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Development of a Smart Plastic Collection System with IoT remote cloud Payment Platform

[1]Amusan A., [2]Afolabi A., and [3]Sambo M.

[1,2]*Department of Electrical and Electronics Engineering, University of Lagos, Nigeria.*

[3]*Department of Electrical and Computer Engineering, Federal University of Technology, Minna, Nigeria.*

[1]aamusan@unilag.edu.ng [2]ayodele.aafolabi@gmail.com [3]mindatsambo@yahoo.com

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Corresponding Author:
ayodele.aafolabi@gmail.com

ABSTRACT

Plastic bottle littering has undoubtedly become an alarming global crisis and a major source of concern that poses potential hazards to landfills, habitats, water bodies, and the ozone layer. A number of these plastic bottles significantly find their way into the drainage systems leading to total drainage blockage resulting in flooding which has rendered many lives dead and homeless. Given the severity of plastic bottle pollution, immediate action is required to lessen its negative consequences. Consequently, while the existing work deployed calibrated sensors that impaired sensing accuracy, and also no consideration for incentives to encourage depositors. This project employs Autodesk Inventor software for robust mechanical modeling, incorporates sensor-based components for precise sensing, implements a control mechanism, and utilizes IoT remote cloud for payment systems to foster local involvement and social accountability aimed at eradicating plastic bottle littering. This initiative outlines the development of a smart plastic collection system with a view to not only curtailing plastic bottle littering but also motivating people with a reward. The smart plastic collection system accepts plastic bottles and all other objects such as glass, metal, and cans.

INTRODUCTION

The lackadaisical disposal of plastic bottles in drainage channels, highways, university campuses, hospitals, supermarkets, eateries, tourist centers, residential and industrial settings, social gatherings, and markets has caused monolithic havoc to lives and properties. Due to the nonbiodegradable nature of plastic, it can linger for over a century and gradually decompose into smaller particles which have a very high propensity to release harmful gases into the ambient air thereby contributing to the greenhouse effect and the depletion of the Ozone layer (Morales-Méndez & Silva-Rodríguez, 2018). As the plastic consumption rate grows exponentially, the manual sorting approach becomes laborious, unsafe, and hazardous. Hence, the adverse effects of plastic bottle littering necessitate a pressing innovative solution.

Smart plastic collection technologies are gaining popularity, and more people are showing interest in using technical breakthroughs to address the challenge of increasing plastic bottle littering. In recent times, the automated plastic collection system has become an effective tracking method, and controlling plastic bottle trash(Meeradevi et al., 2020).

It is therefore critical to embrace a comprehensive strategy that includes reducing plastic bottle production, promoting reusable alternatives, and enhancing recycling infrastructure. IoT has become a leading viable solution. The term "Internet of Things" (IoT) describes a network of linked devices that use Internet access to gather, send, and use data (Zhou et al., 2013). IoT is highly essential to a smart plastic collecting system since it facilitates traditional garbage management more effectively, and data-driven, and it is ecologically beneficial. This integrated system improves the efficiency of operations, promotes ethical waste management with incentives, and fosters ecological sustainability.

RELATED WORKS

The global assessment of accumulated plastic bottle littering and the global ecological and economic impact of waste littering underscore the imperative need for collaborative efforts to promote innovative solutions and deploy mass smart plastic bottle recycling systems for future sustainability. The IoT-based smart collection system automatically detects and separates wastes into different categories depending on their composition.

Lopes & MacHado, (2019) present an IoT smart bin that can detect and segregate garbage into dry(plastic/paper), wet (moist object), and metallic objects (iron). However, one limitation of the system is that it may require steady maintenance and calibration to ensure accurate waste segregation and detection. Saminathan et al. (2019) outline a prototype of a municipal waste segregator that aims to separate waste promptly. This Smart bin is equipped with sensors and motors connected to an Arduino board to facilitate the segregation process and the system is designed to enhance the recyclable materials. However, future recommendations require rectifying errors induced by sensor calibration and detection methods to optimize the system's performance. The pressing issue of plastic waste disposal in India is the invention of an innovative solution in the form of an IoT-based smart plastic waste collection system(Pratap et al., 2019). It incorporates RFID tags for user authentication (Botta et al., 2016), sensors for waste detection, and a central server for monitoring and rewarding users. The primary objective of this system is to highlight the significance of utilizing IoT technology in waste management systems, emphasizing its potential to improve operational efficiency and reduce environmental impact. Nonetheless, this innovation solution has a high chance of inefficiencies due to its collection process. An IoT-based technology smart waste management system often utilizes sensors to monitor the waste levels in dustbins and promptly alerts authorities when they reach full capacity. The technology employs ultrasonic sensors to precisely monitor the waste level within dustbins (Ramesh et al., 2022).

Dudhal et al. (2014) outlines a system that incorporates sensors, a conveyor belt, and a robotic arm, using an automated programmable logic controller (PLC) to separate items. The fundamental drawback of most existing air quality monitoring systems using IoT devices is the adoption of calibrated sensors, which might impair the accuracy of the monitoring systems. Lingaraju et al. (2023) offer an IoT-based Smart Waste Management System for smart cities, that integrates sensors, microcontrollers, and cloud platforms to monitor garbage levels, types, and air quality for waste segregation and air quality categorization. By monitoring garbage levels, tracking location, and sorting waste into distinct sorts, eliminated health hazards, and promoted environmental sustainability. Utilizing IoT technology, sensors, and AI, the system automates trash segregation and real-time waste monitoring. The key constraint here is the reliance on calibrated sensors which can impair the accuracy of the monitoring systems (Debrah et al., 2021). Having reviewed the existing work, we were able to identify a critical incentive gap and this spurred our motivation to create a smart collection system that would give each plastic depositor a reward via IoT remote cloud for each plastic deposited.

METHODOLOGY

To generate a digital or real-world illustration of a product or concept before it is fabricated, modeling is an essential phase in the product creation process. Autodesk inventor software is the choice because it supports proficient mechanical design and performance simulation of smart plastic bottle collection system taking the following steps;

1. Click on new and navigate to create.

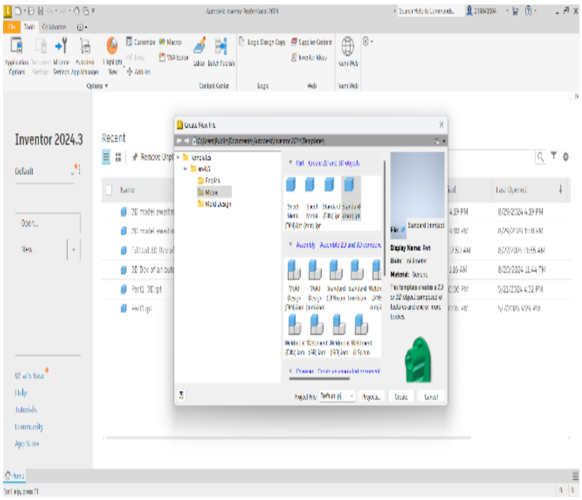


Figure 1: New page

2. Click on Start 2D sketch and choose XY plane so the drawing can lie on XY plane.

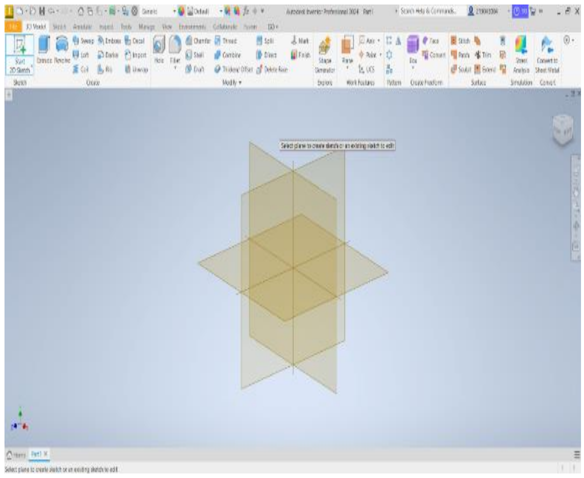


Figure 2: XY plane

3. Extrude the inclined plane inwards at 400m

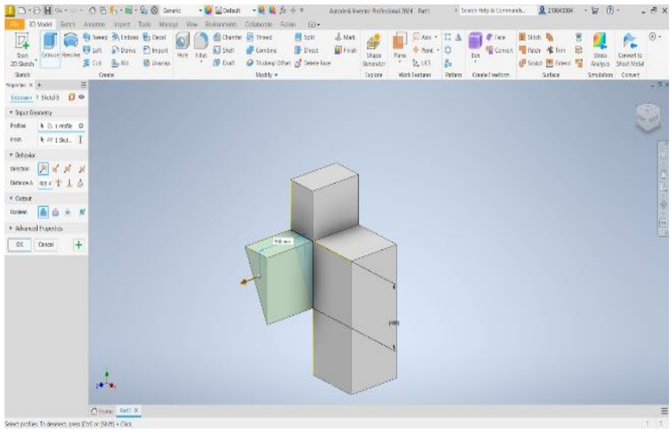
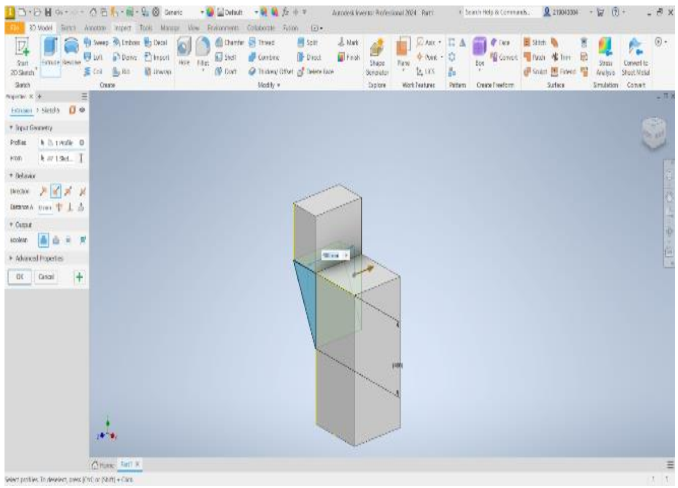


Figure 3: Extrusion of the inclined plane



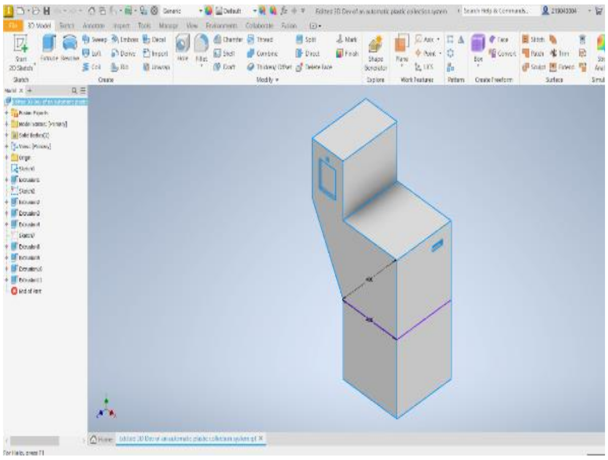


Figure 4: Final model

BLOCK DIAGRAM

The Internet of Things" (IoT) outlines a network of physically connected items, including actuators, sensors, and integrated electronics, that gather and

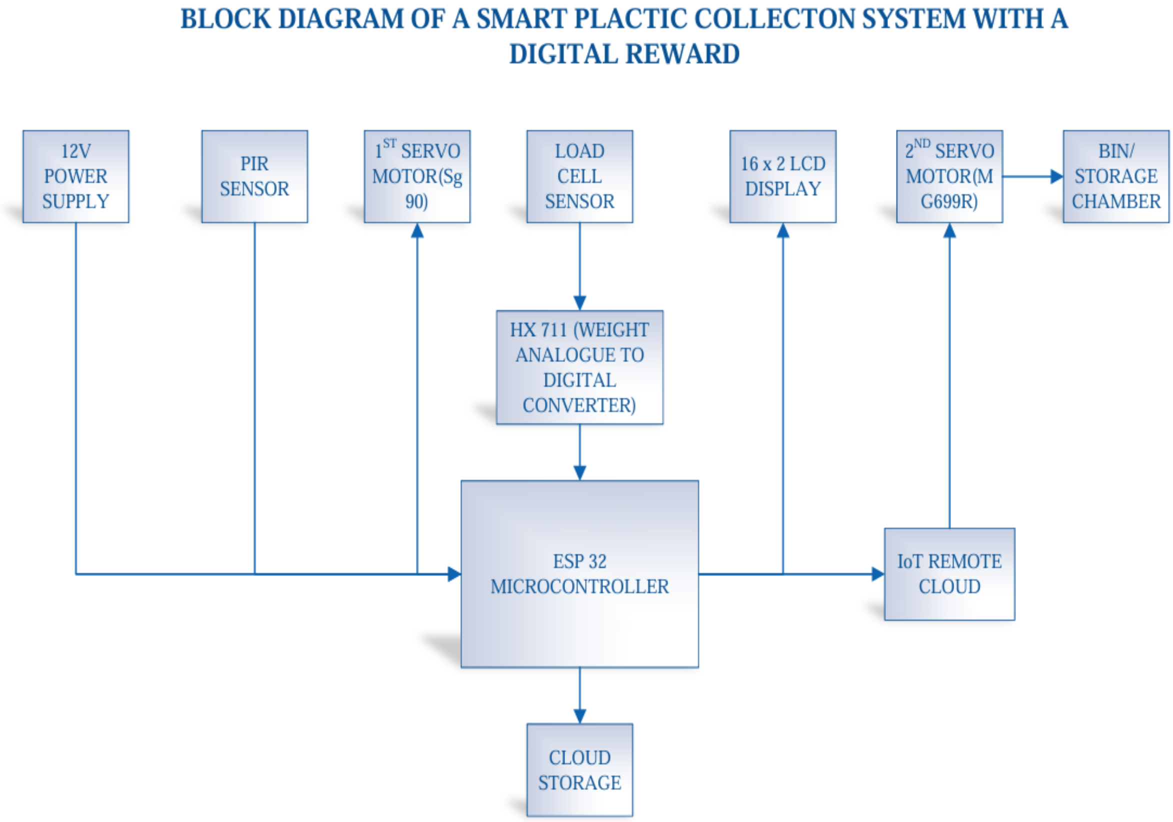


Figure 5: Block diagram of a smart plastic collection system

share information online without the need for face-to-face communication. Smart systems enhance automated processes, remote monitoring, and real-time decision-making across a range of sectors. The smart plastic collection system encompasses PIR sensor, first servo motor (Sg90), buck converter LM2596, digital load cell sensor, HX 711, second servo motor (MG699R), Liquid Crystal Display 16 x 2, I2C module, 12V DC output jack, jumper wires (M-M, M-F), IoT remote cloud, bin/storage, and cloud storage and which interact with ESP 32 microcontroller. The ESP 32 microcontroller is powered by a 12V battery and delivers a signal to the PIR sensor to sense plastic bottles, glass, cans, and metal, which further provides information to the ESP 32. The microcontroller transmits a signal to the first servo motor to open its flap and the accepted plastic bottle proceeds to the second chamber where the load cell measures the weight and sends information to the HX 711 decoder to convert analog weight to digital which is sent to ESP 32 and in turn conveys the signal to LCD 16x 2 to display the value of the weight in gram as well as the corresponding amount in naira.

The IoT remote cloud is a customized mobile app that has a payment switch, weight, and price. An API is used to establish communication between the ESP 32 microcontroller and IoT remote cloud by setting a hotspot that will connect directly from the smartphone to ESP 32 using the following hotspot details.

Mobile Hotspot Setting

Network name: Bowing Manager

Password: 88888888

User ID: samy198

Password: Forget123

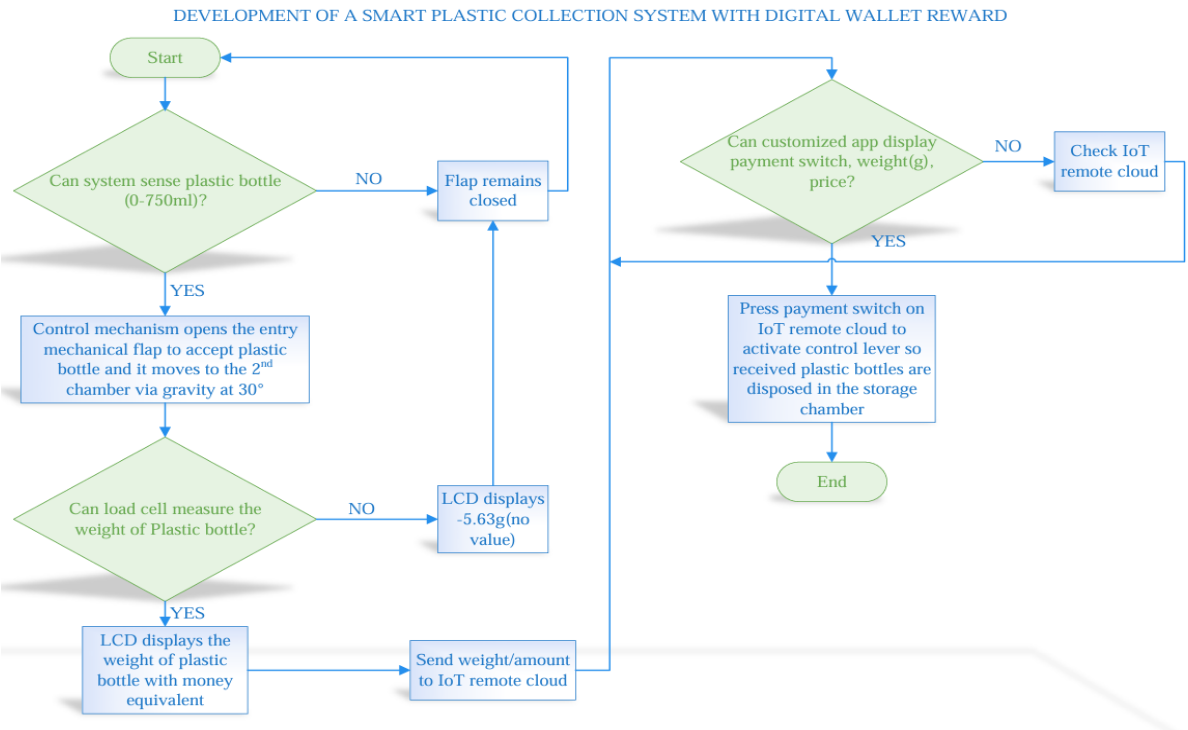


Figure 6: Flow Diagram of the smart plastic collection system

IoT Remote Cloud

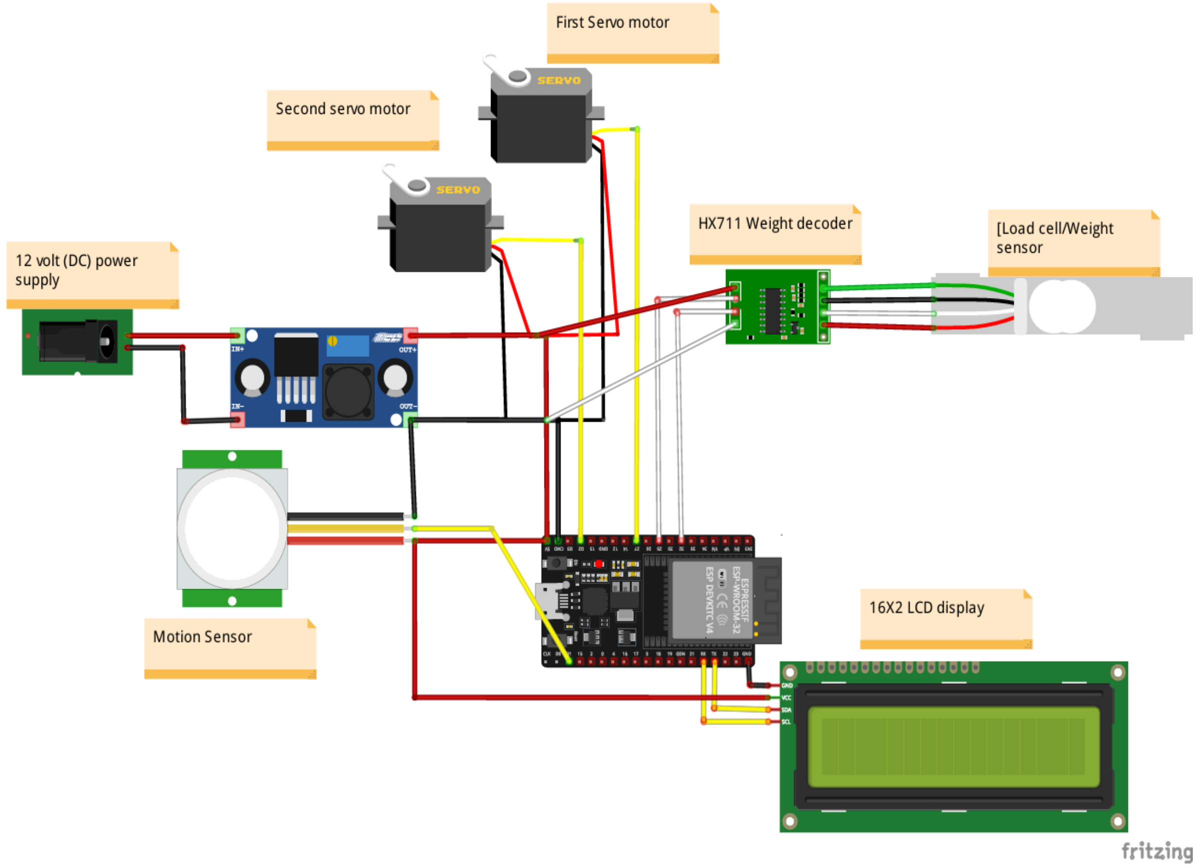


Figure 7: Circuit diagram of smart plastic collection system microcontroller transmits further information to the LCD to display the measured weight and the equivalent allocated amount.

With just a click on the payment switch option on the IoT remote cloud, ESP 32 sends information to the second servo motor and the attached control lever slides down to drop all the received plastic bottles into the storage chamber. The flow diagram in Figure 6 provides an overview of a smart plastic collection system. The smart plastic bottle collection system accepts plastic and all other materials including metal, paper, glass, and cans. The sensor detects the presence of disposable items and conveys signals to the microcontroller, which relays information to the actuator, causing the entry flap to move sideways. The PIR sensor transmits signals to ESP 32, which then instructs the servo motor to open its flap, allowing a plastic bottle/cans/disposable items to slide to the second chamber via an inclined plane. In the second chamber, a load cell sensor measures the weight of the received plastic bottle/cans, while a liquid crystal display presents the weight. Additionally, the ESP 32. The IoT remote cloud transmits the precise amount of the plastic bottle to cloud storage through the Internet of Things, where it is stored for the user.

Figure 8: Implementation of the Proposed Model

RESULT ANALYSIS

The Performance evaluation of the system was tested based on the reliability of the PIR sensor to detect movement at certain distances:

Figure 9: Final fabrication

Table 4.1: Result of reliability of passive infrared sensor

NUMBER OF ATTEMPTS	DETECTION RANGE(m)	MOVEMENT DETECTION(Y/N)
1	0	N
2	0.02	Y
3	0.04	Y
4	0.06	Y
5	0.08	Y
6	0.10	Y
7	0.12	Y
8	0.14	Y
9	0.16	Y
10	0.18	Y
11	0.20	Y
12	0.22	Y
13	0.24	Y
14	0.26	Y
15	0.28	Y
16	0.30	Y
17	0.32	Y
18	0.34	Y
19	0.36	Y
20	0.38	Y
21	0.40	Y
22	0.42	Y
23	0.44	Y
24	0.46	Y
25	0.48	Y
NUMBER OF ATTEMPTS	**DETECTION RANGE (m)**	**MOVEMENT DETECTION (Y/N)**
26	0.50	Y
27	0.52	Y
28	0.54	Y
29	0.56	Y
30	0.58	Y
31	0.60	Y
32	0.62	Y
33	0.64	Y
34	0.66	Y
35	0.68	Y
36	0.70	Y
37	0.72	Y
38	0.74	Y
39	0.76	Y
40	0.78	Y
41	0.80	Y
42	0.82	Y
43	0.84	Y
44	0.86	Y
45	0.88	Y
46	0.90	Y
47	0.92	Y
48	0.94	Y
49	0.96	Y
50	0.98	Y

Recall that :

$$\textbf{Reliability} = \frac{\textbf{Number of Successes}}{\textbf{Number of Attempts}}$$

$$= \frac{49}{50} = 98\%$$

Responsiveness of Control Mechanism

About twenty attempts were made to find the average response time of the control mechanism (servo motors). The table below shows detailed results:

Table 4.2: Result of mechanical flap response time

NUMBER OF ATTEMPTS	IoT RESPONSE TIME(SEC)
1	7
2	6.5
3	5.9
4	6.4
5	7.3
6	7.8
7	7.2
8	6.7
9	5.9
10	8.1
11	7.4
12	7.9
13	8.5
14	9
15	8.7
16	7.9
17	8
18	7.9
19	8
20	9.5

NUMBER OF ATTEMPTS	MECHANICAL FLAP RESPONSE TIME(SEC)
1	4.05
2	5
3	3.7
4	4.01
5	3.9
6	5.6
7	3.5
8	4.8
9	4.4
10	5.03
11	4.1
12	3.9
13	4.6
14	4.3
15	5.08
16	4.7
17	4.9
18	3.8
19	3.75
20	4.3

The control mechanism has an average response time of about 4.371 seconds as seen in the chart below;

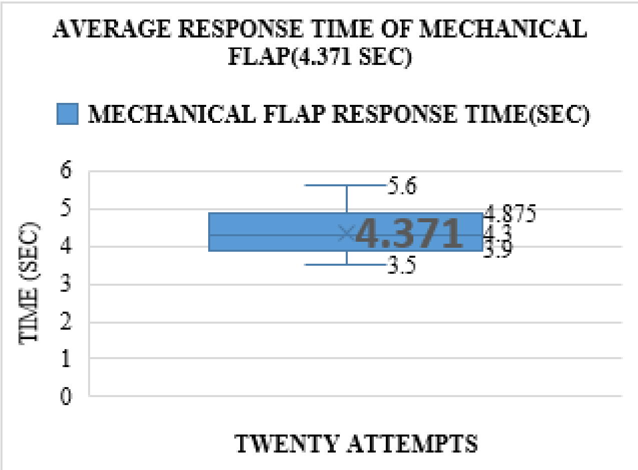


Figure 9: Average response time of mechanical flap

LATENCY OF IoT REMOTE CLOUD

The IoT remote cloud displays the weight of plastic and the corresponding amount in naira in an average of about five to six seconds subject to a stable network. Twenty attempts were made to find the average responsiveness of IoT remote cloud. The table below shows detailed results:

Table 4.3: Result of IoT remote cloud response time

The IoT remote cloud has an average response time of about 7.58 seconds as seen from the chart below;

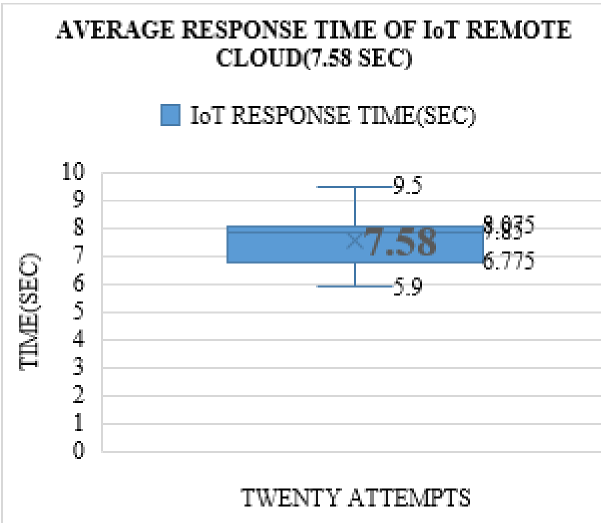


Figure 10: Average response time of IoT remote cloud

CONCLUSION

Given the results of the performance evaluation of a smart collection system in terms of the reliability of the PIR sensor (98%), prompt response of the control mechanism, and IoT remote cloud payment system, it can be deduced that this initiative would reduce herculean manual labor and motivate appropriate disposal of plastic bottles at strategic locations. Future work can limit collection to plastic alone while the system rejects non-plastic items. The use of API, the Firebase platform, can be adopted and also sync with fintech bank for collaboration using NIN or depositors' phone numbers to credit payment seamlessly.

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Akinwumi A. Amusan is a Senior Lecturer in the Department of Electrical and Electronics Engineering at, the University of Lagos, Nigeria. He obtained a Doctor of Engineering degree from the Otto-von-Guericke University, Magdeburg, Germany in 2016. His research interests include Micro/Nano Electronics Devices/Circuits and Intelligent Systems.

Ayodele A. Afolabi is an M.Sc Electrical and Electronics Engineering student from the University of Lagos. His research interests encompass IoT and process automation. He obtained a B.Eng. in Electrical Engineering from the University of Ilorin in 2009.