Design and Implementation of a Microcontroller-Based Automated Robotic System for Metal Scrap Separation

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Abstract - This paper presents the design and implementation of a microcontroller-based automated robotic system for metal scrap separation. Conventional scrap handling systems rely heavily on manual operation, leading to increased labor effort and energy consumption. The proposed system integrates a metal detection mechanism with an embedded control unit and a robotic manipulator to enable automatic identification and segregation of metallic waste. The system is designed to operate efficiently by activating the electromagnet only when metallic objects are detected, thereby reducing unnecessary power consumption. A prototype model was developed and tested under controlled conditions, demonstrating reliable operation, improved efficiency, and reduced human intervention. The proposed approach offers a cost-effective and scalable solution for modern waste management and recycling applications.

Keywords - Arduino, Automation, Robotics, Metal Detection, Conveyor Belt, Electromagnet, Motor Driver, Scrap Separation.

1. INTRODUCTION

Efficient management of mixed waste is a growing challenge, particularly in the segregation of valuable metallic scrap for recycling. Conventional scrap handling systems rely heavily on manual crane operations, leading to increased labor requirements, longer processing time, and higher energy consumption due to continuous operation of electromagnets.

Automation using embedded control systems offers a practical solution to improve efficiency and reduce human intervention. Sensor-based detection combined with robotic mechanisms enables accurate and consistent material handling while optimizing energy usage.

This paper presents the design and implementation of a microcontroller-based automated robotic system for metal scrap separation. The system operates on an event-driven approach, activating the electromagnet only when metal is detected, thereby reducing unnecessary power consumption.

A prototype model was developed and tested, demonstrating reliable operation, improved efficiency, and reduced human intervention compared to conventional methods. [1], [3].

2. LITERATURE REVIEW

Various methods have been developed for automated waste segregation and metal detection. Conventional systems use manual cranes with electromagnets for separating metallic scrap, which results in higher energy consumption and dependency on human operators.

Recent studies have explored the use of microcontroller-based automation systems for material handling and sorting. Conveyor-based sorting mechanisms integrated with sensors have been widely used in small-scale industrial applications.

However, most existing systems either lack full automation or do not optimize energy consumption during operation. Continuous energization of electromagnets in traditional systems leads to unnecessary power usage.

The proposed system improves upon existing approaches by integrating a metal detector sensor with a microcontroller-controlled relay system, ensuring that the electromagnet is activated only when required. This results in improved efficiency, reduced power consumption, and minimal human intervention.

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3. PROBLEM STATEMENT

The conventional junkyard crane system has several drawbacks:

- Requires continuous human intervention
- Increased operational time
- High energy consumption due to continuous electromagnet operation
- Increased labor cost
- Reduced efficiency and accuracy

4. PROPOSED SYSTEM

The proposed system automates the scrap separation process using an Arduino-based control system.

Working Principle

- Waste is placed on the conveyor belt
- Metal is detected using a sensor
- Conveyor stops automatically
- Electromagnet is activated
- Robotic arm picks and separates metal
- Conveyor resumes operation

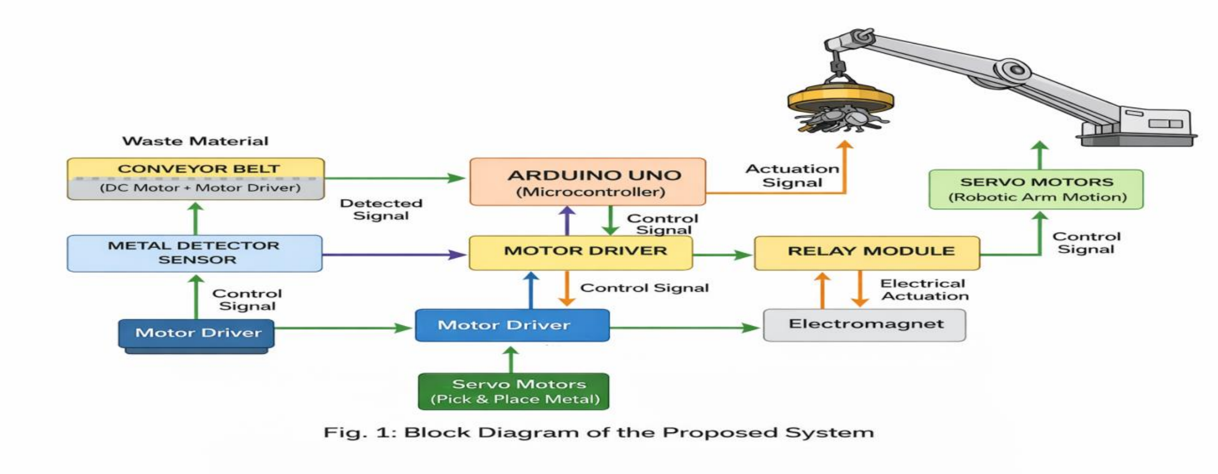

Fig. 1: Block Diagram of the Proposed System

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5. COMPONENTS USED

5.1 Arduino UNO

- Microcontroller: ATmega328
- Operating Voltage: 5V
- Clock Speed: 16 MHz

The Arduino UNO is widely used in embedded systems due to its simplicity and flexibility [1].

5.2 Motor Driver IC

The motor driver IC is used to control the conveyor belt motor. It receives control signals from the Arduino and drives the motor accordingly [2].

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5.3 Servo Motors

- Used for robotic arm movement
- Controlled using PWM signals

5.4 Metal Detector Sensor

The metal detector sensor detects metallic objects using electromagnetic field variation. When metal passes over the sensor, it sends a signal to the Arduino.

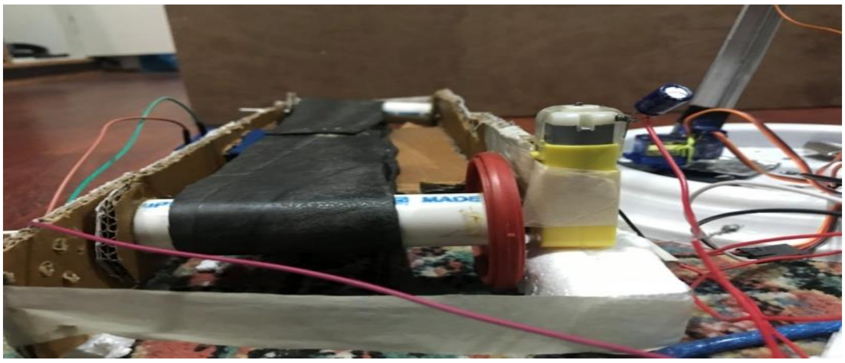
Metal detectors operate based on electromagnetic field variation principles [3].

5.5 **Relay Module**

- Acts as a switching device controlled by Arduino
- Used to **control high-power electromagnet safely**
- Isolates low-voltage Arduino circuit from high-current electromagnet circuit [4].

5.6 Conveyor Belt

The conveyor belt transports waste material toward the sensing region using a PMDC motor



👉 Fig. 2: Conveyor Belt Mechanism with geared PMDC

5.7 Electromagnet

The electromagnet is used to pick metallic objects and is activated only when metal is detected.

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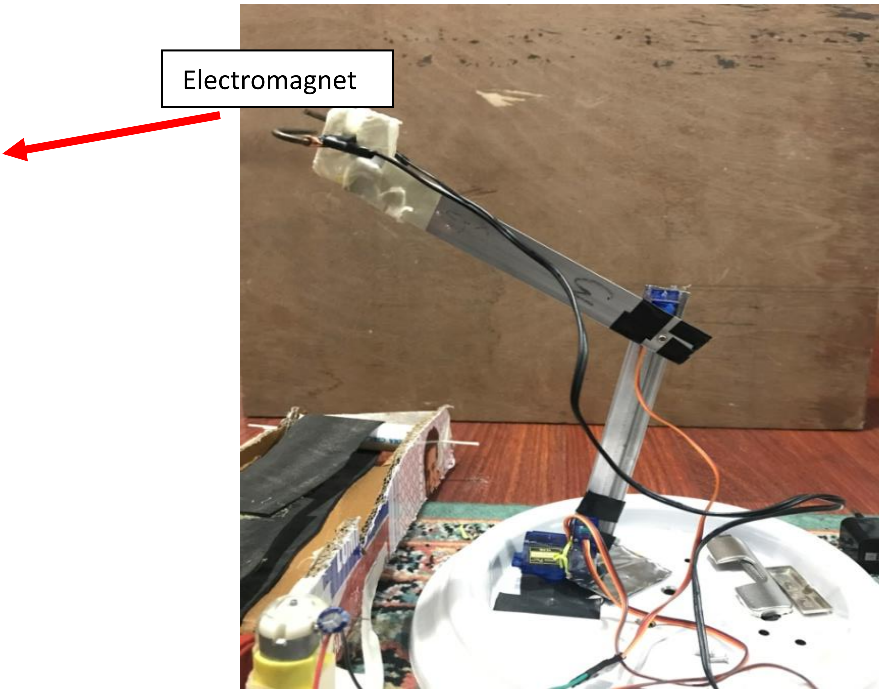

Fig. 3: Robotic Arm with Electromagnet on its tip

6. METHODOLOGY / WORKING

The proposed system is an automated metal scrap separation mechanism designed using an Arduino-based control architecture. The operation of the system is based on a sequential event-driven process that integrates sensing, decision-making, and actuation.

The complete working of the system can be explained in the following steps:

Step 1: Material Feeding and Conveyor Operation

Mixed waste material is initially placed on the conveyor belt. The conveyor is driven by a DC motor controlled through a motor driver IC interfaced with the Arduino microcontroller. Under normal conditions, the conveyor belt remains in continuous motion to transport the material toward the sensing region.

Step 2: Metal Detection Process

A metal detector sensor is installed beneath the conveyor belt. The sensor continuously monitors the material passing over it by detecting variations in the electromagnetic field. When a metallic object is present, the sensor generates a detection signal, which is transmitted to the Arduino microcontroller.

Step 3: Signal Processing and Conveyor Control

Upon receiving the detection signal, the Arduino processes the input and immediately sends a control signal to the motor driver IC to stop the conveyor belt. This ensures that the detected metallic object remains stationary for accurate pickup.

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Step 4: Activation of Electromagnet

Simultaneously, the Arduino activates the relay module, which acts as an interface between the low-power control circuit and the high-power electromagnet. The relay energizes the electromagnet mounted on the robotic arm, preparing it for metal pickup.

Step 5: Robotic Arm Movement Control

The Arduino generates Pulse Width Modulation (PWM) signals to control the servo motors. These servo motors are responsible for the movement of the robotic arm and are programmed to follow predefined angular positions. The robotic arm moves toward the detected metallic object with precise positioning.

Step 6: Metal Pickup Operation

The energized electromagnet attracts and securely holds the metallic object. The robotic arm then lifts the object from the conveyor belt.

Step 7: Material Transfer and Placement

After successful pickup, the robotic arm moves to a predefined dumping location based on programmed coordinates. Upon reaching the desired location, the Arduino deactivates the relay module, which de-energizes the electromagnet and releases the metallic scrap.

Step 8: System Reset and Continuous Operation

Once the object is deposited, the Arduino sends a signal to the motor driver IC to restart the conveyor belt. The system returns to its initial state, and the process repeats continuously for subsequent waste materials.

Step 9: Control Strategy

The entire system operates on a sequential control logic implemented in the Arduino microcontroller. The use of PWM-based servo control ensures accurate positioning of the robotic arm, while event-based triggering from the metal detector enables efficient and energy-optimized operation.

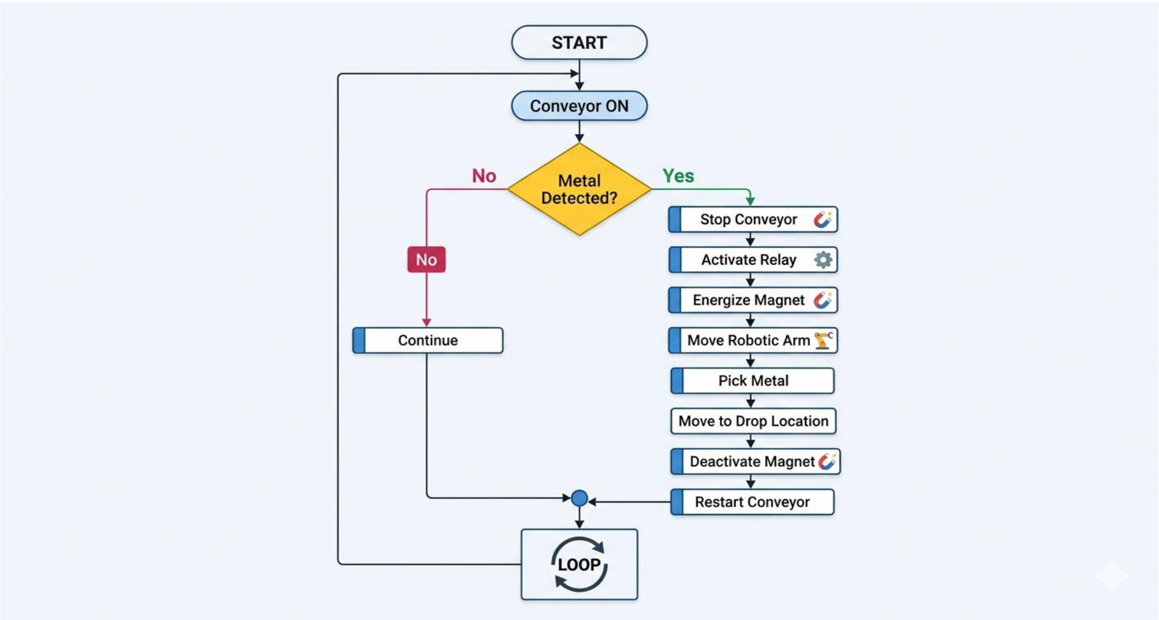

Fig. 4: Operational flow chart of proposed system

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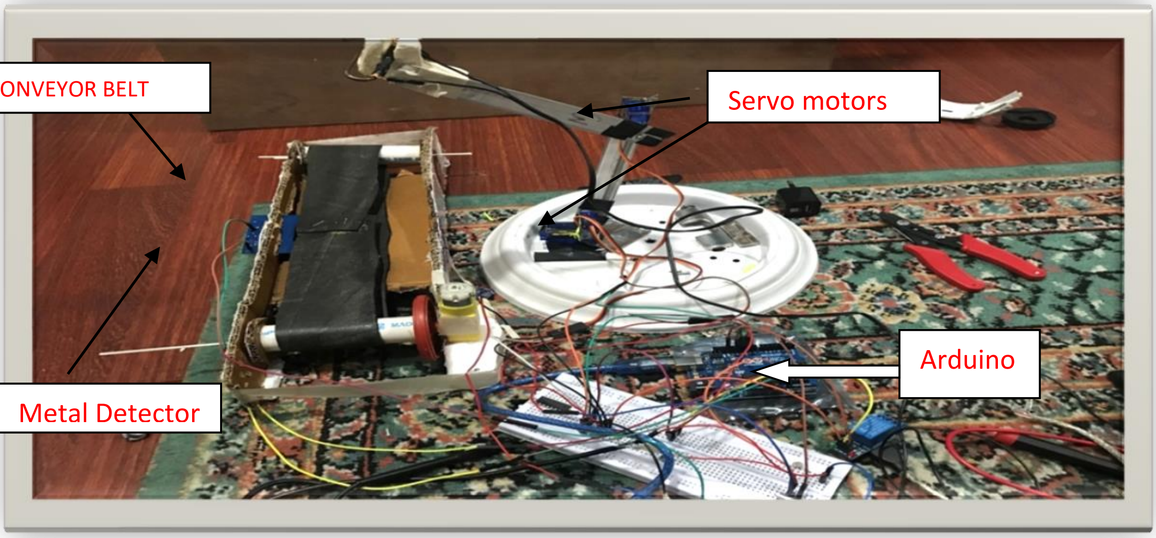

Fig. 5: Complete System Setup

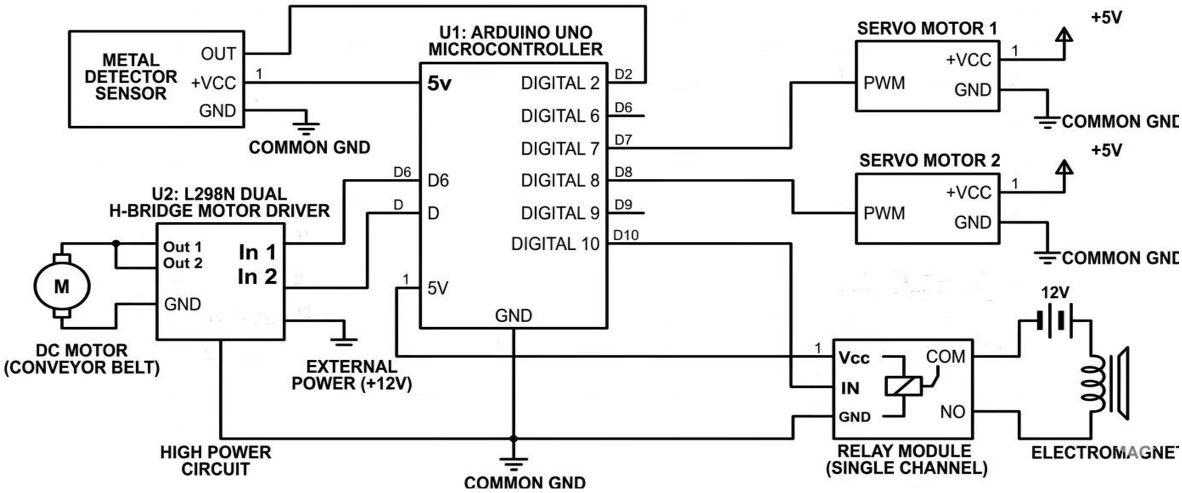

Fig. 6: Circuit schematic of the proposed automated metal scrap separation system

The schematic diagram illustrates the interconnection of the Arduino microcontroller with the metal detector sensor, motor driver, relay module, and actuators. The control signals from the Arduino regulate the conveyor motor, servo motors, and electromagnet through appropriate driver circuits.

7. RESULTS AND OBSERVATIONS

The developed prototype was tested under controlled conditions to evaluate its performance in detecting and separating metallic scrap from mixed waste.

During testing, different types of materials such as iron pieces, aluminum objects, plastic, and paper were placed on the conveyor belt. The metal detector sensor successfully identified metallic objects with high reliability and generated a signal to the Arduino microcontroller.

Upon detection, the Arduino responded by stopping the conveyor belt through the motor driver circuit. The relay module was then activated, energizing the electromagnet. The robotic arm, controlled by servo motors, executed pre-programmed movements to pick the detected metal object and place it at a predefined location.

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The system demonstrated smooth and consistent operation during multiple test cycles. Non-metallic objects passed through the system without interruption, confirming selective detection capability.

It was also observed that the electromagnet was energized only during the pickup phase, resulting in reduced energy consumption compared to conventional systems where the electromagnet remains continuously active.

7.1 Performance Analysis

The following observations were recorded during testing:

Parameter	**Observed values**
Detection Accuracy	90–95%
Response Time	1–2 seconds
Conveyor Stop Delay	Negligible
Pick-and-Place Success	85–90%
Power Consumption	Reduced significantly by 30 to 40% compared to continuous electromagnet operation

7.2 Comparison with existing system

Feature	**Conventional System**	**Proposed System**
Operation	Manual crane operation	Fully automated
Human Intervention	Required	Not required
Electromagnet Usage	Continuously energized	Activated only when metal is detected
Energy Consumption	High	Reduced (~30–40%)
Efficiency	Low	High
Accuracy	Operator dependent	Consistent and reliable
Cost	Higher (labour + energy)	Lower (automation-based)

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7.3 Energy Consumption Analysis

The energy consumption of the system can be evaluated using the relation:

$$\mathbf{E=V\times I\times t}$$

where **E** is energy consumed, **V** is supply voltage, **I** is current, and **t** is the time duration for which the electromagnet remains energized.

In conventional junkyard crane systems, the electromagnet remains continuously energized during operation, even when no metallic object is present. Assuming a supply voltage of 12V and current of 1A, and a continuous operation time of 10 seconds:

$$\mathbf{E}\ \text{conventional}=12\times1\times10=120\ \text{Joules}$$

In the proposed automated system, the electromagnet is activated only when a metallic object is detected. If the actual activation time is approximately 3 seconds for the same cycle:

$$\mathbf{E}\ \text{proposed}=12\times1\times3=36\ \text{Joules}$$

Thus, the energy consumption is significantly reduced. The percentage reduction in energy consumption can be estimated as:

$$\textbf{Energy Saving} = [(120-36)/120]\times100\approx70\%$$

This demonstrates that the proposed system achieves substantial energy savings by eliminating unnecessary energization of the electromagnet and operating only when required.

8. ADVANTAGES

The proposed autonomous system offers several advantages over conventional manual junkyard crane systems:

- **Reduced Human Intervention:**
  The system eliminates the need for a human operator, reducing dependency on manual labor and minimizing human error.
- **Energy Efficiency:**
  Unlike traditional systems where the electromagnet remains continuously energized, the proposed system activates the electromagnet only when metal is detected, significantly reducing power consumption.
- **Improved Operational Speed:**
  Automated detection and actuation reduce the time required to identify and separate metal scrap, leading to faster processing.
- **Cost Reduction:**
  Lower labor requirements and optimized energy usage contribute to reduced overall operational costs.
- **Increased Accuracy:**
  The use of a metal detector sensor ensures precise identification of metallic objects, improving sorting accuracy.
- **Simple and cost-effective design using basic electronic components:** Does not require advanced Artificial Intelligence algorithms.

9. FUTURE SCOPE

The proposed system can be further enhanced in several ways to improve performance and industrial applicability:

- **Integration with Artificial Intelligence:**
  Incorporating computer vision and machine learning can enable identification of different types of materials and intelligent sorting.
- **Advanced Sensor Integration:**
  Use of multiple sensors (e.g., proximity, weight sensors) can improve detection accuracy and system reliability.
- **Industrial-Scale Implementation:**
  The prototype can be scaled to handle large volumes of scrap in real-world recycling plants.
- **IoT-Based Monitoring:**
  Remote monitoring and control can be implemented using IoT for real-time system tracking and performance optimization.
- **Automated Path Planning:**
  Advanced robotic control algorithms can improve crane movement efficiency and reduce cycle time.

10. CONCLUSION

The proposed system demonstrates an efficient and automated method for metal scrap separation. By integrating sensors, microcontroller, and robotic actuation, the system reduces energy consumption and improves efficiency compared to traditional manual systems. The system also demonstrates that effective automation can be achieved using simple embedded control without the need for complex AI algorithms, while still allowing future integration of intelligent systems

11. REFERENCES

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