STM JOURNALS

Journal of
Electronic Design Technology

ISSN: 2229-6980 (Online)
ISSN: 2321-4228 (Print)
Volume 17, Issue 1, 2026
January–April
DOI (Journal): 10.37591/JoEDT

https://journals.stmjournals.com/joedt

Review JoEDT

Design of Scrap Collection and Reward Machine Using Verilog HDL

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Abstract

The growing amount of waste produced in urban environments has led to a demand for effective and automated recycling solutions. In this paper, a scrap collection and reward machine is designed and implemented using the Verilog hardware description language (HDL). The proposed system is developed to provide a reliable and automated approach for managing recyclable materials while motivating users through a reward-based mechanism. The design includes scrap input interfaces, a control unit for processing, and a reward calculation module. It is capable of handling different types of scrap materials, where non-metal items are processed using a count-based method, and metal items are evaluated using pre-defined weight ranges to ensure fair reward distribution. The design is realized at the register transfer level (RTL) with Verilog HDL and developed using the Vivado toolchain. Simulation results confirm the correct operation of scrap detection and reward computation. Moreover, the system features a structured control flow that guarantees the correct identification and classification of input materials prior to reward allocation. The modular design strategy facilitates easy expansion to accommodate additional categories of recyclable waste in the future. The proposed system is designed with a focus on simplicity, scalability, and efficient hardware utilization, making it suitable for integration into smart waste management systems.

Keywords: Scrap collection system, reward machine, Verilog HDL, weight-based calculation, digital system design

INTRODUCTION

The increasing population and rapid urbanization have significantly contributed to the growth of solid waste generation in cities. Improper disposal and inefficient recycling practices not only harm the environment but also reduce the effectiveness of resource reuse [1]. Recycling plays a vital role in sustainable development; however, the lack of efficient segregation systems limits its potential.

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Received Date: March 30, 2026
Accepted Date: March 31, 2026
Published Date: April 02, 2026

Citation: K. Chaitanya, Ch.P. Brahmeswar, D. Ramesh, A.S. Siddardha, B. Sravan Kumar, S. Leela Veni. Design of Scrap Collection and Reward Machine Using Verilog HDL. Journal of Electronic Design Technology. 2026; 17(1): 37–45p.

Traditional waste management systems rely heavily on manual labor to sort recyclable materials. This process is time-consuming, error-prone, and inefficient, particularly in high-volume environments such as public spaces and transportation hubs [2]. Consequently, many recyclable materials are either incorrectly classified or completely wasted. In addition to its ineffectiveness, manual sorting puts workers at risk of health and safety hazards, such as encounters with dangerous substances, sharp items, and unhygienic environments.

Automated systems, such as reverse vending machines, have been introduced to improve recycling participation. These systems accept

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recyclable materials and provide rewards or incentives to users, encouraging responsible waste disposal [3]. However, many existing systems are limited in functionality, often supporting only a specific type of material, such as plastic bottles.

RELATED WORK

Several studies have focused on developing automated recycling and waste management systems using sensor-based technologies and embedded platforms. Reverse vending machines are widely used in public environments to collect recyclable materials and provide incentives, such as coupons or digital rewards [4].

Many existing systems utilize microcontrollers and sensors to detect and classify recyclable objects. These systems typically use optical, proximity, and weight sensors to identify materials and determine reward values [5]. While these designs provide basic automation, they often suffer from limitations, such as reduced processing speed and limited material classification capability.

Most of these systems are implemented using embedded microcontrollers that process input sequentially and have limited scalability. These systems become less efficient as the complexity of the classification and reward mechanisms increases [6].

Field-programmable gate arrays (FPGAs) offer a promising alternative by enabling parallel processing and high speed operation. Verilog HDL allows designers to implement digital systems at the register transfer level (RTL), providing flexibility and efficient hardware realization [7].

In this study, an automated scrap collection and reward machine was designed using Verilog HDL. The system supports multiple types of scrap materials and incorporates both count- and weight-based reward mechanisms to ensure fair and accurate compensation.

Recent advancements in smart waste management have introduced IoT-based systems that monitor waste levels and optimize collection processes [8]. Although these systems improve waste monitoring efficiency, they primarily focus on data collection rather than automated reward-based recycling.

FPGA-based systems have gained attention owing to their ability to handle complex digital operations with high speed and parallel processing capabilities. Compared with traditional embedded systems, FPGA implementations provide better performance and scalability for real-time applications [9].

The proposed system builds on these concepts by implementing scrap detection, classification, and reward calculation using Verilog HDL on an FPGA platform. This approach enhances the system efficiency [10].

SYSTEM ARCHITECTURE

The proposed scrap collection and reward machine was developed as a modular digital system based on FPGA architecture. The entire system operates in a synchronized manner using a clock-driven approach, where all functional units are coordinated through control logic implemented at RTL. The design comprises several interconnected modules, such as input detection, classification, processing, and reward generation. Each module executes a designated task and interacts with other modules to guarantee seamless data transfer and correct functioning. The clock signal ensures that these modules are correctly timed and synchronized, whereas the control signals dictate the order of operations. This methodical approach boosts the dependability of the system, simplifies debugging, and enables straightforward scalability for future enhancements.

The system is composed of the following main modules:

- *Input Detection Unit:* Non-Metal and metal objects such as wrappers, plastic objects, glass, iron, and copper.

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- *Sensor Interface Unit:* Infrared *(*IR), Optical, Inductive, and capacitive sensors are used for the detection of objects.
- *Control and Processing Unit:* This is the main logical flow of the RTL code.
- *Reward Calculation Module:* The reward is calculated using pre-defined prices and based on count and weight.
- *Output Display - Dispensing Unit:* Here, the output is displayed, and the total reward is dispensed to the user.

The operation begins when the user inserts a scrap item into the machine. An IR sensor detects the presence of an object and triggers the system to start processing. The sensor interface unit then gathers signals from the inductive and capacitive sensors to determine whether the material is metallic or non-metallic. It supports multiple scrap types and provides a scalable solution for modern recycling systems.

If the detected material is metal, a load cell is used to measure its weight, and the analog signal is converted into a digital form using an analog-to-digital converter (ADC). All the collected sensor data were then sent to the FPGA-based control unit for further processing.

The control and processing unit is responsible for classifying the material, maintaining the count values, and performing reward calculations using Verilog HDL. Depending on the material type, the reward calculation module applies either a count-based method for non-metal items or a weight-based method for metal items.

Finally, the output unit displays the calculated reward value and activates the dispensing mechanism to provide a reward. This structured and modular design, as shown in Figure 1, ensures reliable operation, efficient processing, and easy scalability for future enhancements.

WORKING FLOW

The proposed system operates sequentially and automatically to ensure accurate scrap classification and reward calculation. The process begins when a scrap item is inserted into the machine, which is detected by an infrared (IR) sensor. The material is then identified using inductive and capacitive sensors.

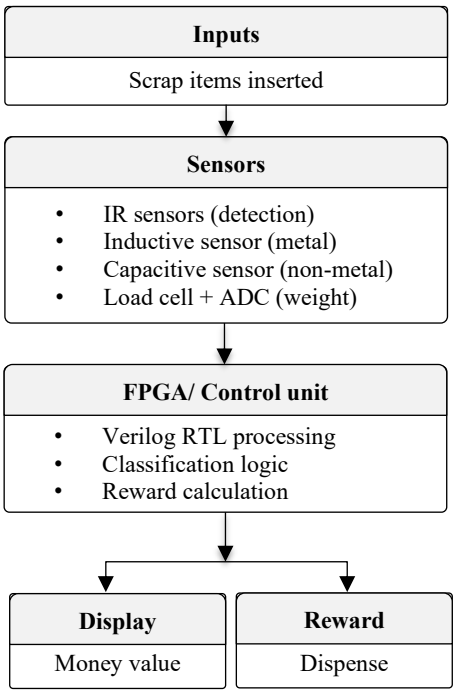

Figure 1. System architecture.

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Based on the classification, non-metal items are counted, whereas metal items are processed through a load cell to measure their weight. The FPGA processes these inputs using Verilog HDL logic and calculates the reward using count- or weight-based methods. Finally, the computed reward is displayed and dispensed to the users.

System operation can be represented using the following algorithm, which ensures reliable and systematic processing of scrap items.

- *Step 1:* Initialize the system and reset counters.
- *Step 2:* Wait for scrap insertion
- *Step 3:* Detect an object using an IR sensor.
- *Step 4:* Identify material type
- Step 5: If the object is nonmetal, increment the count.
- Step 6: If the object is metal, measure its weight.
- *Step 7:* After being done, calculate the reward.
- *Step 8:* Display reward value
- *Step 9:* Reset the system for the next input.

Reward Calculation Model

The reward calculation mechanism is designed to provide fair and flexible incentives based on the type of scrap material used.

The wrapper price is 1, the P_object price is 1, the glass price is 2, the iron price is 3, and the copper price is 4.

Count-Based Reward (Non-Metal)

For non-metal items, such as wrappers, plastic objects, and glass, the reward is calculated based on the number of items inserted.

$R_{count} = (W_c \times 1) + (P_c \times 1) + (G_c \times 2)$,

Where:
W_c= Wrapper count
P_c= Plastic object count
G_c= Glass count

Weight-Based Reward (Metal)

For metal items such as iron and copper, the reward is calculated using a weight-based approach.

$$\text{Weight factor} = \frac{\text{Metal weight}}{50}$$

$$R_{\text{metal}} = (\text{Iron factor} \times 3) + (\text{Copper factor} \times 4)$$

Total Reward

$$R_{total} = R_{count} + R_{metal}$$

This combined approach ensures accurate reward distribution and encourages the recycling of both metal and non-metal materials.

RTL DESIGN IMPLEMENTATION

The system was implemented using Verilog HDL at RTL. Behavioral modeling was used to describe the system functionality, including scrap detection, counting, and reward calculation.

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The RTL design consists of:

- Counters for non-metal items.
- Comparators for weight classification.
- Multipliers for reward calculation.
- Adders for total reward computation.
- Registers for data storage.

The design was synthesized using the Xilinx Vivado 2024.1 design tool, which maps the RTL code to the FPGA hardware resources. The use of an FPGA enables parallel execution of operations, resulting in faster processing compared to embedded systems.

SIMULATION RESULTS AND PERFORMANCE ANALYSIS

The proposed system, as shown in Figure 2, was simulated using Xilinx Vivado 2024.1 to verify its functionality under different input conditions. The simulation confirmed the correct detection, classification, and reward calculation for both count-based and weight-based inputs. The design was further synthesized to evaluate hardware utilization and performance, as shown in Figure 3. To assess the efficiency of the proposed system, a comparison is made, as shown in Figure 4, with existing embedded and very large scale integration (VLSI)-based recycling systems in terms of delay, power, and resource usage.

In the comparison, Table 1 lists the representative values derived from the literature and typical implementations used for the comparative analysis.

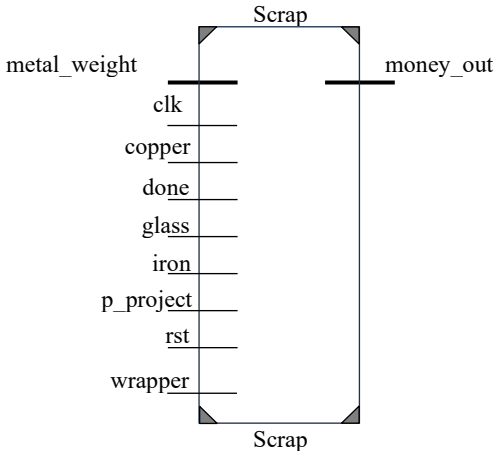

Figure 2. Pin schematic.

Table 1. Comparison table.

Parameter	Existing embedded system	Existing VLSI ASIC system	Proposed system
Technology	Microcontroller based	ASIC level	FPGA (Verilog RTL)
Processing type	Sequential	Limited	Fully parallel
Delay	~10 ms	~7–9 ns	6.99 ns
Power consumption	~10–15 W	~0.2–2 W(optimized)	0.14 W (logic power) 8.4 W (On-chip non-optimized power)
LUT usage	-	~80–110	98
Flip-flops	-	~50–60	47
Slices	-	-	54
Scalability	Limited	Moderate	High
Reward	Basic	Limited	Dynamic
Scrap types	Single	Few	Multiple
Accuracy	Medium	High	High

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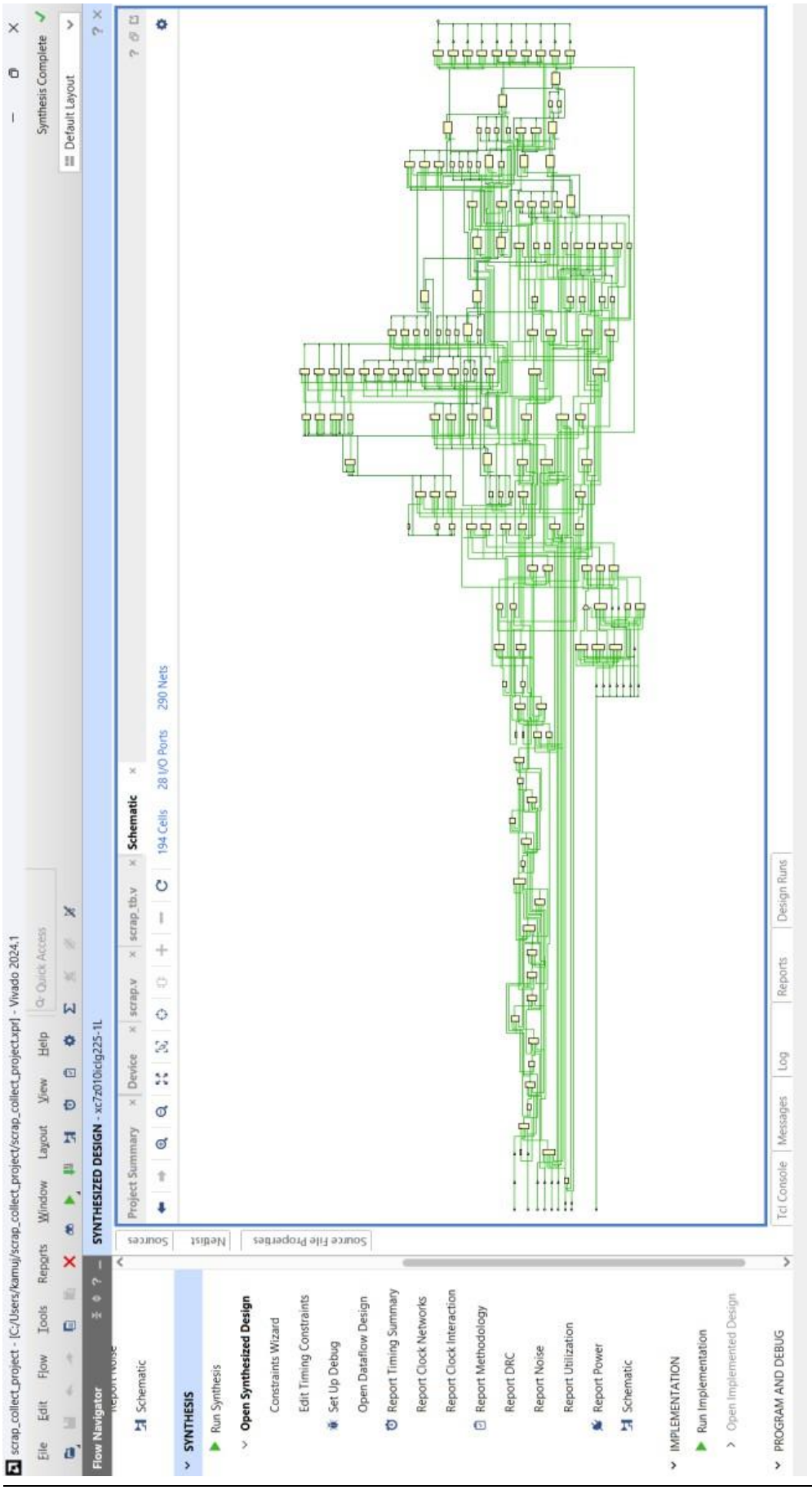

Figure 3. Schematic of hardware utilization and performance.

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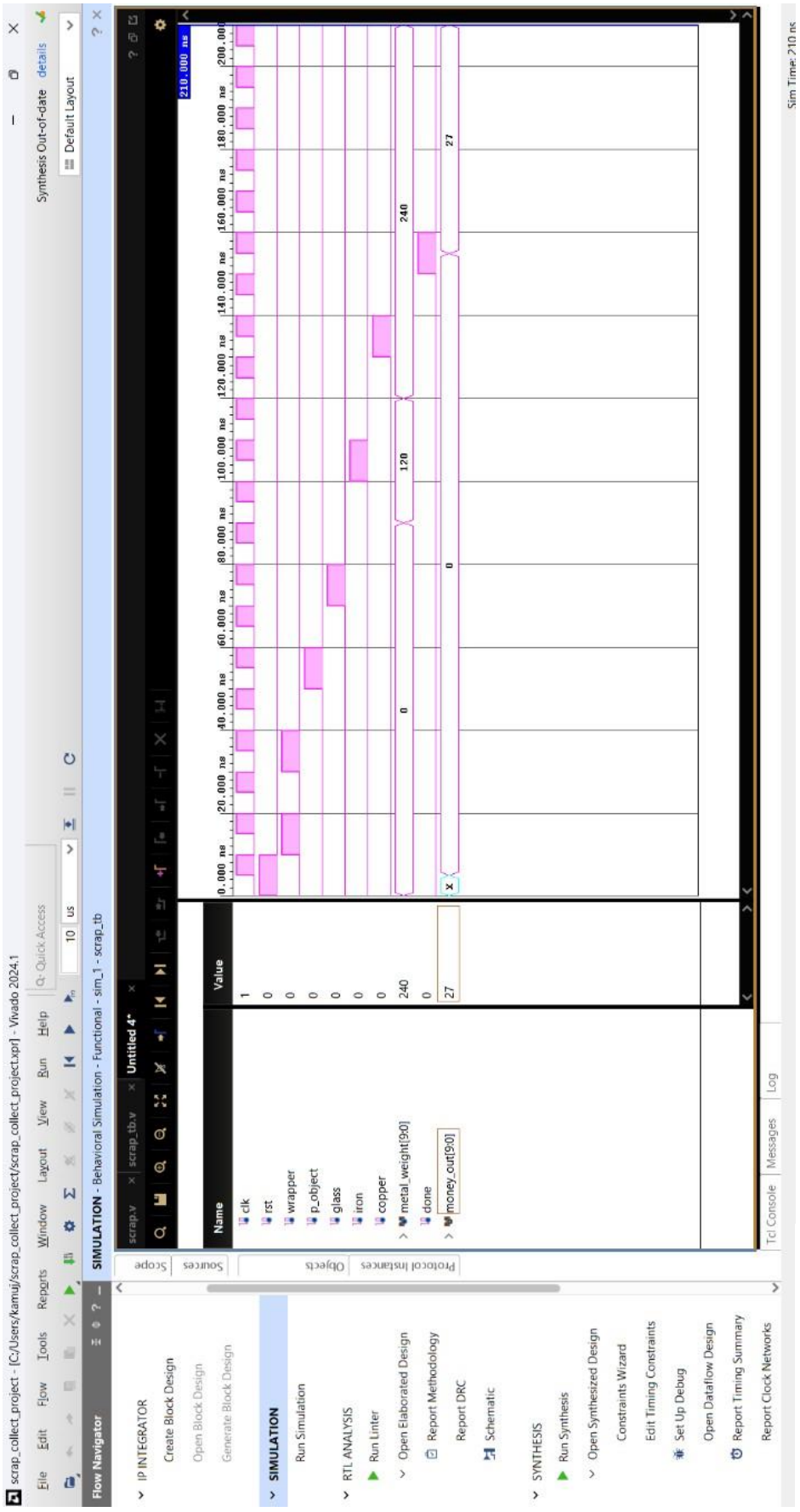

Figure 4. Output waveform.

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The power consumption of the proposed system is higher than that of application-specific integrated circuit (ASIC) designs owing to the additional overhead of the FPGA architecture, including configurable logic and routing resources. However, FPGA implementation offers significant advantages, such as flexibility, easy modification, and faster prototyping. It also supports scalability, making it suitable for real-time and evolving applications.

ADVANTAGES AND APPLICATIONS OF PROPOSED SYSTEM

Advantages

The proposed system provides several advantages over traditional recycling methods:

- Fully automated scrap detection and processing.
- Supports multiple scrap types.
- Accurate reward calculation.
- Faster processing using an FPGA.
- Reduced human intervention.
- Scalable design for future expansion.

Applications

The system can be deployed in:

- Smart waste management systems.
- Public recycling kiosks.
- Railway stations and airports.
- Smart city infrastructure.
- Educational VLSI and FPGA projects.

CONCLUSION AND FUTURE SCOPE

This paper presents the design of an automated scrap collection and reward machine using Verilog HDL. The system integrates sensor-based detection with FPGA-based digital processing to achieve efficient scrap classification and reward calculations.

The design supports both count- and weight-based reward mechanisms, ensuring fair and flexible operation. The simulation and synthesis results confirmed the correct functionality and hardware efficiency of the system.

Future enhancements may include integration with real hardware sensors, implementation on FPGA development boards, IoT-based monitoring, and mobile-based reward systems. Furthermore, the system can be enhanced by integrating sophisticated sorting methods that utilize machine-learning algorithms to improve the precision of material identification. To avert abuse, protective elements such as user verification and transaction monitoring can be incorporated. Incorporating design strategies that promote energy efficiency will enhance the optimization of power consumption, thereby increasing the sustainability of the system. Furthermore, the incorporation of cloud connectivity allows centralized data monitoring, analysis, and reporting. This capability supports large-scale implementation in smart city environments and fosters effective waste management.

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