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Design and Development of a Smart Trash Bin for Recyclable Wastes

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Abstract – *Most human activities generate solid waste, which is an unavoidable byproduct. Solid waste management is critical to reducing waste and improving recycling. Uncollected trash and poor waste disposal have severe health and environmental repercussions. Furthermore, most public trash bins overflow due to inefficient waste management practices. As a result, for an immediate and optimized waste collection operation, a waste classification management and remote monitoring system are required to properly segregate trash and notify relevant authorities about the trash levels of the bins. This paper presents the design and development of a smart trash bin that uses an Arduino microcontroller to segregate recyclable materials, monitor trash levels in bins, and send an SMS alarm to authorities through GSM communication. A 12V battery powers the system, supplemented by a solar panel. The smart trash bin's design is appropriate for proper waste disposal of recyclable materials. It will assist authorities in planning an efficient waste collection strategy. The designed trash bin costs 180 USD, which is comparable and affordable to existing smart trash bins.*

Keywords – *GSM Communication, Recyclable Waste Segregation, Sensor-based System, Trash Level Monitoring, Waste Management System*

INTRODUCTION

According to the World Bank Urban Development department report, the expected volume of municipal solid waste (MSW) will increase from 1.3 billion tons annually to 2.2 billion tons annually by 2025 (Hoornweg & Bhada-Tate, 2012). Most of the growth will occur in rapidly growing cities in developing nations. Over the next 30 years, rapid urbanization, population growth, and economic development will drive a 70% increase in world trash generation. Uncollected trash and improper waste disposal have severe health and environmental consequences. Frequently, the expense of mitigating these effects exceeds establishing and operating simple, adequate waste management systems (Ella et al., 2022).

Like any other developing economy, solid waste management remains a significant obstacle (Moriguchi & Hashimoto, 2015). The Philippines' waste generation has increased from $37 \cdot 10^3$ kg·a^{-1} in 2012 to $40 \cdot 10^3$ kg·a^{-1} in 2016, with daily garbage per capita ranging between 300 and 700 grams in rural and urban areas (Lagman-Bautista & Eleria, 2020). According to the National Solid Waste Management Status Report of DENR, recyclable waste accounts for nearly a third (27.87%) of Municipal Solid Waste. Recyclable garbage includes plastics (10.56 %), paper and cardboard (8.61 %), glass (2.43 %), metal (4.22 %), textiles (1.61 %), rubber and leather (0.44 %) (DENR, 2018). If trash is not effectively managed, environmental issues will worsen over time and become the most significant obstacle to sustainable development. Municipal solid waste contains numerous recyclable components; recycling reduces waste emissions, adds value, and cuts costs. Waste classification management will therefore be the most effective method (Zhang et al., 2021).

The term waste management is essential in everyone's life. Pollution and the accumulation of enormous volumes of garbage in the lack of an

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appropriate waste management system have become one of humanity's most serious problems (Goutam Mukherjee et al., 2021). Trash bins in public places are not optimized and poorly maintained, which is unappealing, especially if garbages overflow. Most people are reluctant to throw their garbage in trash bins because the conventional design of such bins necessitates the user to open the bin's lid to throw their garbage. These lids are prone to spread germs and bacteria, which can cause a variety of diseases because it dirty and not properly maintained.

Moreover, these trash bins cannot be emptied for an extended time, and some people do not segregate their trash. As a result, improper waste management and segregation contribute to the spreading diseases and unpleasant odors to the surrounding area. People may quickly become ill as a result of this odor. In addition, many believe it is more practical to neglect waste segregation and dispose of their garbage on roadsides or rivers (Chandra & Tawami, 2020).

To address this problem, researchers develop ways to dispose of and manage waste properly. Smart Trash Bins are among the smart waste management solutions that are being developed. This technique helps reduce operational expenses and resolve environmental problems. This technology will contribute to the effectiveness and efficiency of waste management and recycling operations and reduce human labor.

The studies presented by (Chandramohan et al., 2017; Rafeeq et al., 2016; Sharanya et al., 2017) demonstrated automated waste sorting technologies. Their waste segregation system for recyclable materials such as metal, plastic, and glass is simple to implement. Their technology can detect metallic objects using inductive and capacitive sensors to differentiate between metallic trash and non-metallic garbage.

A dynamic waste collecting system must be implemented to address urban waste management's high costs and inefficiency. It is necessary to monitor the trash bins' levels to establish a dynamic waste collection method. The design of the smart trash bins featured in studies of (Ashwin et al., 2021; Haribabu et al., 2018; Kolhatkar et al., 2018; Kristanto et al., 2016; Utomo et al., 2018; Widiastiwi & Satria, 2020) often uses ultrasonic sensors to determine trash levels and integrate wireless communication technologies to inform authorities of trash level status to optimize waste collection.

The idea for smart trash bins uses the Internet of Things (IoT) and wireless sensor network technologies. Using Internet of Things (IoT) devices and Radio Frequency Identification (RFID) tags has entirely changed how waste is managed (Brancoli et al., 2020; Zeb et al., 2019). These bins are called "smart" because they have IoT devices built-in and other new technologies like RFID readers, ultrasonic sensors, weight sensors, solar cells, and light-emitting diodes as indicators (Al-Jabi & Diab, 2017). These sensors help detect the total garbage volume and are designed to be attached to trash bins and capable of detecting waste.

Objectives Of The Study

The objective of this study is to develop a smart trash bin for recyclable wastes. The smart trash bin is a sensor-based system wherein capacitive, and inductive proximity sensors will be used to detect and sort trash. The study will only be limited to sorting non-metal and recyclable metal trash such as tin cans and plastic bottles. Other classifications of trash, such as paper, wood, plastics, and others, can be detected by the smart trash bin but will not be sorted appropriately and will not be included in this study. Furthermore, the lid of the trash bins can automatically close and open if the user wants to throw their trash. This feature will ensure that users will not be touching the trash bins' filthy lids, which can spread germs and viruses. In addition, an autonomous trash level detection via an ultrasonic sensor will be integrated to address the overflowing trash over an extended period. A GSM module is also integrated to achieve wireless monitoring and control of the system. The development of this smart trash bin will improve accessibility and allow authorities to conduct proper waste disposal planning.

Materials and Methods

System Architecture

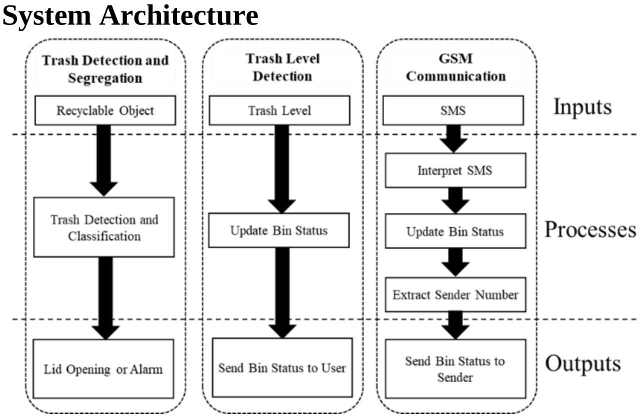

Figure 1. System Architecture of the Proposed System

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Fig.1 depicts the System Architecture of the features that make up the Smart Trash Bin System: Trash Detection and Segregation, Trash Level Detection, and GSM Communication. Each feature is addressed in greater detail in the sections that follow.

Trash Detection and Segregation

The Smart Trash Bin's waste segregation functionality comprises servo motors and capacitive and inductive sensors. A capacitive sensor is a non-contact device that is capable of sensing the presence or absence of nearly any object, regardless of its material composition, without the need for physical contact (Du, 2014). An inductive sensor is a device that utilizes electromagnetic induction to detect metallic objects (Du, 2014). A servo motor is a rotary actuator used to rotate components precisely. The servo motor of the Smart Trash Bins rotates a lid mechanism to open and close the bins automatically if a sensor detects trash at the bin's opening. When a user dumps waste in the Bins, the capacitive and inductive sensors detect the material's properties. The microcontroller will process the sensor's input data based on the summary of the waste segregation operation in Tables 1 and 2. The microcontroller will transmit the required signals to the servo motors and buzzer. For instance, if the trash dumped in the bin is of the correct type, the servo will open the lid. Otherwise, if the type of trash put into the bin is incorrect, the servo will not actuate. A buzzer will sound to warn the user that the wrong type of trash is being thrown into the bin.

Table 1. Summary of Waste Segregation Operation in Non-Metal Bin

Type of Recyclable Trash	Non-Metal Bin Sensor		Non-Metal Bin Lid	Buzzer
	Capacitive	Inductive		
Metal	Detected	Detected	Close	ON
Non-Metal	Detected	Not Detected	Open	OFF

Table 2. Summary of Waste Segregation Operation in Metal Bin

Type of Recyclable Trash	Metal Bin Sensor		Non-Metal Bin Lid	Buzzer
	Capacitive	Inductive		
Metal	Detected	Detected	Open	OFF
Non-Metal	Detected	Not Detected	Close	ON

Trash Level Detection

Fig. 2 shows how an ultrasonic sensor measures the trash level in the bin. The HC-SR04 is an ultrasonic sensor for measuring the amount of garbage in a trash bin. Two components comprise the sensor: a transmitter and a receiver. The controller receives ultrasonic wave signals from the transmitter. The module emits and reflects ultrasonic waves when an object is positioned in front of the transmitter. The receiver detects the reflections and transmits the signal to the module (Karthik et al., 2021). The operation of Trash Level Detection is summarized in Table 3. If the measured trash bin level exceeds 10 cm, the trash bin status is Not Full, the indicator light turns off, and the GSM goes into standby mode. Otherwise, if the trash bin measurement is less than 10 cm, the trash bin status is Full, and the GSM sends an SMS notice to the user that the trash bin is full.

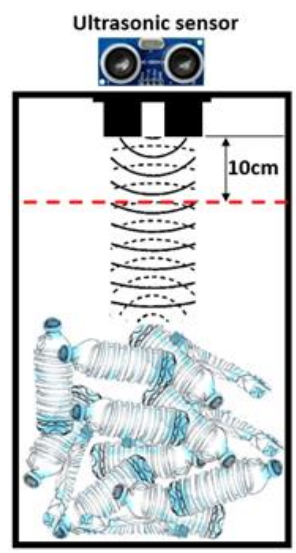

Figure 2. Trash Level Measurement using Ultrasonic Sensor

Table 3. Summary of Trash Level Detection Operation

Bin Level	Indicator Light	GSM	Bin Status
Bin Level > 10 cm	OFF	Standby	Not Full
Bin Level < 10 cm	ON	Send SMS Notification	Full

GSM Communication

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The Saleng GSM Module by Layad Circuit that uses SIM800L was used to integrate GSM connectivity into the system. The Saleng GSM Module makes GSM communication integration considerably easier because it contains a built-in circuit to provide the 3.6-4.2V 2A power required by the SIM800L to function correctly.

Solar Power

Solar energy is collected using a photovoltaic panel. A solar battery pack is fixed within the smart trash bin to store renewable solar energy generated by photovoltaic cells. The solar battery is used to power all the devices of the smart trash bin system. Fig. 3 shows the parts and connections of the solar power setup. A 10W Solar Panel is connected to the Solar Charge Controller to regulate the voltage supplied to charge the 12V 15Ah AGM Gel Battery. The battery is connected to a DC breaker before the DC-DC step-down converter, which supplies multiple DC voltages to the system. The first step-down converter has a fixed 5V DC output that powers the Arduino board and the 5V I/O devices. The second step-down converter has a variable DC output adjusted to 6V to power the two servo motors. In addition, the third step-down converter has a variable DC output that was adjusted to 5V to power the Saleng GSM module. Although the DC supply of the GSM module and the Arduino is similar, their supply was separated because there is a current spike every time the GSM module sends an SMS, which may affect the functionality of other system devices.

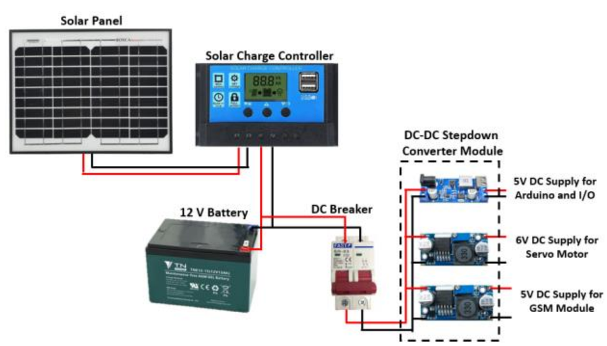

Figure 3. Parts and connection of the Solar Power Setup

Hardware Block Diagram

Fig. 4 depicts the Smart Trash Bin's Hardware Block Diagram, which consists of the Power Supply, Sensor Module, Arduino Microcontroller, Actuator Module, and GSM Module. First, the Power Supply delivers DC power to the system's various modules. A DC-DC converter circuit converts the 12V DC from the battery to the microcontroller-required 5V DC. Second, the capacitive, inductive, and ultrasonic sensors of the Sensor Module are connected to the input pins of the Arduino microcontroller. The capacitive and inductive sensors are connected to an optocoupler circuit so that a 12V sensor can be safely wired to a 5V microcontroller. Third, the Arduino microcontroller processes the input data from the sensor module and sends the appropriate signals to the various actuator devices based on the uploaded C code of the programmer. The Arduino IDE Desktop was utilized to write and upload C code from the computer to the Arduino board via a USB cable. Fourth, the Actuator Module contains servo motors, a buzzer, and an indicator light. Each actuator is activated if certain system conditions are met. Lastly, the GSM Module can communicate in both directions with the Arduino board. The microcontroller will instruct the GSM module to communicate data from the system to the user and vice versa if certain conditions are met. The user can control the system by sending an SMS to the GSM module.

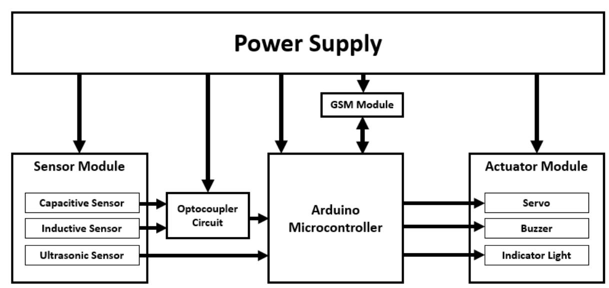

Figure 4. Hardware Block Diagram

Software Algorithm

Fig. 5 depicts the algorithm for Recyclable Waste Segregation. It begins by initializing the microcontroller and reads each trash bin's capacitive sensor. The inductive sensor will be read if the capacitive sensor recognizes a trash object. Suppose the inductive sensor for the Non-metal bin does not detect the trash object. In that case, it is categorized as a non-metal object. The servo motor will rotate to open the Non-metal Bin, which will close after a 2-second delay. However, if the inductive sensor detects the trash object, it is classified as a metal object. Therefore, the Non-metal trash bin will not open, and the buzzer will ring for two seconds.

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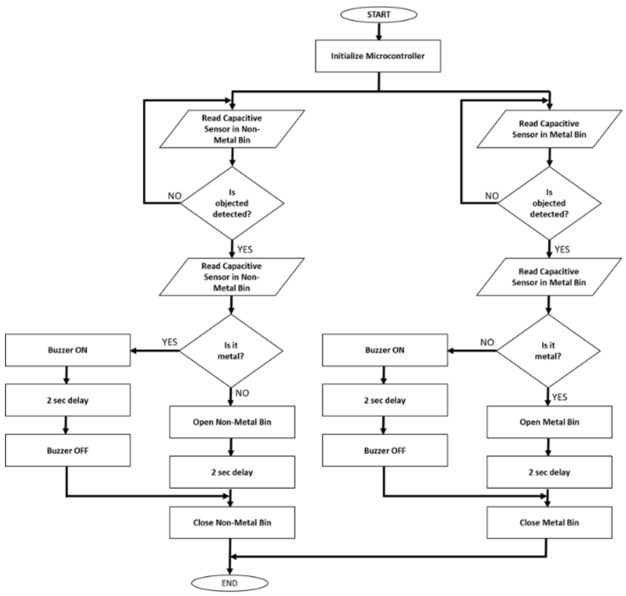

Figure 5. Recyclable Waste Segregation Algorithm

In contrast, if the capacitive sensor of the metal bin detects trash, the inductive sensor of the metal bin will be read. Suppose the inductive sensor detects a metal object. In that case, the servo motor will rotate to open the Metal Bin, which will then close after a 2-second delay. However, if the inductive sensor fails to detect it, the trash object is classified as a non-metal object. Therefore, the Metal trash bin will not open, and the buzzer will ring for two seconds.

Fig. 6 illustrates the algorithm for detecting trash levels. The algorithm begins by initializing the microcontroller and then reading the ultrasonic sensor in both bins to calculate the trash level. Suppose the garbage level is less than 10 cm. In that case, the indicator light turns on, and an SMS notification indicating that the trash bin is full is sent to the user's mobile number. Otherwise, the bins are not yet full if the trash level exceeds 10 cm, so it loops back to read the trash level

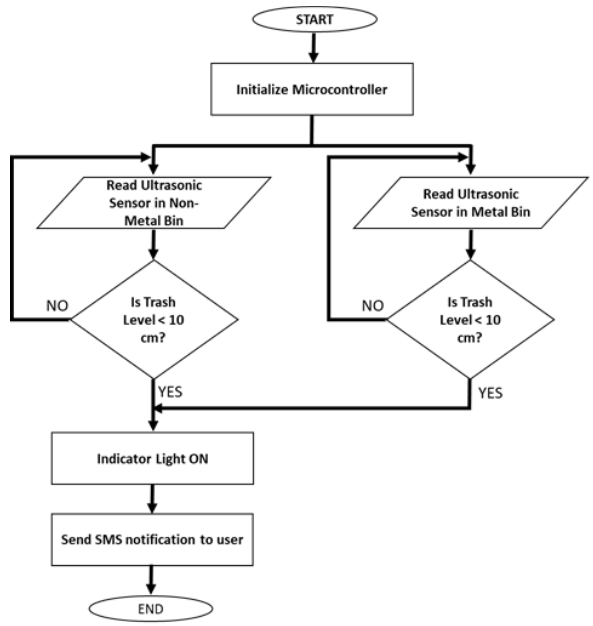

Figure 6. Trash Level Detection Algorithm

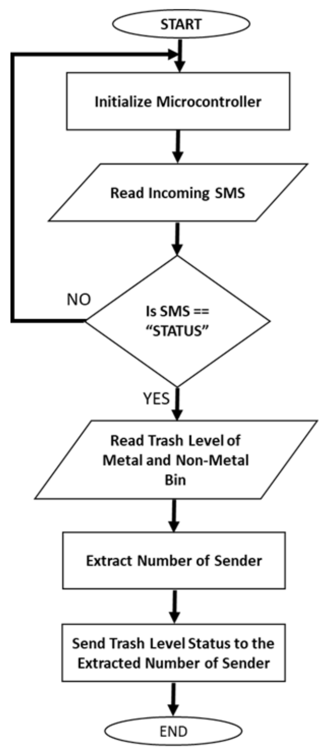

Figure 7. SMS Status Update Algorithm

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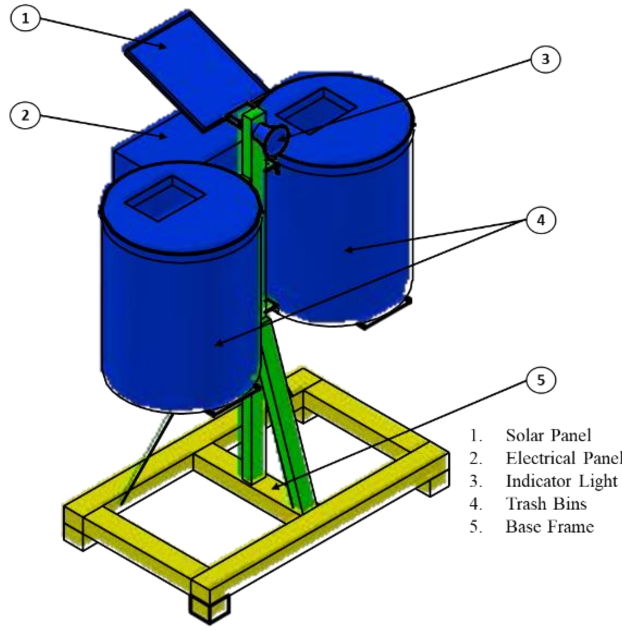
SMS Status Update Algorithm is illustrated in Fig. 7. It begins by initializing the microcontroller and reading incoming SMS messages afterward. If the SMS contains the keyword "STATUS," the algorithm will read the trash level in the metal and non-metal bins. Otherwise, it will loop back to read incoming SMS messages. After reading the trash level of the bins, the sender's number will be extracted. The Trash Level Status will then be delivered through SMS to the sender's mobile number.

RESULTS AND DISCUSSION

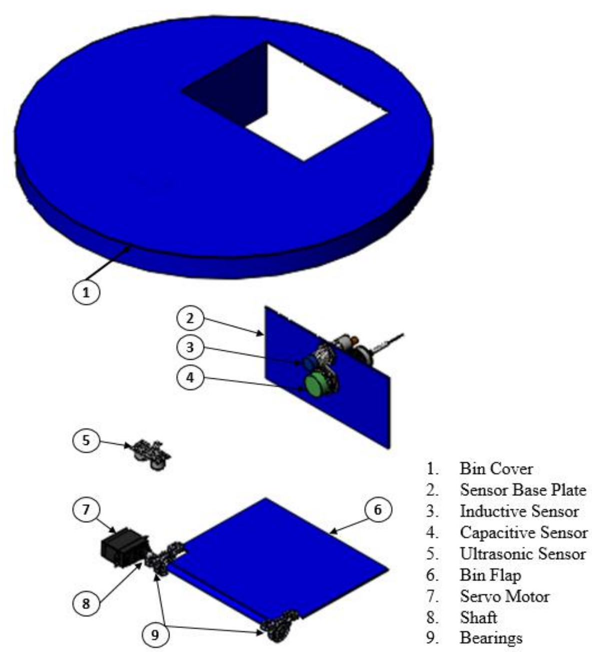
Hardware Design and Testing

The smart trash bin was developed using the CAD drawings shown in Fig. 8. Hardware functionality testing was performed to validate the developed Smart Trash Bin. The trash bin had a maximum unfilled height of 580 mm and a diameter of 480 mm. An ultrasonic sensor facing the bin was mounted on the bin cover to measure the trash level, as illustrated in item 5 of Fig. 8b. The researchers filled the bin to determine the trash level reading when the bins were full. A trash level reading of less than 10 cm indicates that the bin is full. Further testing revealed that trash level detection could accurately determine when the bins are full, and the system can send SMS notifications to users. During testing, however, it was observed that the SIM800L module could not receive or send SMS since the cellular signal was weak within the building. Therefore, the smart trash bin was placed in an open field to receive a stronger cellular connection. It is also recommended to utilize a SIM card network with a strong signal in the area to boost the system's reliability.

The trash objects are thrown in the rectangular opening of the bin cover, which measures 140x200 mm. The capacitive and inductive sensors mounted on the base plate, as illustrated in items 2-4 of Fig. 8b, are utilized to determine the property of the thrown recyclable trash object. The sensors' placement and sensing distance were calibrated to identify the recyclable object's property accurately. While testing the recyclable waste segregation function, it was discovered that the inductive sensor should be placed slightly forward of the capacitive sensor since it has a more extended sensing range than the inductive sensor used in the study.



(a)



(b)

Figure 8. CAD Drawing (a) Isometric View (b)Exploded View of Trash Bin Cover

The lid flap will open when the right recyclable object is thrown into the appropriate bin. The bin flap, servo motor, shaft, and bearings comprise the lid flap opening and closing mechanism, as indicated in the assembly drawing of items 6-9 in fig. 8b. This

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mechanism was capable of closing and opening the lid flap automatically. However, the lid flaps were not fully closing; therefore, the servo motors' rotation angles were modified until the lid flaps were fully closed. It is advised that the servo motors be properly mounted so they do not wobble while turning the lid flap. Furthermore, the lid flap should be made of a lighter material, and the alignment of the servo motor, shaft, and bearings should be checked so that the servo motor does not have difficulties rotating.

Developed Smart Trash Bin

Figure 9. Developed Smart Trash Bin

Fig. 9 shows the developed Smart Trash Bin alongside the researchers. It has two containers for recyclable non-metal and metal waste. Each bin has a label indicating what types of trash can be placed in that bin. In addition, a solar panel is installed to charge the solar battery that powers the entire system.

Fig. 11 shows the actual wiring of the smart trash bin based on the schematic diagram illustrated in Fig. 10. The various electrical component and control devices were mounted on plywood using screws and adhesives. The wires were connected in a terminal block, and the cover of the terminal block was labeled with the pin designation to identify the connections quickly.

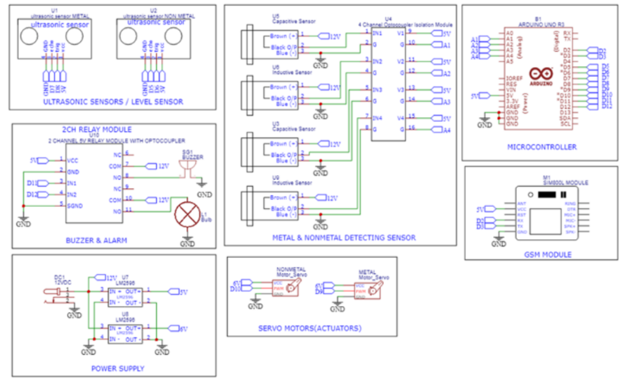

Figure 10. Schematic Diagram of the Smart Trash Bin

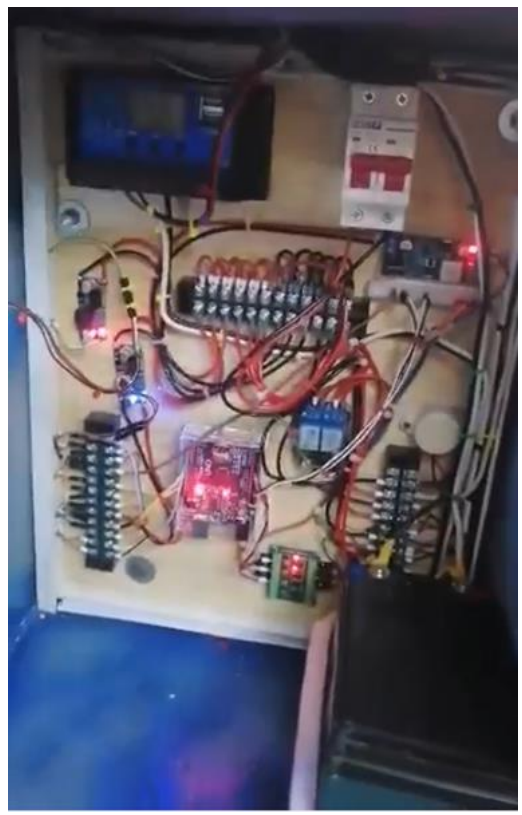

Figure 11. Electrical Panel of the Smart Trash Bin

Cost Analysis

The total cost of the smart trash bin is shown in Table 4. According to the table, the total cost of the designed smart trash bin is USD 180. Furthermore, Fig. 12 depicts a cost comparison between the developed and previously existing trash bins presented in (Al Mamun et al., 2015; Samann, 2017). To summarize, the developed trash bin is less expensive than the existing trash bins,

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costing around USD 160 and USD 560. It should be noted that while the designed system of (Samann, 2017) was less expensive, the reported total cost did not include the cost of the bin. Furthermore, the developed system has two trash bins, which have a larger capacity than the single bins developed in (Al Mamun et al., 2015; Samann, 2017).

Table 4. Overall cost of the System

Item	**Qty**	**Unit Cost**	**Total Cost**
Inductive Proximity Sensor	2	$ 4.5	$ 9.00
Capacitive Proximity Sensor	2	$ 6.00	$ 12.00
Ultrasonic Sensor	2	$ 1.00	$ 2.00
DC-DC Stepdown Converter (Variable)	2	$ 1.00	$ 2.00
DC-DC Stepdown Converter (Fixed)	1	$ 2.00	$ 2.00
4-way Optocoupler Module	1	$ 1.00	$ 1.00
Saleng GSM Module	1	$ 7.00	$ 7.00
Arduino Uno	1	$ 12.00	$ 12.00
Servo Motor	2	$ 9.00	$ 18.00
2-channel Relay Module	1	$ 1.50	$ 1.50
Buzzer	1	$ 1.00	$ 1.00
Indicator Light	1	$ 1.00	$ 1.00
Solar Panel	1	$ 9.00	$ 9.00
Charge Controller	1	$ 4.50	$ 4.50
12V Battery	1	$ 18.00	$ 18.00
Trash Bins and Frame	1	$ 70.00	$ 70.00
Wires and connectors	1	$ 10.00	$ 10.00
Total			$ 180.00

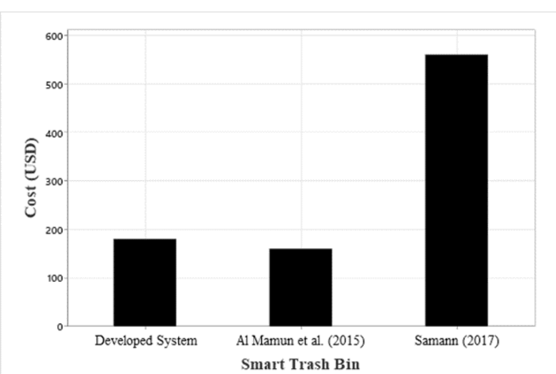

Figure 12. Cost comparison between the developed smart trash bin and existing smart trash bin

CONCLUSION AND RECOMMENDATION

This paper presented the design and development of a solar-powered, GSM-connected system for recyclable waste management. Three subsystems of the Smart Trash Bin were successfully created. First, the Recyclable Waste Segregation subsystem can separate the trash into metal and non-metal waste based on materials' inductive and capacitive properties. In addition, a mechanism for automatically opening and closing the trash bin covers was developed to dispose of trash in the correct bins. Second, Trash Level Detection employing ultrasonic sensors proved a reliable and cost-effective method for monitoring the bin's trash level. Lastly, the GSM communication demonstrated that the system could be remotely monitored and automatically notify the user if the trash bins are full. The development cost of the system has been compared to that of existing trash bins, and it has been determined that the cost of the developed system is very favorable because it is affordable and has a greater capacity.

In future studies, computer vision and deep learning research may be considered for detecting and classifying various types of trash.

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