AN IOT BASED SEMI-AUTOMATION TECHNOLOGY FOR E-WASTE SEGREGATION

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Keywords:

E-waste recycling, PCB desoldering, semi-automation, electronic waste segregation, component recovery, three-axis robotic arm.

Introduction:

The treatment of electronic waste (e-waste) has emerged as a significant global challenge due to the rapid advancement of technology and the shortened lifespan of electronic devices. By the year 2030, the amount of waste generated from electrical and electronic equipment is projected to exceed 75 million tons, creating severe environmental, economic, and public health concerns. Improper disposal and unscientific recycling practices lead to soil, water, and air pollution due to the release of toxic substances such as lead, mercury, and cadmium. At present, most e-waste recycling processes depend on manual segregation, which is labor-intensive, unsafe, and inefficient. Workers are exposed to hazardous materials, and valuable components are often lost due to improper handling. Large scale automated recycling systems exist, but they are expensive and inaccessible to small and medium-scale recycling units. The individual electronic components create e-waste and lead to pollution and there is not much importance given to those components. Hence, there is a pressing need to develop economically viable, semi-automated technologies that can safely handle and segregate e-waste while ensuring material recovery in small and medium-scale recycling units.

Objectives:

1. To design and develop an IoT-based semi-automated system for effective segregation of electronic waste, specifically Printed Circuit Boards (PCBs).
2. To minimize human involvement and exposure to hazardous materials during e waste handling and recycling processes.
3. To implement a three-axis robotic arm mechanism for accurate and reliable pick-and-place operations of PCBs.
4. To achieve efficient separation of electronic components from PCBs using controlled mechanical action.

5. To develop a cost-effective and scalable solution suitable for small and medium scale e-waste recycling units.

Methodology:

The proposed system adopts a semi-automated robotic technology for the segregation of e-waste, with a primary focus on printed circuit boards (PCBs). The methodology integrates mechanical automation with controlled thermal desoldering to achieve efficient and non-destructive component separation. A three-axis robotic arm is used to handle PCBs and perform repetitive tasks with consistent accuracy. The robotic arm movements along the X, Y, and Z axes are achieved using DC gear motors driven through L298N motor driver modules and controlled by an Arduino Uno. The system follows a time-based open-loop control method, where all movements are predefined and executed without feedback from sensors. PCB boards are manually placed in an input tray, marking the semi-automated nature of the system. The robotic arm moves to the PCB location, grips the board using a servo-operated gripper, and lifts it securely. The PCB's soldered surface faces downward, preparing it for the desoldering stage. A thermal desoldering technique is employed by dipping the PCB into a heated solder pot for a fixed duration. This process softens the solder joints and weakens the bond between the components and the PCB substrate. Following this, a mechanical shaking method is applied by the robotic arm to dislodge the loosened electronic components. The separated components fall into a collection tray, while the bare or partially processed PCB is transferred to another tray. The use of threaded rods and smooth guide rods ensures smooth, stable, and aligned linear motion of the robotic arm, reducing vibrations and mechanical wear. The methodology avoids destructive shredding processes, preserves component integrity, and minimizes manual handling. Overall, this approach provides a safe, cost-effective, and scalable solution for small-scale e-waste recycling and serves as a foundation for future upgrades toward intelligent automation.

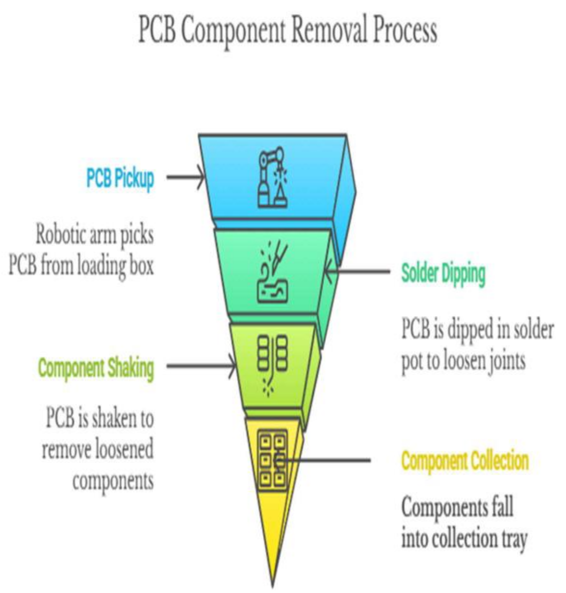

Figure 1: Processing model

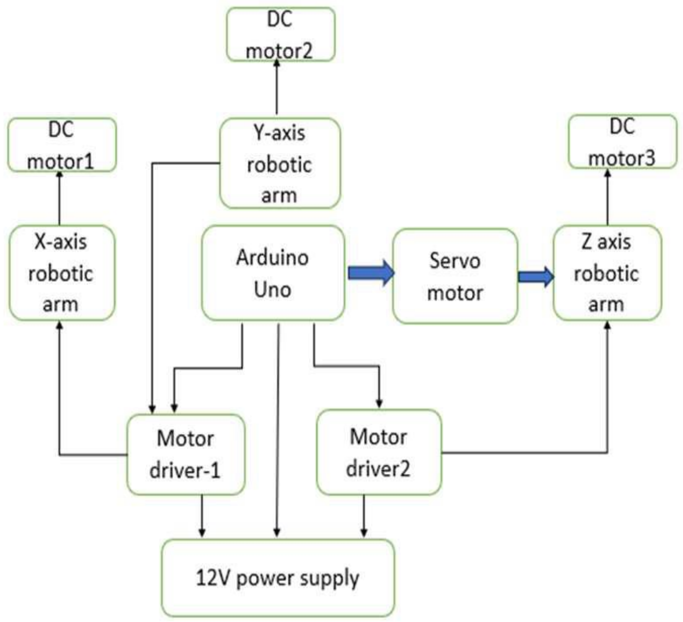

Figure 2: Block diagram of the proposed project

Result and Conclusion:

Before testing, PCB modules contained firmly soldered surface-mounted components that required external heat for removal. Manual desoldering involves direct human contact with heat and tools, making it unsafe. After testing, the robotic system successfully processed PCBs using a solder pot and robotic arm. Dipping the PCB in molten solder for 2 to 3 seconds softened the solder joints effectively. As a result, small components such as resistors, capacitors, and ICs detached and fell into the collection tray. The system demonstrated consistent performance across multiple test cycles without mechanical failure. The gripper securely handled lightweight PCBs, and the Z-axis enabled accurate dipping and lifting. The solder pot temperature was sufficient to loosen joints without damaging the PCB during short exposure.

The results confirm that controlled thermal exposure combined with mechanical shaking enables effective component separation. However, some larger or multi-pin components did not detach completely and may require longer dip time or additional shaking. This limitation is due to time-based control and absence of feedback mechanisms. Despite this, the system significantly reduces manual effort and improves operator safety. Compared to manual methods, it offers better consistency and repeatability. Overall, the project demonstrates a cost-effective and feasible solution for small-scale PCB e-waste segregation.

Parameter	Measured Value	Remarks
Cycle Time per PCB	10–15 seconds	Includes pick → dip → shake → drop
Optimal Dip Time	2 seconds	Maximum removal without overheating
Removal Efficiency	50–60%	Based on SMD components
Gripper Success Rate	60%	Lightweight mobile PCBs
Position Accuracy	±2–3 mm	Sufficient for fixed stations

Table1: Results value

Project Outcomes, Industry Relevance & Learnings

The project successfully demonstrates a low-cost, semi-automated solution for PCB component separation using a robotic arm and controlled thermal desoldering. It reduces the need for manual intervention, thereby improving operator safety by minimizing exposure to heat and toxic solder fumes. The system enhances consistency and repeatability compared to traditional manual desoldering methods. It contributes to the field of electronics and e-waste management by introducing an accessible automation approach suitable for small-scale applications.

From an industry perspective, this solution can be applied in e-waste recycling units, repair workshops, and refurbishing industries for efficient component recovery. It is especially useful for mobile PCB recycling, where large volumes of small boards need processing. The project supports sustainable practices by enabling reuse and proper segregation of electronic components. It also aligns with growing environmental regulations on e-waste

disposal. Overall, the project bridges the gap between manual recycling and fully automated industrial systems, promoting safer and smarter e-waste handling solutions.
I learned practical skills in hardware integration, IoT implementation, and automation control systems. The project enhanced my understanding of real-time problem solving, circuit design, and mechanical coordination and also leadership qualities to handle the team in tough times, encouraging teammates to work with confidence and hard work and also learnt to operate the 3D printer, Laser machine and also mechanical design. Overall, it developed my ability to convert a real-world problem into a functional engineering solution.

Working Model

The project involves the development of a **physical working model** rather than just a simulation or theoretical study. A robotic arm is designed and implemented to handle PCB boards for component separation. The system performs real actions such as picking, dipping, shaking, and brushing components. Hardware components like motors, controllers, and mechanical structures are actively used. IoT integration enables monitoring and control of the processing real time. The working model demonstrates practical feasibility in e-waste segregation. Unlike simulations, it validates performance through actual physical operation. Testing is conducted on real PCB boards to observe efficiency and accuracy. This makes the project more application-oriented and industry-relevant.

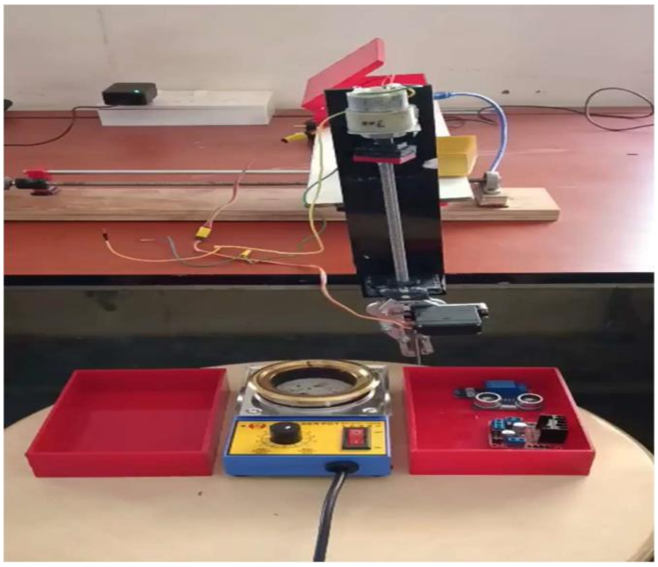

Figure 3: Prototype Image

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Future Scope:

The future scope of this project includes:

1. The proposed IoT-based semi-automated PCB segregation system demonstrates significant potential for advancement in e-waste management. Future improvements can focus on integrating sensor-based feedback systems such as proximity sensors, temperature sensors, and force sensors to enhance accuracy, safety, and reliability of operations.
2. The incorporation of computer vision and machine learning techniques can enable intelligent identification and selective removal of electronic components based on type, size, and reuse potential. This would transform the system from semi-automation to fully intelligent automation.
3. The system can be scaled for industrial applications by increasing load capacity, speed, and integrating conveyor-based feeding mechanisms for continuous PCB processing. Multiple robotic arms can be deployed in parallel to increase throughput.
4. Future work can also include automated classification of extracted components into reusable, recyclable, and waste categories using sorting mechanisms.
5. Safety features such as fume extraction systems, enclosed chambers, and emergency shutdown mechanisms can be added to make the system suitable for real-world deployment.
6. The system can be adapted to handle different types of PCBs such as mobile, laptop, and industrial boards by designing adjustable grippers and flexible configurations.
7. Energy-efficient designs and alternative heating methods like induction or localized heating can be explored to reduce power consumption and environmental impact.
8. Finally, with further development and testing, the system has strong potential for commercialization in small-scale recycling industries and can contribute significantly to sustainable e-waste management and circular economy practices.