in e-waste has emerged as a serious issue because it poses negative impacts to human health. E-waste has some hazardous substances like heavy metals and toxic chemicals. When these materials are not handled properly, they can pose serious health risks to both workers and the surrounding environment. Proper segregation of e-waste is therefore one of the most important steps before recycling can begin. Sorting electronic components correctly not only makes further processing safer but also improves the overall efficiency of the recycling pipeline.

Historically, e-waste segregation has been carried out by hand. This approach is slow, inconsistent, and demands a large workforce. Beyond the operational drawbacks, workers are routinely exposed to toxic substances, making the process a genuine safety concern. Given these challenges — slow throughput, frequent errors, and unacceptable health risks — there is a clear need for a more intelligent approach to e-waste sorting.

This project addresses that need by developing an AI-driven system that uses a robotic arm to sort e-waste automatically. A camera captures images of incoming items, and a machine learning model, YOLOv5, identifies and classifies each one in real time. Based on that classification, a microcontroller instructs the robotic arm to pick up the item and place it into the correct container.

The system is evaluated on three fronts: speed, accuracy, and overall efficiency. These results are then compared directly against traditional manual sorting. The findings are expected to confirm tangible advantages — reduced physical strain on workers, a safer sorting environment, and more consistent and reliable outcomes overall. Ultimately, this project makes the case that an automated approach is not just a technological upgrade, but a practical and necessary step toward handling e-waste more responsibly. To resolve this issue, the current project will be devoted to an AI-based e-waste segregation system with the help of a robotic hand. The system employs a camera to take pictures of e-waste products. The images are then subjected to a machine learning algorithm like YOLOv5 which identifies and categorizes the objects. According to the outcomes of the classification, a robotic arm or a robotic claw is controlled by a

microcontroller to retrieve and put the objects in separate containers. The primary objective of this project is to examine the effectiveness of the segregation system in regards to accuracy, speed and efficiency.

To identify its strengths, the system is contrasted to the old manual segregation techniques that used to be used to identify the benefits of the system, including less human effort, increased safety, and enhanced precision. Lastly, the project addresses the constraints of the system and recommends potential ways the system could be improved to achieve a higher performance. This paper demonstrates that integrating artificial intelligence with robotics presents a promising and practical approach to addressing the e-waste sorting problem. The study also acknowledges the current limitations of the system and puts forward several recommendations for improving its performance in future iterations. Overall, this work reinforces the idea that the combination of AI and robotics holds real potential as an effective long-term solution for automated e-waste segregation.

II. SYSTEM OVERVIEW

The proposed system is an automated electronic waste sorting system using AI technology. In the sorting process, a robotic hand can detect and sort different kinds of electronic wastes. The components of this system include a camera module, processor unit, sensor units, microcontroller, and robotic arm. Unlike the existing e-waste sorting systems that use a conveyor belt to move electronic waste products, this system uses manual placement of the e-wastes in a fixed position. A camera module is located at the top of the platform, and it takes pictures of the e-waste products. The processed data is then fed to the processor unit, where the object is classified

IR sensors can be used to detect whether any objects are present and for proper functioning of the system. The processor unit sends signals to the robotic arm based on the object's classification. The robotic hand, consisting of servo motors and gripper, approaches the detected object, picks it, and sorts it in a specific category. Such categories include metals, plastics, and electronic components.

Hardware:

Raspberry Pi 3 Model B+



Figure 1

The Raspberry Pi 3 Model B+ is a mini computer which will act as the central controller of the system. It executes the program, processes data and links all the components together with its GPIO pins. It is also equipped with Wi-Fi and Bluetooth that aids in wireless communication. In this project, it regulates the overall operation and makes decisions on the basis of the input it gets.

Raspberry Pi Camera Module 5MP



Figure 2

I use the Raspberry Pi Camera Module 5MP to take pictures and videos. It is directly linked to the Raspberry Pi with a special camera port, enabling quick data transfer. The camera aids in activities such as detection of objects or surveillance as it presents visual data to the system.

MG996R Servo Motor



Figure 3

The MG996R Servo Motor is applied in movement and positioning. Depending on the signal it receives it can be tilted to a particular angle of 0 degrees to 180 degrees. It is robust and can be used in areas where you need to have controlled movement like moving components in a sorting machine.

ESP32 Microcontroller

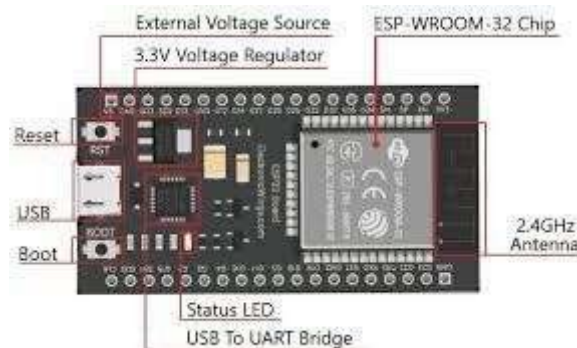


Figure 4

The ESP32 is a microcontroller with built-in Wi-Fi and Bluetooth capabilities, making it well suited for wireless communication and sensor data management. It can both transmit and receive data without the need for additional hardware, and it supports a broad range of IoT-based applications.

Buck Converter Module



Figure 5

To decrease the voltage of 12V to 5V, the 5V 10A Buck Converter Module is used. This is significant since certain parts such as the Raspberry Pi require a reduced voltage to operate safely. It assists in giving a steady and secure power supply.

SMPS



Figure 6

The 12V 10A SMPS Power Supply is the main power source of the system. It transforms AC power into 12 V DC and delivers it to all parts. It is sufficient to power motors and other gadgets adequately.

Servo motor



Figure 7

Servo motor is easily controlled by the Servo Motor Driver Module. It produces the necessary signals and decreases the burden of the main controller. This assists in the appropriate and smooth functioning of the motor.

SanDisk 32GB

**Figure 8**

The operating system and program files of the Raspberry Pi are stored in SanDisk 32GB 120MB/s MicroSD Card. It is similar to the storage memory of the system and assists in the smooth functioning of the software.

Software :**Arduino IDE**

Arduino IDE is a simple to use IDE to write, edit, and upload programs to Arduino and ESP32. It has an easy to use interface where code can be written in C/C++ and uploaded via USB. It has many libraries that allow you to work with sensors, motors, and communication devices without writing complex code from scratch. It also has a serial monitor for debugging and checking the output values. For this project, I used Arduino IDE to program the ESP32 to read data from sensors, control actuators, and send messages between different parts of the system.

Python 3.11

Python 3.11 is an extremely popular programming language known for its simple syntax and ease of understanding. It supports many different styles of programming and a large number of libraries for automating, analyzing data, and image processing. Python is a relatively light-weight language that runs on the Raspberry Pi and is used to automate the hardware or run AI-driven tasks. In the Raspberry Pi, Python is used to write the main control program, process images from the camera, and run object detection algorithms. Python's readability and flexibility makes development easier, especially with more complex operations.

YOLOv5 LITE

YOLOv5 Lite is a lightweight version of the YOLO (You Only Look Once) object detection algorithm designed for low-power devices, such as the Raspberry Pi. Unlike heavy models, YOLOv5 Lite consumes less power and has good performance when detecting objects. It can detect multiple objects in real time from images or video. In this project, it was used to classify objects captured by the camera, so that the system could take appropriate actions. The speed of its processing makes it suitable for small devices like the Raspberry Pi.

Raspberry Pi OS Lite

Raspberry Pi OS Lite is a lightweight Linux operating system designed specifically for Raspberry Pi devices. Raspberry Pi OS Lite does not include graphical user interface (GUI), which saves memory and improves performance. It is mainly controlled via command line, which is ideal for embedded and automation projects. Raspberry Pi OS supports Python and other development tools. This operating system provides the basis on which all programs are run, manages hardware resources, and enables communication between software and hardware components.

III. LIMITATION

The proposed AI-driven e-waste sorting system has some limitations. First, the accuracy of the system depends on the camera's quality and lighting conditions. Poor lighting or shadows could lead to incorrect object detection. It may struggle to identify small items or items that overlap with each other. Second, the robot arm has a limited range and

speed, which could impact the overall performance. Since users manually place items on a fixed platform, the system may function slower than automatic conveyors. Third, it relies on the trained dataset and may not correctly classifying new types of e-waste. Future improvements could include better hardware, improved models, and better system design.

IV. FUTURE SCOPE

There are many ways to improve the system. One way is to improve the accuracy of the system using better cameras and AI models. The system could learn to sort new types of e-waste through training it on a larger dataset. Another way to improve the speed of the system is to use faster processors and better robotics. A futuristic version of the system could be fully automated with a conveyor belt and IoT monitoring. It could be scaled up for industrial applications to sort large amounts of e-waste. Developing mobile or smart applications would enable remote monitoring and control of the system, making it more efficient, reliable, and ready for use in real life.

V. RESULT

The developed system was tested using different types of e-waste items such as wires, plastic parts, and small electronic components. The camera successfully captured the objects, and the YOLOv5 model identified them with good accuracy. After detection, the robotic hand picked up each item and placed it in the correct container. The system worked faster and more accurately than manual sorting. It also reduced human effort and avoided direct contact with harmful waste materials. However, the performance decreased slightly when the lighting was poor or when objects overlapped. Overall, the project proved that combining artificial intelligence with a robotic hand can make e-waste segregation easier, safer, and more efficient.

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