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RESEARCH ARTICLE

Concealed Automated Trash Bin with Shredder for Solid Wastes

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Abstract

The common difficulty in populated developing countries like the Philippines is inappropriate waste management practices. The improper use of waste bins and waste segregation are some of those. One of the major causes is the irresponsibility of the people. As expected, the consequences are environmental and health risks experienced by people. The countermeasure to minimize these risks is the solution proposed by people, particularly the development of an automated segregation system. The waste bins are designed to be concealed to conserve space, slow down the decomposition rate and reduce the foul odor of waste. The design is fully automated to minimize direct contact with the waste. The classifying section is capable of collecting and segregating waste using a gripper, servo motors, ultrasonic, capacitive, and photoelectric sensors. To conserve power, the segregated waste is held in a storage bin prior to shredding. Shredded waste is routed to their respective transport bins for collection after shredding.The ultrasonic sensors provide data about the capacity of the transport bins and allow the GSM module to send an SMS informing the concerned authority regarding the bins' status. These messages facilitate easier waste collection. Two tests were conducted to determine the performance of the prototype: response-time and garbage level detection tests. The result shows that the prototype performed well and can successfully achieve the desired function. It took 23.745 and 2.711 seconds to collect and segregate the waste, respectively. Likewise, the monitoring system successfully expedited the checking of the waste bins. However, it is recommended to include quality of output and SMS delay tests. These tests can improve the overall performance of the prototype.

KEYWORDS:
response-time, garbage level detection, automated segregation system

1 | INTRODUCTION

The problem of solid waste is a global issue that every single person must be concerned with. Environmental and health risks are two major negative effects of waste that affect the entire human population. Living with these threats endangers the environment and natural resources such as fresh water sources, soil for agricultural use, and clean, fresh air. Leachate from solid waste can contaminate waters, marine litter can cause water pollution, methane gases from dumpsites can affect the health of exposed populations, and improperly managed solid waste results in increased flooding and destruction of infrastructures. As high as 88% of diarrhea cases, 100% of helminthiasis cases, 50% of hepatitis cases, and 100% of cholera fever cases worldwide were attributed to water pollution due to leachate from open dumps. Poor handling of waste and direct exposure of humans are the perceived reasons for the alarming record (National Solid Waste Management Status Report)[1].

This is why a strategic plan on solid waste management is vital and relevant in order to mitigate the worsening problem of waste management. An automated waste system is believed to be a promising and simple solution to reduce the environmental and health problems associated with waste. To minimize the direct exposure of humans to waste, the collection and segregation of waste need to be automated. To reduce the amount of air pollution contributed by waste collection vehicles, the monitoring of the waste also needs to be automated.

An in-depth literature review was conducted to develop the automated waste system. Several studies have proven the usefulness of segregating waste to minimize direct contact, especially for those whose jobs are related to waste collection. Norhafiza, S., Masiri, K., Nor Faezah, A., Nurul Nadiah, A.L., and Aslila, A.K. [2] developed an automated isolation recycling bin through the integration of the Arduino Uno program, inductive, capacitive, and infrared sensors, and DC Motors. The goal of the project was to classify waste according to three different categories: paper, plastic, and metal. The results showed that an average of 1.9, 2.2, and 2.1 seconds were consumed to classify each waste, respectively. The benefit of the project was that it achieved the goal of not depending on human reasoning and evaluation to classify waste. The drawback identified by the researchers was that it classifies waste one at a time. A similar innovation was developed by Ahmad, I.K., Mukhlisin, M., and Basri, H. [3], where an intelligent sorting system consisting of capacitive proximity sensors and LABVIEW software was integrated. The results showed that the capacitance proximity sensors are a reliable and suitable system to automatically detect non-metallic materials (plastic and paper) without involving manual separation. However, there were limitations identified when the target size and the distance between the sensor and the target influenced the capability of the sensors to detect.

The following studies demonstrate a more sophisticated innovation using machine learning algorithms. In the study of Sakr, G.E., Mokbel, M., Darwich, A., Khneisser, M.N., and Hadi, A. [4], a machine learning technique to classify paper, plastic, and metal was used through two popular learning algorithms, Support Vector Machines (SVM) and Convolutional Neural Networks (CNN). The classifiers were implemented on a Raspberry Pi 3 connected to a high-definition Pi camera, and the model was trained using Matlab 2016a, where it produced a quick classification of 0.1 seconds (average) per image. Furthermore, it achieved an accuracy rate of 94.8% and 83% for SVM and CNN, respectively. The drawback identified in the study was the small number of images stored in the training set. Hence, it is recommended in this study to use a machine learning server with 2 Tesla GPUs with 12 GB of memory each, so that a greater variety of images can be stored in their training set.The device automatically classifies and separates garbage by using a multimedia embedded processor, an object classification algorithm, and machine learning features. However, the limitations identified were that the IWS can only process one piece of waste at a time due to the segmentation limitation and it cannot identify deformed waste because the system relies on the shape of waste.

The waste monitoring system was relatively remarkable in the existing literature. In fact, many studies have proven the significance of this in response to the problems with waste management. One of them was the low-cost IoT—based (Internet of Things-based) study on garbage level monitoring systems studied by Parilla, R.A.G., Leorna, O.J.C., Attos, R.D.P., Palconit, M.G.B., and Obiso, J.A. [5]. The study was found effective in providing a real-time status of the garbage level in the drainage. Ultrasonic sensors, IoT Module, Arduino Uno Microcontroller Module, and Global System for Mobile Communications (GSM) Module were systematically connected to monitor the clogging of drainages due to garbage accumulation in Cebu City, Philippines. One of the limitations of the developed system, since it primarily depended on internet connectivity, was the fluctuating internet connectivity in the Philippines. Thus, 5G technology was recommended to be used for higher reliability. A similar cost-effective and real-time waste management system study using an IoT-based system was conducted by Yusof, N.M., Zulkifli, M.F., Yusof, N.Y.A.M., and Azman, A.A. [6]. However, the same drawback was emphasized for internet connectivity; thus, it was also recommended to use a strong Wi-Fi connection to make it function.

Another refined waste monitoring innovation was studied by Prof. S.A. Mahajan, Akshay K., Apoorva S., Mrunaya S., and Shivani I.[7], where the garbage bins were equipped with unique IDs for easier identification and accuracy, a Raspberry Pi 3, and an IoT module to collect data from UV sensors and load sensors for level detection, and a humidity sensor for wet and dry garbage detection. The advantages identified were that the system assures the collection of garbage as soon as its maximum level is reached; and with the help of the real-time monitoring system used in their study, the total number of trips required for a collection vehicle is reduced. Thus, the total expenditures associated with garbage collection are also reduced. Also, an IoT-based system for trash bins was developed by Sathish, A., and Prakash, M. [8]. The system used an ultrasonic sensor to monitor the status of the waste materials in the bins and the IoT Module to effectively monitor them on a real-time basis. It also used a flame sensor to prevent fire, and a moisture sensor to classify whether a material is wet or dry waste. The downside of the study is that the system was unable to distinguish between solid and liquid waste materials. The ideas, concepts, and applications of technologies are well underscored in the literature cited. However, these studies are mostly limited to either (1) segregation, (2) collection, (3) classifying, or (4) monitoring alone. Some of these are combinations of two or three processes, but a study that integrates these four processes is non-existent. That's why the gap to be bridged by this study is the integration of these four common waste management processes into a single automated waste system. In addition, a crushing mechanism in the form of a shredder, which is less likely to be considered in a waste system despite its significant advantages, is to be incorporated into this system. To name a few significance of shredder, waste materials which are reduced to small particles also reduce the waste capacity to about 30% (Othman, N. and Choon, N.C.)[9]; and the plastic shredding machine of Ayo, A. W, Olukunle, OJ and Adelabu, DJ. [10] enhanced the portability, easiness and readiness of the waste materials for use into another new product.

Moreover, the objectives of this study are to design, fabricate, and evaluate the performance of a waste segregation system that collects, classifies, segregates, monitors, and shreds waste at the same time. As described in this paper, machine learning techniques and IoT-based systems are not going to be considered for this objective despite their promising performances. The reasons for this matter are evident in the literature above. Instead, this system aims to automate these processes through the integration of a cost-effective set of sensors, microcontrollers, monitoring modules, and motors. In this way, this study can be of great help to at least minimize the adverse effects of solid waste problems on people and the environment in general.

In the succeeding sections, the prototype development process is succinctly described. The prototype development process is comprised of four stages, which are presented and discussed individually. They are the planning, designing, fabrication, and evaluation stages. The results of the two tests performed, their corresponding discussions, and finally the formulated conclusions are also briefly explained. The response-time test and garbage level detection test are the two performed tests that are also discussed separately in the succeeding sections. Similarly, discussion and conclusion sections are provided.

2 | METHODOLOGY

The overall performance of the prototype is measured via the time taken to sort out the solid waste into two different categories: paper and plastic, and the effectiveness of the monitoring system employed. The development process of a prototype is divided into four main stages: planning, designing, fabrication, and evaluation.

2.1 | Planning Stage

2.1.1 | Hardware Gathering

The materials were collected by purchasing them both from local hardware shops and online stores. The devices and materials gathered include capacitive, ultrasonic, and photoelectric sensors; Arduino Uno and Mega Modules; Relays; and Servo and AC Motors.

Arduino Modules

Arduino Uno and Mega Modules were used as the main microcontrollers of the entire prototype. Arduino modules was tasked to control all the synchronous function offered by this segregation system. The devices integrated in the modules include GSM Module, Capacitive, Ultrasonic and Photoelectric sensors and Servo motors.

Sensors

LJC30A3-H-Z/BY PNP Capacitive Proximity Sensor was tasked to classify plastic wastes; E18-D80NK Photoelectric sensor was used to sort out paper from plastic wastes; and HC-SRO4 Ultrasonic sensors were used to: measure the level of depth of the transport bins; to recognize people who wishes to throw a waste in the trash bin; and to collect the waste materials present in the classifying section to aid the gripper system.

Motors

A 220V 60Hz 120W 4 Pole AC Wash Motor was used to conceal and reveal the main bin from the pavement; MG995 Servo Motors were used to open and close the retractable plate and lids and to control the mechanism of the gripper system; and a 220V 60Hz 1HP 1 Pole AC Water Pump Motor was used to power up the shredder.

Global System for Mobile Communications (GSM) Module

A SIM800L Arduino GSM Development Board Module was used to monitor the depth of the transport bins and alert the concerned personnel about the status of the bins. It was used to send SMS when the bins are at the full capacity and command the concerned personnel to unload the bin immediately.

2.2 | Designing Stage

2.2.1 | Prototype Design

The following figures drawn 3-dimensionally in SketchUp Make 2017 shows what the prototype looked like and its dimensions. Figure 1 below shows the front, side, and isometric views of the prototype. Figure 2 presents the front elevation of the prototype design showing the main sections and the corresponding devices used.

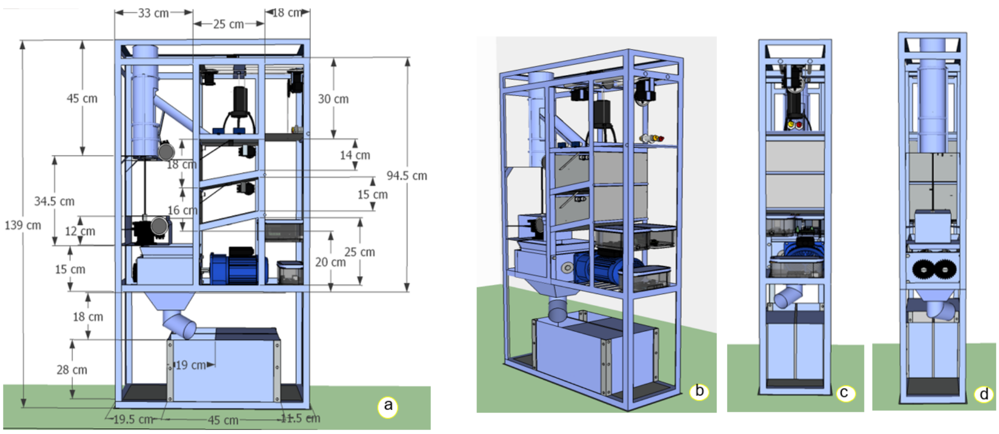

FIGURE 1 *The prototype design in 3D): (a) front elevation with dimensions, (b) isometric, (c) left and (d) right side elevations*

The CATBinSS has six identified main sections namely, Main Bin Section (A), Gripper Assembly (B), Classifying Section (C), Containing Bin Section (D), Shredder Assembly (E), and Transport Bins Section (F).

The Main Bin Section (A) consists of the movable Main Bin (1) made up of PVC Pipe, and an Ultrasonic Sensor used to trigger the AC Wash Motor (2) to move up and down the main bin whenever someone wishes to throw a waste. The Gripper Assembly Section (B) consists of four servo motors – two for the gripping mechanism and two for the linear motion of the gripper. There are also two ultrasonic sensors, which detects the position of the waste, and a Three-Armed Gripper (3) made from recycled materials that is used to bring wastes into the classifying section. Located in the Classifying Section (C) are two of the sensors from the core components, specifically Photoelectric Sensor and Capacitive Sensor (4). They are used to classify paper and plastic, respectively. Also located in this section are the Retractable Plate (5) and the servo motor, which is used to open and close the retractable plate. The segregated wastes can be found in the Containing Bin Section (D) of the prototype. One separate containing bin is allotted for paper wastes and one also for plastic wastes. There are also two ultrasonic sensors that are used to determine how much wastes are stored prior to shredding, and two servo motors that are used to open and close the Retractable Lids/Doors (6) whenever a waste is successfully classified in the classifying section. The Shredder Assembly Section (E) contains the blades/knives of the Shredder (7) itself and the AC Pump Motor (8) used to power up this section. The blades are made of steel bars to cut waste into smaller pieces. The Transport Bins Section (F) contains two separate Transport Bins (9) for the shredded paper wastes and plastic wastes. Two servo motors are used to divert the Outlet Tube (10) from one transport bin to another, and two ultrasonic sensors are used to detect the garbage level of the transport bins. The information detected by these sensors are used to trigger the GSM Module (11) to send messages informing the concerned authority about the status of the transport bins.

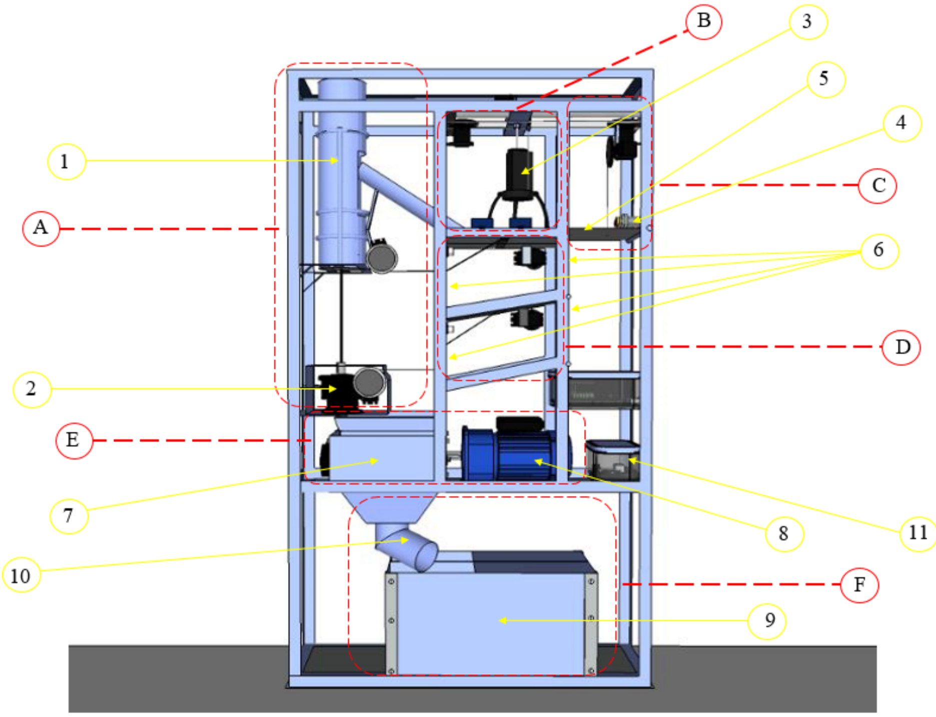

FIGURE 2 *Labeled front elevation of the prototype*

2.2.2 | Circuit Design

The design of the circuit is presented in a block diagram. The Figure 3 shows the overall system of the prototype. The main mechanisms included are the movement of the main bin, opening of the retractable plate and lids, gripping mechanism, classifying, segregating and shredding mechanisms.

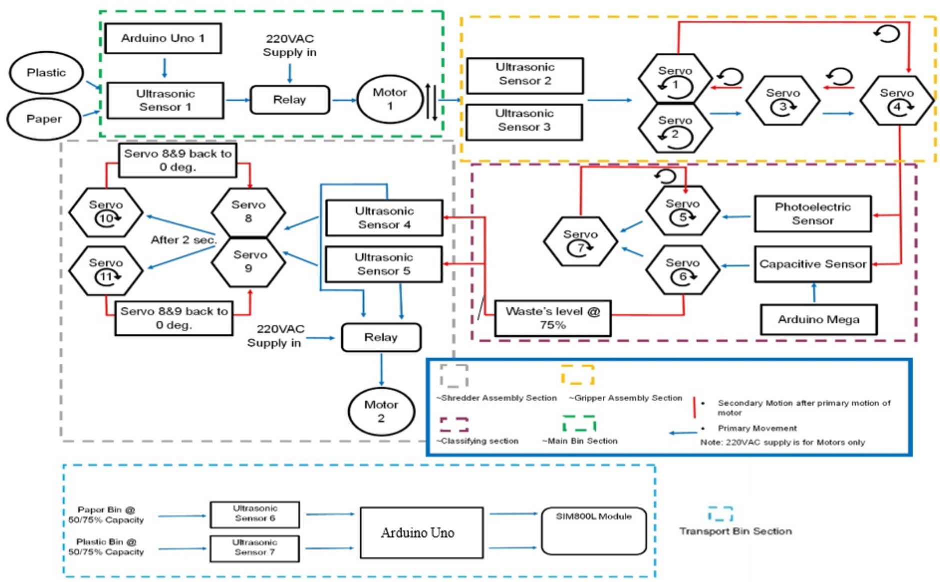

FIGURE 3 *Block Diagram of the Circuit*

2.3 | Fabrication Stage

2.3.1 | Prototype Fabrication

The prototype was fabricated based on the three-dimensionally designed prototype. The gripper mechanism assembly, the retractable plate and lids, the main bin, and transport bins were handcrafted using recycled and ready-at-home materials. The fabrication and installation of the shredder assembly were delicately completed by manually cutting the metals into blade-shaped pieces, then welding them into the shaft and finally bolting them into the motor shaft. Similarly, the installation of the main bin assembly was carefully done, first by joining the steel linear guide of the bin into the framing/enclosure of the prototype, which was also bonded through welding, second by safely securing the AC Wash Motor into the frame and fastening its shaft into the bin, and lastly by creating the forward-reverse motion of the motor and bin to achieve the concealment feature of the system. The electrical wiring was installed using electronic wires and cables, tape, cable ties, and glue sticks.

2.3.2 | Programming

The mechanism of the prototype was made possible by the integration of Arduino Uno and Mega Modules along with Servo Motors, AC Motors, Capacitive and Photoelectric Sensors, among others. Each of the required mechanism from the system was programmed separately prior to unit integration and synchronization of all the automation features.

2.3.3 | Preliminary Tests and Modification

The final phase for the fabrication stage was the preliminary system test and modifications. In this stage is where the system is pre-tested according to the required mechanisms. Every error that occurred in the first attempts was traced here and given a solution. For instance, when the retractable plate and lids were not synchronously functioning together, the system underwent troubleshooting, modifications, and necessary calibration and adjustments until such that the desired functions and mechanisms were achieved.

2.4 | Evaluation Stage

2.4.1 | Prototype Launch

A fully functional prototype ready for user training and for public use was presented at this stage. Likewise, for the evaluation of its overall performance. The photos of the fabricated prototype are shown in Figure 4 .

FIGURE 4 *Photos of the fabricated prototype when it is (a) closed, (b) half-closed for demonstration and (b) fully-opened for viewing.*

2.4.2 | Performance Test

The performance tests provide the data on how well the prototype performed. There were two performance tests were conducted for this study. They are the Response-Time Test and the Garbage Level Detection Test.

- **Response Time Test.** The response time is to be determined from 10 trials in order to obtain an average response time (in seconds) in the classifying section. Two time responses (collection time and segregation time) are to be determined from the sections comprised of the gripper, sensors, and motors. The Collection Time responses correspond to the time taken once the gripper system attempts to collect a waste and bring it into the classifying section where the retractable plate and sensors are placed. The Segregation Time responses are the times to be determined after the waste is successfully classified and transported into its proper containment bin. The computed average time using the mean formula, $X = (\Sigma x)/n$ for each of the two response-times serves as the response time of the waste system. The recorded time responses determine how fast this prototype collects and segregates waste.

- **Garbage Level Detection Test.** The garbage level detection test is to be performed by an ultrasonic sensor in each transport bin. The Ultrasonic Sensor automatically emits ultrasonic sound waves in the Kilo-Hertz range and converts the reflected sound into an electrical signal. The transmission of the signal occurs in a very quick period of time, from micro- to nanoseconds. The propagation time of the signal from the emission of sound to the reception of sound after it travels to and from the target is to be computed through the mathematical formula shown below. The time obtained is to be used to determine the depth of the transport bins. This equation was also used by Parilla, R.A. et al. (2020) in their study.

$$D_t = \frac{T(highlevel)xS(sound)}{2}$$

where; $D_t = testdistance, m, T(highlevel) = highleveltime, s, S(sound) = speedofsound(343m/s)$

The detected distance is to be used to decide how much shredded waste is present in each transport bin. The greater the computed distance, the lower the level of garbage collected. It indicates that the transport bin is not yet full. On the other hand, the lesser the computed distance, the more it implies that the status of the transport bin is near to full capacity. It then implies that the transport bin is reaching its capacity. Each of the contained shredded wastes of two transport bins is to be measured and the remaining 25% (6.25 cm) capacity is to be considered as "at full capacity". The performance is to be evaluated using 10 trials with direct observation. The ultrasonic sensors are to be programmed to trigger the GSM Module to send a message when the pre-determined range of distances is met. The sent SMS when the transport bins reach their full capacity contains the actual remaining capacity of the bins (in cm) and an alert message informing the concerned authorities regarding its status and commanding them to unload the bins immediately.

3 | RESULTS

In this section, the results of the two performed tests—response time and garbage level detection tests—are presented and interpreted. These tests were the time it takes for the gripper assembly to collect and for the classifying section to classify and segregate a waste (a response time test) and how much shredded waste is contained in each transport bin (a garbage level detection test). Under the response-time test, there are two types of responses: collection phase and segregation phase responses.

3.1 | Response-Time Test

3.1.1 | Collection Phase

The Collection response-time was the time it took for the gripper to pick up the waste from the gripper assembly section to the classifying section in preparation for classifying. Table 1 shows the results of the collection response time.

Based on results from the collection time, 6 out of 10 or 60% of the trials show similar response times. The reason for the variance of 4 trials was the performance of the gripper assembly. When the gripper itself was unsuccessful in picking up a waste in the first attempt, the gripper went back to pick up the waste still detected by the ultrasonic sensors. Similarly, when the following attempts of the gripper were still unsuccessful, it was perceived as the reason for the variance of the 4 trials.

TABLE 1 Response-time of the collection phase

No. of Trials	Collection Time (in sec)
Trial 1	14.06
Trial 2	15.23
Trial 3	12.24
Trial 4	46.21
Trial 5	15.53
Trial 6	14.02
Trial 7	29.61
Trial 8	31.86
Trial 9	13.86
Trial 10	44.83
Average Time	**23.745 s**

In the case of trials 4, 7, 8, and 10, it recorded higher response times because the gripper went back several times to successfully collect the waste from the gripper assembly section. Specifically, during trial 4, when the gripper went back four times to successfully collect the waste. Results shows that it requires an average time of 23.745 seconds to pick up the waste from the gripper assembly section to the classifying section in preparation for classifying.

3.1.2 | Segregation Phase

The segregation response time shown in Table 2 was the time after the waste was successfully classified and then segregated into their respective containing bins.

TABLE 2 Response-time of the collection phase

No. of Trials	Collection Time (in sec)
Trial 1	1.34
Trial 2	1.56
Trial 3	5.84
Trial 4	4.66
Trial 5	1.11
Trial 6	1.01
Trial 7	2.13
Trial 8	2.73
Trial 9	3.64
Trial 10	3.09
Average Time	**2.711 s**

Based on the results of the segregation response time, 8 out of 10 or 80% of the trials performed show similar response times. The reason for the variance between the 2 trials was the confined space allotted for the classifying section, specifically for the capacitive and photoelectric sensors. The sizes of plastic bottles and the allotted space are the reasons why it takes a few more seconds to successfully drop the waste into their respective containment bins. In these 2 trials, the plastic bottles were not dropped immediately when the retractable plate opened. Specifically, during trials 3 and 4 when the plastic bottles were stuck in between the retractable plate and lid for few seconds. The table presents that that the average time it took for the sensors to classify and for the servo motors to segregate a waste material was 2.711 seconds.

TABLE 3 Garbage Level Detection data at Full Capacity

	Full Capacity (Below 25%), cm	Action (Alert Message)	
Trial 1	6.14	Sent Successfully	Received Successfully
Trial 2	5.00	Sent Successfully	Received Successfully
Trial 3	4.96	Sent Successfully	Received Successfully
Trial 4	4.40	Sent Successfully	Received Successfully
Trial 5	3.98	Sent Successfully	Received Successfully
Trial 6	3.10	Sent Successfully	Received Successfully
Trial 7	2.53	Sent Successfully	Received Successfully
Trial 8	1.42	Sent Successfully	Received Successfully
Trial 9	1.00	Sent Successfully	Received Successfully
Trial 10	0.00	Sent Successfully	Received Successfully

3.2 | Garbage Level Detection

Table 3 shows the amount of waste contained inside the transport bin, particularly the remaining capacity of the bin measured in centimeters. The second column shows the remaining capacity of the transport bin when it was at full capacity, and the third and fourth columns show the action performed by the system when the given conditions are met.

In the first trial, it was measured by the ultrasonic sensor that the remaining capacity of the transport bin was 6.14 cm, and it was below 25% (6.25 cm). Hence, an alert message was sent immediately, informing the concerned authorities that the transport bin needed to be unloaded immediately.

Out of 10 trials, 10 alert messages were successfully sent and received, or 100% was achieved by the system on garbage level detection and monitoring. Sent and received messages contained the actual distances recorded and the alert message commanding the concerned persons to unload the bins immediately. In addition, consistent plummeting results from trials 1–10 were recorded. It means that no fluctuating results were recorded and it was proof that the monitoring system used was effective.

4 | DISCUSSION

The design was found to be feasible and can be made of low-cost and effective electronic devices such as Capacitive and Photoelectric sensors, GSM Module, Ultrasonic Sensors, AC and Servo motors and Arduino Uno and Mega microcontrollers. The devices' being reasonable in terms of price makes them worth replicating.

For a smoother, more effective, and efficient performance, the prototype can be upgraded with higher features and specifications of devices. For the design of gripper assembly, a four or five arm design can be used for a stronger gripping mechanism to reduce the consumed time to collect wastes. In addition, another safety measure can be considered when all of the bins in the prototype are full. A mechanism can be introduced to stop the system from accepting waste. The main bin should be revealed or accept waste provided that the transport bins are unloaded.

In terms of the shredder used, it was found effective to cut waste into smaller pieces. It was capable of shredding paper materials. Hard plastic materials like PET bottles, on the other hand, are not feasible for shredding. The problem arises due to the unavailability of a type of motor that has high torque and a low speed rating. Thus, it was highly suggested to use a high torque and low speed motor for this prototype. In addition, a pulley can be used instead of a roller chain to reduce the noise produced by it when shredding.

The performance in terms of the response time and garbage level detection was successfully administered. From the response time test, it was found that the average results show similar response times in both classifiers. In terms of the performance, the 10 trials to determine how well the gripper, sensors, and servo motors performed were sufficient. For a shorter response time and better results in the collection and segregation response time, the design of the gripper assembly can be modified, and the classifying section allotted for the sensors can be enlarged. While in terms of the garbage level detection, it was found that the integration of ultrasonic sensors and GSM Module was effective. The 10 trials with consistent results proved how well the monitoring system performed and how it effectively monitored the transport bins without manually and physically checking on their status. However, using a GSM module also relies on a strong signal. In the absence of that, no transmission of data would occur from the bin location to the registered user. For future implementation, the best network pair for the monitoring system should be identified.

5 | CONCLUSION

Since the researchers used effective yet low-cost electronic devices, the time consumed by the prototype to collect, classify, and segregate waste was far too high compared to the hypothesized response times. For a shorter response time, the system needs to be upgraded with more sophisticated automation features like an image recognition algorithm, for faster and more accurate object detection and classification. Likewise, the monitoring system employed in the prototype needs to be upgraded to an IoT-based system for more effective real-time status monitoring. Other devices, materials, and parts of the system that are recommended for upgrading and redesigning also need to be considered. Overall, the prototype has performed well and achieved the necessary automation mechanisms required. Therefore, it is evident to assert that the objective of the study was to develop a waste segregation system that automates the collection, segregation, classifying, and monitoring processes at the same time in a single system. This objective was achieved. The result of this study could be used to call on the concerned authorities relating to waste management sectors to consider automating their waste segregation systems to minimize the health and environmental effects associated with waste. Through this, the problems encountered in the development of this study could be addressed and a more superior system could be developed to achieve the common objectives.

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