DESIGN AND FABRICATION OF A SMART WASTE BIN USING ARDUINO

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CERTIFICATION

This is to certify that the project title "DESIGN AND FABRICATION OF A SMART WASTE BIN USING AUDRINO" was undertaking by CHUKWURAH DANIEL DAVID, with matriculation number ENG2006292 A student of the department of Industrial Engineering, Faculty of Engineering, University of Benin, Benin City, in partial fulfillment of the award of B.ENG in Industrial Engineering.

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DEDICATION

To God almighty for his mercies and abundant grace that kept me through and to my mom, PEACE LAYO CHUKWURAH for her endless love supports

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My profound gratitude goes to Jehovah God who has sustained me all my life and leading me on the right path.

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Abstract

Effective waste management remains one of the major challenges of modern urban environments. Traditional waste bins that require manual contact during use pose hygiene risks and contribute to the spread of germs and diseases, especially in public spaces, hospitals, and offices. The COVID-19 pandemic further exposed the dangers of surface contamination, creating the need for contactless systems that minimize human interaction. To address these issues, this project focuses on the design and construction of a smart waste bin that automates lid operation using sensor-based control.

The smart waste bin utilizes an ultrasonic sensor (HC-SR04) to detect the proximity of a user’s hand and an Arduino microcontroller programmed to activate a servo motor for lid movement. The system operates on a simple logic: when an object or hand is detected within a set distance, the microcontroller signals the motor to open the lid, then closes it automatically after a short delay. The circuit was designed and tested using affordable, readily available components to ensure low cost, simplicity, and ease of replication.

The constructed system was evaluated for detection accuracy, response speed, and reliability. Results showed that the smart bin performed efficiently, responding consistently to hand motion without physical contact. This innovation promotes hygiene, user convenience, and efficient waste disposal in domestic, institutional, and public settings. The project demonstrates that embedded systems and low-cost automation technologies can significantly improve sanitation and environmental management practices.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Waste management is one of the most significant challenges facing modern societies, especially as urbanization and population growth continue to accelerate worldwide (Yusof et al., 2018). Proper disposal and management of waste are essential not only for maintaining environmental cleanliness but also for safeguarding public health. Traditional waste bins, which are commonly used in homes, offices, and public spaces, typically require manual operation. Users have to physically lift or touch the lid to dispose of waste. This manual interaction exposes users to potentially harmful microorganisms and contributes to the spread of germs and diseases (Bello et al., 2023). Additionally, users may sometimes neglect to close the bin lid properly, leading to unpleasant odors, attracting pests, and increasing the risk of environmental contamination.

In recent years, there has been growing interest in integrating smart technologies into everyday objects to enhance convenience, hygiene, and efficiency (Patel et al., 2020). Automated waste bins are a prime example of this trend, designed to minimize human contact and improve waste disposal practices. Various types of sensors, such as ultrasonic, infrared, and capacitive proximity sensors, have been employed to detect user presence and trigger automatic lid operation (Reaño et al., 2021). However, many existing smart waste bin solutions are either too expensive or technologically complex for widespread adoption, especially in developing regions or for domestic use.

The advent of affordable microcontroller platforms like Arduino has revolutionized the development of automated systems (Shinde et al., 2022). Arduino boards offer a flexible, user-friendly, and cost-effective means to prototype and implement embedded systems that can control sensors and actuators with precision. By leveraging Arduino technology, it becomes feasible to design smart waste bins that respond to proximity-based interactions and automate lid movement without the need for complex hardware or expensive components.

This study focuses on the design and construction of a smart waste bin that opens its lid when a hand is brought near the Ultra-sonic sensor and closes automatically after a short delay. The project addresses the challenges of hygiene, convenience, and operational efficiency in waste disposal. By utilizing Arduino technology, a capacitive sensor, and a servo motor, this smart waste bin provides a practical and elegant solution that can be implemented in homes, offices, and public areas.

In summary, this background highlights the growing need for improved waste disposal systems, the limitations of manual bins, and the potential of proximity-based automation in transforming waste management into a cleaner, safer, and more user-friendly process.

1.2 Concept of an Ultrasonic Sensor-Based Smart Waste Bin

The design and fabrication of an ultrasonic sensor-based smart waste bin is rooted in the growing need for improved hygiene, convenience, and efficiency in waste disposal (Bello et al., 2023). As societies experience rising population density, urban expansion, and heightened concern for public health, traditional waste bins often requiring users to lift lids manually have become outdated and insufficient. These conventional bins present hygiene risks, contribute to the spread of disease through physical contact, and fail to offer the level of user-friendly automation that modern environments increasingly demand (Patel et al., 2020).

This project aims to solve these issues by presenting a smart waste bin design that utilizes an ultrasonic sensor (HC-SR04)**.** Unlike mechanical or touch-based systems, the ultrasonic sensor detects the presence of a hand or object by emitting high-frequency sound waves and measuring the time it takes for the echo to return (Reaño et al., 2021). When a hand approaches within a set distance, the sensor sends a signal to a microcontroller (Arduino Uno), which activates a servo motor to open the lid automatically. After a short delay, the lid closes again, preparing the system for the next user. This operation minimizes physical contact, promotes hygiene, and ensures intuitive and efficient waste disposal. An important advantage of using an ultrasonic sensor over infrared or motion sensors is its accuracy and immunity to ambient light interference**.** While infrared sensors can be affected by reflections or sunlight, ultrasonic sensors rely on sound waves, which makes them more reliable in varying environmental conditions (Shinde et al., 2022). The detection range can also be adjusted in software, allowing the system to respond precisely to user proximity without unnecessary lid movement or power waste.

The core electronics—Arduino microcontroller and servo motor are chosen for their affordability, accessibility, and ease of integration. Arduino offers a flexible, open-source platform for implementing real-time control logic, while the servo motor provides accurate angular motion necessary for smooth lid operation. This simple yet effective combination enables developers to build a system that is functional, scalable, and suitable for deployment in a wide range of environments.

In addition to utility, the project also considers aesthetic appeal. The common waste bin is usually ugly, unattractive, and odious. In fact, bins often detract from spaces when not fully closed or overfilled. Conversely, the smart waste bin is fashionable and elegant granting sleek, modern feel in an indoor and outdoor environment, while maintaining a traditional can shape. The action of using the automatic lid provides the eye protection from the ugly waste without exposing it.

The smart waste bin essentially becomes much more than utility, it adds meaning beyond a normal object that can help change the aesthetic of an office, living area, clinical environment, hospitality, or public space. When we want to maintain a certain degree of professionalism, we must consider design as it adds value to cleanliness, beauty, and brand essence.

Further, the energy efficiency, low maintenance, and approachable engagement of the system makes it a reasonable solution for home and institutional contexts. In care-giving environments like hospitals, schools, or elderly care homes, it will alleviate the need for individuals to bend down or touch germ infested surfaces.

In conclusion, the ultrasonic sensor-based smart waste bin illustrates how simple, cost-effective technologies can transform everyday objects to meet modern expectations of hygiene, convenience, and efficiency. It embodies the principle that innovation does not always require complexity small, thoughtful changes can significantly enhance quality of life.

1.3 Statement of Problem

Traditional waste bins, though widely used in homes, offices, public parks, hospitals, and institutions, present several challenges that compromise hygiene, efficiency, and user experience. Chief among these is the requirement for physical contact when opening the bin lid, which not only causes inconvenience but also increases the risk of transmitting harmful microorganisms. This issue becomes especially critical in healthcare environments, shared public spaces, and households where multiple users interact with the same surface. During global health crises, such as the COVID-19 pandemic, the risk associated with such contact became even more apparent, reinforcing the need for contactless systems. (World Health Organization, 2020; Chin et al., 2020; Singh & Mahapatra, 2021).

In many instances, users neglect to close bin lids after disposal, either due to forgetfulness, inconvenience, or laziness. This leaves the waste exposed, creating unpleasant sights and odors that degrade the cleanliness of the surrounding environment. Open waste bins can also attract insects, rodents, and other disease vectors, contributing to the spread of infections and lowering the quality of public hygiene.

Furthermore, the aesthetic design of most traditional bins is basic and utilitarian, often appearing unattractive or out of place in modern architectural settings. In locations like offices, hotels, clinics, and educational institutions, where image and cleanliness are both important, traditional bins tend to be eyesores—especially when not properly maintained.

While some advanced smart bins exist that use motion sensors or AI, many of these systems are too expensive, overly complex, or power-hungry for widespread use—particularly in developing regions. Motion sensors, for example, often suffer from false triggers, causing bins to open unnecessarily when someone merely walks by. This results in wasted energy and accelerates wear and tear on mechanical components.

These challenges reveal a clear need for a smarter, more hygienic, and aesthetically pleasing alternative to traditional waste bins—one that:

1. Reduces physical contact, thus minimizing the spread of germs.

2. Opens and closes reliably, without the need for manual operation.

3. Avoids false triggers, preserving energy and extending component life.

4. Blends well with modern spaces, adding to the environment rather than detracting from it.

5. Remains affordable and simple, ensuring practical adoption in both private and public settings.

The lack of widely available solutions that meet all of these requirements simultaneously particularly in cost-sensitive or infrastructure-challenged regions, forms the basis of this project's motivation.

1.4 Aims and Objectives

The primary aim of this project is to design and construct a smart waste bin that utilizes an ultrasonic sensor (HC-SR04) and Arduino microcontroller to enable automated, touchless lid operation, thereby promoting better hygiene and user convenience. .

To achieve this aim, the following specific objectives have been set:

1. Design a circuit system that integrates an ultrasonic sensor (HC-SR04), an Arduino microcontroller, and a servo motor for automatic lid operation.
2. Program the Arduino microcontroller to detect the proximity of a user’s hand and trigger the opening and closing mechanism of the bin.
3. Construct the physical body of the bin using appropriate materials that securely accommodate all electronic components.
4. Implement a delay mechanism that allows the lid to remain open for a short period before closing automatically.
5. Provide a steady power supper that can power various componets
6. Evaluate the system’s performance based on accuracy, response time, and power efficiency.

1.5 Scope of the Work

This project covers the design and construction of a smart waste bin that uses an ultrasonic sensor (HC-SR04)**,** an Arduino microcontroller, and a servo motor for automatic, touch-free lid operation. The system is limited to local operation without internet or mobile connectivity and focuses on improving hygiene, convenience, and efficiency in waste disposal.

1.6 Significance of the Study

The design and construction of a proximity-activated smart waste bin addresses several important challenges in modern sanitation and environmental management. Its significance spans health, technology, urban planning, and aesthetics, offering both practical and developmental benefits.

To begin with, this project supports public health by eliminating direct contact with contaminated bin surface**s**, which is a major vector for the spread of diseases. Studies have shown that touch-based bin lids harbor harmful microorganisms, especially in hospitals, markets, and schools (Agarwal et al., 2020; Alsayaydeh et al., 2020; Pereira et al., 2019). By using a capacitive proximity sensor, the system allows for touchless operation—users simply bring their hand close to the sensor, and the lid opens automatically. This reduces the risk of germ transmission, which has become even more critical in the post-COVID era.

Secondly, the smart bin promotes environmental cleanliness and odor control by ensuring that the lid closes after a short delay, thereby preventing the accumulation of exposed waste. Exposed trash often leads to pest infestations and unpleasant odors, particularly in public spaces and highuse environments (Singh & Tiwari, 2021). Automating the lid closure process also ensures better waste containment and reduces the risk of accidental spills or user negligence.

Technologically, the project showcases the practical use of embedded systems and real-time automation. The system is built around an Arduino microcontroller, which is a cost-effective and accessible platform widely used for prototyping automation systems (Kouhia, 2016). This makes the project a strong learning tool for students and engineers interested in sensor-based systems and electromechanical integration.

Furthermore, the project supports broader smart city and sustainability goals. Waste management is a core pillar of smart urban infrastructure, and innovations like automated bins help reduce labor dependency and improve efficiency (R & Shital, 2019; Bhandari et al., 2019). Although the current system focuses on proximity-based lid automation, the design is scalable and could later incorporate wireless communication, solar power, and smart monitoring features, as seen in commercial systems like Bigbelly (Chin & Callaghan, 2014).

Another often-overlooked benefit of this design is its aesthetic contribution to the environment. Unlike traditional metal or plastic bins, which are often visually intrusive and utilitarian, the smart waste bin is designed with visual appeal in mind. Its clean look and responsive automation make it suitable for modern offices, residential buildings, hospitals, and educational institutions—spaces where both functionality and form matter. Integrating smart waste solutions into the aesthetic layout of public areas supports user compliance and contributes to better waste behavior (Utomo et al., 2018).

Finally, the project reflects the growing shift toward affordable and inclusive innovation. Unlike more complex or expensive AI-powered bins, this system uses accessible components and can be assembled with basic technical skills. This makes it suitable for developing countries or lowresource environments like many communities in Nigeria, where cost and simplicity are essential for adoption (Manupati & Begum, 2023; Tsebesebe et al., 2025).

In conclusion, this study is significant for its impact on hygiene, environmental sustainability, user experience, and educational value. It provides a strong example of how technology can be applied to solve common problems in a simple yet effective way, contributing both to immediate public health needs and the long-term vision of smarter, cleaner cities.

CHAPTER TWO

LITERATURE REVIEW

2.1 History of Smart Waste Bins

The issue of waste management is as old as human civilization. Early societies used simple methods like open dumping, burying, or burning to get rid of waste. These methods worked for small populations, but they fell short with the rise of industrialization and urbanization. By the 19th century, growing urban waste became a public health issue. This led to the establishment of the first municipal waste collection services in Europe and North America. (Melosi, 2013; Mason, 2018; Wilson, 2007).

2.1.1 Emergence of Sensor-Based Systems (2000–2010)

The early 2000s brought a major change with the addition of sensors in waste management. Ultrasonic sensors, which measure distances using sound waves, were among the first tools used to check how full waste bins were. These sensors worked alongside microcontrollers like the PIC16F877A, enabling basic automation by sending alerts when bins reached a set capacity. During this time, waste bins started to include simple actuators, such as servo motors, to automate lid opening and closing, cutting down on the need for human help. The introduction of Global System for Mobile (GSM) communication in waste bins allowed for basic notifications to waste management authorities. This marked the shift from manual to semi-automated systems. Research during this period aimed to improve waste collection efficiency in urban areas, especially in developing countries experiencing rapid urban growth.

2.1.2 Rise of Internet of Things (IoT) and Smart Cities (2010–2020)

The emergence of the Internet of Things (IoT) in the 2010s transformed waste management into a data-driven process. IoT-enabled smart bins began combining multiple sensors such as ultrasonic, infrared, weight, and gas sensors with wireless technologies like Wi-Fi, Bluetooth, GSM, and LoRa for real-time communication and monitoring (Al Mamun et al., 2016). These systems could send data to cloud platforms, allowing waste authorities to optimize collection schedules and routes based on actual bin status.

The Arduino microcontroller, introduced in 2005, became one of the most widely adopted platforms for smart bin designs due to its affordability, simplicity, and open-source flexibility (Patel et al., 2020). By 2017, several IoT-based projects such as the Smart Garbage Monitoring System Using IoT demonstrated how Arduino boards combined with ultrasonic sensors and GSM/Wi-Fi modules could notify authorities via mobile applications (Kumar & Singh, 2017).

The concept of smart cities gained momentum in this decade, with cities like New York, Barcelona, and London adopting IoT-based waste management systems. Companies such as Bigbelly introduced solar-powered bins equipped with internal compactors and fill-level sensors that transmitted data to cloud-based platforms for optimized collection (Bigbelly, 2015). This innovation reduced collection frequency and operational costs significantly while promoting sustainable waste management.

In Nigeria, increasing population density and limited infrastructure worsened urban waste problems. Research efforts began exploring low-cost IoT solutions. For instance, studies at Afe Babalola University (2021) demonstrated the use of Arduino-based smart bins integrated with ultrasonic sensors and GSM modules to address the unique challenges of local waste collection (Afe Babalola University, 2021).

2.1.3 Recent Developments (2020–2025)

The 2020s have seen rapid advancements in smart waste management through the integration of artificial intelligence (AI)**,** machine learning, and deep learning algorithms. Techniques such as

Convolutional Neural Networks (CNNs) and object detection models (e.g., YOLO) are being applied to automate the sorting of recyclable and non-recyclable waste (Wang et al., 2022). Additionally, blockchain technology has been explored to improve transparency and accountability in waste collection and recycling operations (Zhang et al., 2023). In Nigeria, recent studies (Fang, 2023) proposed IoT-based smart waste bins with unique IP addresses for real-time location tracking and monitoring, enhancing system traceability and management efficiency.

The use of capacitive and ultrasonic sensors, alongside servo motors, has become more common in achieving touchless lid operation and improving user interaction. Furthermore, solar energy systems and energy-efficient algorithms like AHA-LEACH are being used to extend the life of smart bin networks, particularly in regions with limited power infrastructure (Park,S.,et al.2023).

Overall, the history of smart waste bins demonstrates a clear evolution from manual, labor-intensive systems to highly automated, intelligent, and sustainable waste management solutions. The integration of IoT, AI, and advanced sensing technologies has transformed waste collection into a key component of smart city frameworks, with continuing innovations focused on improving hygiene, efficiency, and sustainability.

2.2 Types of Smart Waste Bins

Smart waste bins come in many forms, evolving with advancements in automation, sensing technologies, and communication systems. Each type of smart bin is designed to address specific challenges in waste disposal, ranging from hygiene and operational efficiency to data collection and environmental sustainability. The classification of smart bins is largely based on their core technologies and intended use-cases, such as household applications, public space deployment, or industrial monitoring systems.

2.2.1 Motion-Activated Smart Waste Bins

Motion-sensitive smart bins are among the most widely used automatic waste disposal systems, particularly in public and semi-public environments such as airports, hospitals, malls, and office complexes. Motion-sensitive smart bins are the bins that open their lids automatically when they detect movement within a specific radius typically 10 to 30 centimeters eliminating the necessity of direct contact. This feature makes them extremely popular for installation in environments that are hygiene-sensitive, where surface contact must be minimized to a bare minimum.

2.2.1.1Sensor Technologies Used

The motion trigger mechanism relies fundamentally on either one of two types of sensors:

1. Passive Infrared (PIR) Sensors

   These sensors are capable of detecting changes in infrared radiation of body heat. When a person is going to move within the line of sight of the sensor, the sensor will detect a temperature difference and trigger the lid mechanism. PIR sensors are cost-effective and power-efficient and, as such, can be utilized for simple deployments.

2. Ultrasonic Sensors

   Ultrasonic sensors operate by emitting high-frequency sound and measuring the time it takes to return as an echo. As a person comes within a pre-programmed distance, the difference in time between emission and detection senses proximity. Ultrasonic sensors are more precise than PIR sensors and less susceptible to variations in environmental temperature.

Figure 2.1: Motion-Activated Smart Waste Bins

Some advanced systems combine both the PIR and ultrasonic technologies to improve accuracy and minimize false triggering. For example, in environments of constant ambient motion (such as moving shadows or moving curtains), double-sensor setups offer certainty that the bin is opened at a time when a user approaches.

The application of ultrasonic sensors in smart dustbins tremendously reduced physical contact indoors, enhancing overall hygiene and user satisfaction. They are also incredibly efficient in overflow prevention in dense environments. (Alsayaydeh et al.;2020. Bhatt et al. 2019)

Motion-sensitive smart bins have definite advantages, not least in their ability to improve hygiene and user convenience by being touch-free. Their sensitivity to the presence of a user means that they are well-suited for busy or hygiene-sensitive surroundings like hospitals or cafeterias. That said, the systems are not flawless. In dense traffic patterns, for example, they can be subject to spurious activation, which not only results in power wastage but could eventually result in mechanical degradation. Second, their reliance on sensors and electricity causes hassle in some weathers or regions with compromised infrastructure. Apart from these drawbacks, motion sensor bins remain among the most easy-to-use and most commonly applied approaches to smart waste management.

2.2.2 Capacitive Proximity-Activated Smart Bins

Capacitive proximity-activated smart trash cans operate on the capacitive sensing principle, or the act of sensing the presence of nearby conductive objects most commonly the human body without the aid of physical contact. The cans possess capacitive sensors that respond when the user's hand or finger comes near a certain sensing area, typically within 2–10 centimeters. Upon detection, the sensor triggers a microcontroller (such as an Arduino board) that, in turn, runs a servo motor to automatically open the lid of the bin. The lid shuts after a short, pre-programmed delay, resetting the system for the next use.

Capacitive sensors operate by emitting a low-level electrostatic field and sensing changes in capacitance caused by nearby conductive objects, human skin being the primary one. This type of input is increasingly widespread in newer consumer electronics, from elevator buttons to smart phones, since it is durable and low-maintenance. Capacitive sensors for smart bins are typically mounted beneath a plastic or acrylic surface, offering both functionality and improved aesthetics.

This smart bin design, as implemented in the current project, uses an Arduino Uno microcontroller board, a capacitive touch/proximity sensor (typically a TTP223 or similar), and a standard servo motor. When the user waves a hand near the sensor panel, the Arduino detects the signal and tells the servo to open the lid. After a set time delay (e.g., 3–5 seconds), the lid closes once more. This simple yet ingenious design presents a workable compromise between technology and usability, particularly for environments in which reliability and cost are of equal importance.

Capacitive proximity-activated bins provide several important benefits. Their targeted detection system minimizes false positives, which prolongs battery life and reduces motor wear. They are also less prone to interference from environmental conditions like sunlight or temperature changes, which may impact infrared or ultrasonic sensors. The enclosed sensor arrangement also enhances durability and enables integration into a streamlined, contemporary enclosure—adding aesthetic value to the bin over conventional open-top or manual waste receptacles (Abidin et al.,2024).

Figure 2.2: **Capacitive Proximity-Activated Smart Bins**

Nonetheless, they also have their limitations. They still require the user to hold their hand in proximity to a specific region, which may not be intuitive or natural for all users. Also, while capacitive sensors are relatively robust, their functionality can be compromised by thick gloves or non-conductive materials, which reduces their accessibility in some contexts. Despite these constraints, capacitive proximity bins remain one of the most effective and visually appealing solutions in the smart waste bin market particularly where hygiene, controlled triggering, and user interaction are high on the agenda.

2.2.3 Internet of Things (IoT)-Enabled Smart Waste Bins

IoT-enabled smart waste bins represent a significant advancement in waste management by leveraging the Internet of Things (IoT) to facilitate real-time monitoring, remote communication, and data-driven decision-making. These bins are equipped with sensors—typically ultrasonic, weight, gas, or infrared—that collect environmental data and transmit it through communication modules such as Wi-Fi, GSM, LoRa, or Bluetooth to a central platform or cloud-based system. The integration of these components allows stakeholders to track fill levels, detect hazardous gases, optimize collection routes, and manage resources more efficiently.

A distinguishing feature of IoT-based bins is their ability to integrate with broader smart city infrastructure. For example, cities like Barcelona and San Francisco have implemented IoT waste systems to reduce traffic from waste collection vehicles, lower emissions, and improve service reliability. In Nigeria, a 2025 study demonstrated the use of Arduino-based smart bins connected via GSM modules, enabling authorities to receive SMS alerts when bins reached capacity—an innovation particularly useful in areas with inconsistent internet access.

IoT-enabled bins often fall into specialized categories:

1. Static IoT Bins: These are fixed in location and equipped with long-range communication modules like LoRa or GSM. They are suitable for large cities or industrial zones where bin locations are permanent.

2. Mobile IoT Bins: Typically used in campuses or markets, these are movable and use short-range wireless tech (e.g., Bluetooth) to sync data to nearby hubs or mobile collection units.
3. Smart Sorting Bins: These bins combine IoT with AI algorithms to detect and categorize waste into recyclable or non-recyclable sections before transmitting data to backend systems for monitoring and feedback loops.

While these bins offer increased efficiency, cost savings, and environmental benefits, they come with notable challenges. Issues such as initial deployment costs, data security vulnerabilities, and system maintenance can hinder widespread adoption—especially in developing regions. Nevertheless, the long-term advantages of improved operational planning, reduced collection frequency, and real-time responsiveness continue to make IoT smart bins a cornerstone of next generation waste management. (Han et al., 2012; Singh et al., 2022; Patil & Kale., 2016).

. **Figure 2.3: Internet of Things (IoT)-Enabled Smart Waste Bins**

2.2.4 Robotic Smart Bins

Another notable category is the robotic smart trash can that is designed to introduce mobility into the waste collection process. Unlike traditional or stationary bins, robotic smart cans possess built-in navigation and motorized wheels that allow them to move around a designated space on their own., and sometimes they can be used for cleaning certain ground surfaces. These bins rely on infrared sensors, ultrasonic sensors, and sometimes light detection and ranging (LIDAR) to navigate and prevent collisions in locations such as office buildings, hospitals, smart campuses, and airports. Their most significant advantage is that they reduce the level of human labor by either traveling to users when they need to throw something away or by traveling along predetermined cleaning paths around a location. Some experimental prototypes are built with object detection capabilities, enabling them to identify trash thrown on the ground and move towards it to collect it.

Figure 2.4: Robotic Smart Bins

However, with the complexities of navigation in dynamic environments and the relatively higher cost of components such as drive motors, navigation processors, and power systems, robotic intelligent trash cans are still largely in the prototype or pilot phase. Their dependency on constant power and frequent maintenance also limits widespread use. Their development, however, is an important precursor to the full automation of waste management, especially in facilities seeking to integrate robotics in routine operation.

2.2.5 Smart Sorting Bin (AI-Based)

Most closely related in technological advances is the range of smart sorting bins, which are designed to sort and segregate garbage automatically into the correct categories. They are meant to reduce human error in recycling and sort the materials in a way that enables efficient processing. Intelligent sorting bins typically consist of a suite of sensors and, sometimes, visual recognition systems that work in concert to recognize plastic, metal, paper, glass, organic matter, and general trash. Material type detection can be achieved using capacitive and inductive sensors, and weight sensors and color detection modules can be used to sort out waste materials. In more intelligent implementations, smart sorting bins have cameras and microprocessors running object recognition algorithms that allow them to identify objects by shape, color, and labeling. Once the material is recognized, an internal mechanism such as a rotating flap or sliding panel redirects the waste into the correct bin in the compartment. These types of bins are especially handy where lots of waste is generated, e.g., stadiums, schools, business offices, and transportation terminals. Though highly effective in controlled environments, smart sorting bins are faced with challenges of sensor reliability in messy or mixed-waste environments, high cost of development, and needing users to adhere to disposing of materials correctly. Despite these limitations, they are an innovative approach to improving recycling efficiency and reducing contamination of the waste stream, and thus play a critical role in the overall pursuit of sustainable solutions for waste management.

Figure 2.5: Smart Sorting Bin

2.3 Advantages of Smart Waste Bin

The use of smart waste bins offers several advantages that greatly improve the efficiency, safety, and sustainability of waste management systems. These benefits affect both how operations run and the overall user experience. They also support the larger goals of urban development, environmental protection, and public health. The advantages are as follow:

1. Improved Efficiency: One major advantage of smart waste bins is their operational efficiency. Real-time monitoring of fill levels helps waste management services avoid unnecessary collection trips. Bins with ultrasonic or weight sensors can send alerts when they are close to full. This allows for better scheduling and reduces fuel use, labor costs, and time. Studies show that optimizing routes through IoT can cut operating costs by up to 50% in some urban waste systems.
2. Enhanced Hygiene and Public Health: Smart bins improve hygiene by using servo motors and proximity sensors to automate the lid mechanism. This means users do not have to touch the bin, which lowers contact with potentially contaminated surfaces and helps prevent disease spread—especially important in busy places like hospitals, schools, and offices. Additionally, gas sensors can detect harmful emissions from decaying waste, allowing for prompt action.
3. Environmental Sustainability: Smart bins support environmental goals in several ways. Automated and efficient waste collection reduces fuel consumption and greenhouse gas emissions. AI systems that sort recyclable materials also minimize the waste sent to landfills. In solar-powered models, using renewable energy sources lowers the carbon footprint of waste management.

4. Cost Savings: While initial installation costs may be high, smart bins lead to savings over time. Better collection schedules lower fuel and personnel expenses, while predictive analytics help prevent bin overflow and cleanup costs. In smart city settings, data analytics can assist city planners in better distributing waste management budgets.
5. Data-Driven Decision Making: Smart bins provide municipalities and private operators with access to important waste data including frequency of disposal, peak usage levels and time, and types of material thrown away.

   This data allows municipalities to make evidence-based policies and inform their infrastructure. When used in combination with a cloud-based data dashboard, municipalities can also observe their systems remotely and are able to monitor site diagnostics.
6. Touchless operation using capacitive or proximity sensors enhances user experience, especially in urban locations where pedestrian foot traffic is substantial. When operating lids automatically, it also eliminates manual lifting and unnecessary physical effort for the elderly or differently abled. Visual and auditory outputs can provide guidance for the proper disposal of waste.

2.4 Disadvantages of Smart Waste Bins

While smart waste bins offer numerous benefits, they are not without limitations. These drawbacks stem from technological, economic, and infrastructural challenges that can hinder widespread adoption, especially in developing countries. A critical understanding of these disadvantages is essential for developing more sustainable and inclusive solutions. The disadvantages include:

1. High Initial Costs: One of the primary barriers to adoption is the high upfront cost of implementing smart waste bin systems. Expenses associated with sensors, microcontrollers, servo motors, communication modules, and power components (e.g., solar panels) can be prohibitive particularly in regions with limited funding for public infrastructure. Maintenance costs also add to the total cost of ownership.
2. Technology Dependence and Reliability Issues: Smart bins are highly reliant on embedded systems, communication networks, and sensor functionality. Any failure in these components such as malfunctioning ultrasonic sensors, WiFi module breakdowns, or power disruptions can render the system inoperable. In environments with inconsistent internet or electricity supply, reliability becomes a major concern.
3. Maintenance Requirements: Unlike traditional bins that require little upkeep, smart bins demand regular maintenance. Sensors need recalibration, batteries must be charged or replaced, and electronic components are prone to wear and tear. In areas without trained technicians or spare parts, maintaining these systems can become difficult and expensive.
4. Limited Infrastructure in Developing Countries: In many parts of the developing world, basic infrastructure such as stable power supply, internet connectivity, and skilled personnel is lacking. This limits the scalability and reliability of smart bin deployments. Even in pilot programs, inconsistent infrastructure has been cited as a major obstacle to sustainability.
5. System Complexity and Skills Gap: Operating and maintaining smart waste bin systems especially those integrating AI or IoT capabilities requires proficiency in embedded programming, networking, hardware troubleshooting, and sensor calibration. In many communities, particularly in developing regions, this level of

technical expertise is scarce. For example, Kenya has made strides in mobile and IoT innovation, yet still faces a notable shortage of trained professionals capable of developing and maintaining such systems (Awi Ellie, 2024 medium.com). This lack of skilled personnel poses a real barrier to the long-term sustainability of smart waste solutions, especially when systems fail or require updates and local teams cannot manage them.

6. Environmental Impact of E-Waste: Ironically, smart bins designed to promote sustainability can contribute to electronic waste (e-waste) if not properly managed. Sensors, batteries, microcontrollers, and display units all contain components that can become environmental hazards when discarded improperly. As adoption grows, so does the need for safe disposal and recycling of smart bin hardware.
7. False Triggers: In some sensor-based bin, for example the motion sensors waste bin, nearby movement may cause the lid or top of the bin to activate unnecessarily. Although this is minimized in capacitive proximity sensor systems.

2.5 Previous Work Done in This Area

The field of smart waste bin development has witnessed a steady stream of innovations, especially with the integration of microcontrollers, sensors, and IoT technologies. Numerous researchers and institutions both globally and within Nigeria have developed prototypes and systems aimed at improving waste monitoring, collection efficiency, and user hygiene. Some of these include:

Several studies and design implementations have contributed significantly to the development of smart waste bins in recent years. For instance, Samann (2017**)** designed and implemented a smart trash bin incorporating an Arduino Nano, ultrasonic sensors for fill-level detection, and a GSM module for real-time communication. Notably, this project was powered by a solar-charged lithium battery, and it featured a PIR motion sensor for user detection, alongside a memory card for data logging and audio playback for user instructions. The integration of renewable energy and user engagement made it stand out for rural deployment scenarios.

In a more recent development, Padmane (2025) introduced an ultrasonic-based shutter dustbin using an Arduino microcontroller, ultrasonic sensors, and GSM modules. The system was IoT-enabled, offering real-time waste level monitoring and alert notifications. The primary focus of this design was enhancing the reliability and responsiveness of urban waste bins, especially in public spaces with high traffic.

Similarly, Girhepunje (2025) developed a "Smart Garbage Monitoring System Using IoT" that utilized Arduino Uno boards, ultrasonic sensors, and GSM modules, with Blynk integration for real-time mobile data visualization. The system emphasized ease of monitoring through SMS alerts, making it user-friendly for both municipal workers and citizens.

Singhvi (2019) presented an IoT-based smart waste management system tailored to the Indian context. This system incorporated both ultrasonic and gas sensors to detect waste levels and potential hazardous gases. It used GSM/GPRS for data communication and offered a web-based interface for waste monitoring and citizen feedback. Its dual-sensor setup and citizen involvement component addressed broader environmental and safety concerns.

Arduino Based Smart Trash Can- A Solution for Efficient Waste Management (Rahul V, Balakrishnan E, Pradeep Raj S, Jawahar Vignesh E, Tamilarasan B, S. M,.2024). Rahul V (2024) proposed an Arduino-based smart trash can that combined ultrasonic sensors, GSM modules, PIR motion detection, and solar-powered lithium batteries. This system aimed to minimize power consumption and enhance hygiene through contactless operation. The automatic lid opening function helped reduce germ transmission in public and hospital settings.

Akinwumi Amusan & Emmanuel A. Sanni (2023). "Development of an IoT-Enabled Smart Waste Bin and Urban Waste Management Framework: A Case Study of Lagos State."
In this study, the authors designed a smart waste bin system with proximity-based automatic lid control and fill-level monitoring using sensors. Gas sensors detect decomposition levels, while data is transmitted to a web-based interface for municipal oversight. The study emphasizes urban applicability, showing how technology can optimize collection, reduce overflows, and improve sanitation. The authors also discuss integrating the prototype into larger city-wide frameworks for efficient waste management in Lagos State, Nigeria.

Abdulkader, O., et al. (2020). "Smart waste management system using IoT." Expanding on basic monitoring, this research explores a comprehensive smart waste management system that leverages IoT connectivity for dynamic data collection and analysis. The paper discusses the use of sensor data not only for fill-level monitoring but also for predicting waste accumulation patterns. It emphasizes the system's potential to transform municipal waste handling from a static, scheduled service into a responsive, data-driven operation that can adapt to real-time urban needs.

Lawal et al (2023): A publication by Lawal in 2023 titled "Smart Bin and IoT: A Sustainable Future for Waste Management System in Nigeria" discusses the development of a low-cost, intelligent waste bin system using Internet of Things (IoT) technology. He designed a smart waste management system for Bauchi, Nigeria, integrating sensors, real-time monitoring, and a user application. The system used ultrasonic sensors to detect bin fill levels and GSM modules for notifications. The project demonstrated improved efficiency, reduced costs, and enhanced sustainability through route optimization and data-driven decision-making.

Jain (2017) designed a smart solid waste monitoring and collection system using Renesas microcontrollers. The project featured sensors for detecting waste levels, GSM/GPRS modules for communication, and an Android application for monitoring. It offered a more holistic view of waste collection logistics, bridging the gap between physical hardware and digital interfaces.

Panchal et al. (2023) Presented a detailed report on an Arduino-controlled smart dustbin prototype. This design utilized ultrasonic sensors for fill-level detection and servo motors for lid actuation, emphasizing ease of assembly and practical application in households. Their work focused on creating an accessible and functional smart bin for everyday use, leveraging common components.

One of the most high-profile real-world deployments is the Bigbelly (2010) smart trash can system, in use across the United States. It's a network of solar-powered compactors, GSM modules, and cloud-based monitoring software. Bigbelly cans have been reported to reduce collection frequency by as much as 80% in some urban areas, showing the promise of smart, networked waste infrastructure.

In 2024, Sivapriya K., Mohanapriya N., and colleagues developed a smart-bin system titled “Waste Management by Smart Bin and App System using IoT.” The prototype integrates ultrasonic sensors for fill-level detection, an automated lid mechanism for hygiene, and a mobile app interface that allows real-time monitoring of bin status. Data from the bin is transmitted via Wi-Fi to a cloud dashboard, enabling municipal teams to receive alerts and plan collection based on fill status. The system was tested in a campus environment, with results showing reduced manual checks, fewer overflow incidents, and faster response times. The authors emphasised cost-effectiveness, user-friendly design, and scalability for wider urban deployment. (Sivapriya K., Mohanapriya N. 2024 ijert.org)

Shweta Patil et al (2017). reported a design that coupled a load cell with ultrasonic level sensing. The weight of the trash was recorded through the load cell, and GSM communication was used to transmit notifications. The project was directed towards institutional environments such as university campuses, where both volume and weight measurements are beneficial.

Sharma Dhawan Chachra (2015) Designed a multi-sensor bin that, apart from the ultrasonic and IR sensors, also included flame and gas sensors, making it highly suitable for placement in industrial areas where there was a danger of fire. Automatic shutdown in case of detection of poisonous gases or excessive heat was included as a safety feature in the system.

Institute of Engineering & Management, Kolkata, 2023 – Arduino Smart Dustbin A dual-ultrasonic sensor setup was implemented in this smart bin project. One sensor was dedicated to detecting hand proximity to trigger the lid-opening servo, while the second monitored the fill level of the bin. Additional features included LED indicators and a buzzer alarm to signal full capacity, creating an efficient and hygienic waste disposal system suitable for indoor environments

In another Nigerian academic project, Adeyemi and co-workers at FUTA used an IR sensor to detect lids. While the system worked under controlled conditions, they reported ambient light interference, exposing IR's drawback in outdoor or brightly lit conditions.

Yusof, M. F., et al. (2018). "Smart Waste Bin with Real-Time Monitoring System."
In this work, the authors developed a smart waste bin using Arduino, ultrasonic sensors, and GSM/GPRS modules to monitor fill levels continuously. The system automatically alerts waste collection teams when bins are nearing capacity, thereby reducing overflow incidents. The study emphasizes the integration of simple IoT solutions to streamline municipal waste management,

improve operational efficiency, and maintain hygiene in public spaces. They also analyzed cost-effectiveness and proposed deploying the system across multiple bins in urban settings to reduce manual labor and optimize collection schedules.

Viral Rambhia, Aman Valera, Rahul Punjabi (2019). "Smart Dustbins – Automatic Segregation & Efficient Solid Waste Management using IoT Solutions for Smart Cities."
This study presents a smart dustbin system capable of automatically segregating dry and wet waste using sensor arrays and microcontroller logic. The IoT-enabled system transmits bin status to a central server, allowing municipal authorities to monitor fill levels in real time. The research highlights improved recycling rates, reduced manual sorting, and enhanced efficiency in urban waste management. The authors demonstrate the practicality of implementing smart bins in smart city initiatives, emphasizing both technological feasibility and environmental benefits.

Joni Welman & Abdul Aziz Ar-Rafif (2021). "Prototype of A Smart Trash Bin for Trash Composting Based on Load Cell HX711 and Ultrasonic Sensor."
This research focused on developing a smart composting bin prototype for organic waste management. The system used an ultrasonic sensor to monitor fill levels and a load cell (HX711) to measure weight, with an Arduino microcontroller coordinating data display and alerts. The study highlighted the potential to streamline organic waste collection, reduce human monitoring, and improve composting efficiency. Field testing indicated that real-time monitoring could optimize collection schedules and reduce overflow, supporting sustainable urban waste management practices. (Jurnal Serambi Engineering jse.serambimekkah.id)

Rindi Wulandari, M. Riyad Ariwibowo, Taryo Taryo, Galieh Ananda (2022). "Design Smart Trash Based On the Inductive Proximity Sensor."

This study designed a smart trash bin using an inductive proximity sensor to detect metallic and non-metallic objects near the lid. The Arduino-controlled system automated lid operation and employed a conveyor mechanism to transport waste. The research emphasizes sensor reliability and proposes this design for environments where precise detection is critical, such as laboratories or industrial settings. The authors also explored energy efficiency, ease of maintenance, and practical deployment in medium-traffic areas.

Xueying Li & Ryan Grammenos (2022). "A Smart Recycling Bin Using Waste Image Classification At The Edge." In this study, the authors developed an AI-powered smart recycling bin using embedded edge computing devices for image-based waste classification. The system accurately identified paper, glass, metal, and plastic, sorting items automatically. The research focused on reducing human error in recycling processes, enhancing urban sustainability, and demonstrating the feasibility of low-power AI deployment in smart bins. Field tests confirmed high classification accuracy and real-time operation, suggesting practical integration into municipal recycling programs.

Jerome B. Sigongan, Hamer P. Sinodlay, Shahida Xerxy P. Cuizon, Joanna S. Redondo, Maricel G. Macapulay, Charlene O. Bulahan-Undag, Kenn M. Vincent C. Gumonan (2023). "GULP: Solar-Powered Smart Garbage Segregation Bins with SMS Notification and Machine Learning Image Processing." This study reports the development of solar-powered smart bins capable of waste segregation using machine learning image processing. The system sends SMS notifications when bins reach full capacity, integrating renewable energy for autonomous operation. The authors highlight sustainability, operational efficiency, and data-driven monitoring. The research also evaluates quality through ISO/IEC metrics, proposing future improvements such as compactor mechanisms and solar tracking to maximize efficiency in urban waste management.

Anirudh Diware, Prof Ketaki Katre, Aarti Kalegar, Rajendra Jogdand, Hanumant Bamdale (2023). "Smart Bin Using IoT."

This research presents a smart waste bin prototype that differentiates dry and wet waste using moisture and ultrasonic sensors, integrated with an Arduino microcontroller. The system enables real-time monitoring via Bluetooth and automates lid operation, reducing manual labor. The study highlights how IoT-enabled monitoring can optimize waste collection schedules, reduce operational costs, and maintain cleanliness in urban environments. Field trials demonstrated improved hygiene and efficiency compared to conventional bins.

Abdul Aziz Ar-Rafif (2021). “Prototype of A Smart Trash Bin for Trash Composting Based on Load Cell HX711 and Ultrasonic Sensor*”* (Jurnal Serambi Engineering jse.serambimekkah.id)

The study develops a smart bin prototype tailored to organic waste composting: an ultrasonic sensor monitors fill level, a load cell (HX711) measures weight, and the system uses an Arduino to display results. The context is high organic waste volumes in Indonesia; the work links bin monitoring with composting process and suggests integration with waste-management workflow.Abubakar et al., 2020 – Solar-Powered Automatic Waste Bin

Kumar, N. M., et al. (2018). "IoT based smart waste bin monitoring system." This study presents a foundational IoT framework for waste management, detailing the integration of ultrasonic sensors with a microcontroller to monitor waste levels in real-time. The system proposes transmitting this data via a Wi-Fi module to a cloud server, enabling municipal authorities to access bin status through a web interface. The primary goal is to optimize collection routes, thereby reducing unnecessary pickups, cutting fuel costs, and improving overall operational efficiency in urban sanitation services

In 2020, Waste Management Through Smart Bin by Shubham Rai and Nipun Goyal reported the development of a smart bin prototype that measures fill-level using ultrasonic sensors, alerts maintenance via GSM when full, and includes a microcontroller to drive a motorised lid. The study discusses field tests in a college campus, emphasizing improved hygiene and fewer clogging incidents compared to ordinary bins. (Shubham Rai & Nipun Goyal,.2020 ijert.org)

Jinjing Guo's 2024 publication explores the integration of IoT technologies into urban waste management with a focus on smart waste bins. The paper highlights the use of fill-level sensors, cloud data storage, and wireless communication modules to improve the responsiveness of municipal waste systems. Guo emphasizes how smart bins enable predictive waste collection schedules and real-time tracking, which help reduce overflow, optimize collection routes, and promote cleaner cities. The study provides insights into smart bin implementations across urban centers in Asia and Europe, noting their contribution to sustainable waste management strategies.

Ande et al., 2024 – Smart Waste Bins using DCNN and IoT. This study presented an intelligent smart waste bin system integrating Deep Convolutional Neural Networks (DCNN) with IoT infrastructure for automatic waste classification. The system used image-based recognition to categorize waste types before depositing them into separate bins, enhancing sorting accuracy and real-time monitoring for efficient urban waste management.

Sung, P. C., Devi, R. K., Hsiao, C. H., and Fadillah, R. (2022). "Smart Garbage Bin Based on AIoT.". This research introduced an Artificial Intelligence of Things (AIoT)-based smart garbage bin that combined ultrasonic sensors, Wi-Fi/Bluetooth connectivity, and image classification for waste identification. The system featured a mobile application that enabled users to monitor bin status and receive notifications when bins were nearly full. The authors implemented a machine learning model capable of distinguishing between recyclable and non-recyclable materials, enhancing waste segregation accuracy. Tested in indoor and semi-public environments, the prototype showed effective operation with minimal energy consumption. The study concluded that integrating AIoT technologies in waste management could revolutionize smart city sanitation systems by improving efficiency and reducing manual oversight.

In **2024**, Okubanjo A., Odufuwa B., and Okandeji A. developed a "Smart Bin and IoT: A Sustainable Future for Waste Management System in Nigeria." Their study proposes a low-cost intelligent waste-bin system integrating an Arduino Uno, WiFi module, ultrasonic sensor, and servo-motor to monitor waste fill levels and automatically open lids. The data is sent via WiFi to a web-based application where municipal teams can monitor bin status in real time. The authors emphasise benefits such as reduced labour cost, improved energy/time efficiency, and less overflowing of bins in urban Nigerian environments. Field testing in Nigeria demonstrated the system's capability to improve remote bin management and suggested its scalability to broader city-wide waste infrastructure. (researchgate.net)

Arduino & Ultrasonic-Servo Bins: Angadiameya's "Smart Dustbin with Ultrasonic Sensor and Servo" (2021) demonstrates a basic yet functional system where a servo motor automatically opens the lid when an ultrasonic sensor detects an object within approximately 20 cm (electroniclinic.com/smart-dustbin, researchgate.net smart dustbin using arduino nano *2022*, Arduino Project Hub). This project, widely shared on Arduino Project Hub, aligns well with early prototypes of smart bins.

Solar-Powered Compactors: Smart bins equipped with solar panels have gained traction as a sustainable solution for off-grid or high-traffic environments. These systems generate their own power, allowing them to operate autonomously without relying on external electricity sources. A prime example is the Bigbelly smart waste bin, introduced in the mid-2010s. Bigbelly bins are equipped with internal compactors, fill-level sensors, and wireless communication modules, enabling them to compress waste and reduce the number of collections needed. In cities like Philadelphia and New York, the deployment of these bins led to a significant drop in waste pickups—by as much as 80% in some areas. This translated into reduced operational costs, lower emissions from collection trucks, and a cleaner urban environment. According to a 2014 article by *Governing.com* titled “Trash Gets Smart”, the success of Bigbelly(2015) bins helped pave the way for broader smart waste management initiatives in smart city planning.

These prior works highlight a consistent trend the fusion of microcontrollers, sensors (ultrasonic or capacitive), and servo motors to automate lid operation, focusing on improving sanitation, usability, and basic data reporting. While there is increasing integration of IoT and renewable power, the essential building blocks of Arduino-based, sensor-driven bins remain the foundation upon which your capacitive proximity bin builds—especially as it refines non-contact activation to enhance hygiene.

2.6 Research Gap

Despite the significant progress in the field of smart waste management, several gaps still exist particularly in terms of simplicity, affordability, and adaptability. Many existing models focus on high-end applications, such as IoT connectivity and AI-powered sorting, which are often not feasible for small communities, schools, or individual households.

Additionally, systems relying on motion sensors often face issues with false triggering and power inefficiency. While some projects have explored capacitive touch sensors, few combine them with a minimalist design that focuses solely on improving hygiene and usability at a low cost.

This project fills the gap by developing a touch-activated smart waste bin that:

1. Focuses on essential automation without excessive complexity.
2. Reduces unnecessary movement by using deliberate touch input via a capacitive sensor.
3. Uses low-cost, accessible components like the Arduino microcontroller and servo motor.
4. Emphasizes practical application in real-world domestic and semi-public settings.

By narrowing the focus to deliberate user interaction and basic automation, this project offers a balanced, scalable solution that can inspire future extensions without overburdening users or developers with complicated technology requirements.

CHAPTER 3
METHODOLOGY: MATERIALS AND METHODS

3.1 Materials

The materials assembled for the production of the smart waste bin are listed in the Table 3.1.

Table 3.1 Materials required for the production of smart waste bin.

Materials	**Function**
Ultrasonic sensor (HC-SR04)	This is a sensor which uses sound waves to detect motion by emitting high-frequency sound pulses and measuring the time it takes for the echo to return after reflecting off an object
Servo motor (SG90):	It is used to open and close the bin lid
DC motors	For advanced features like moving the bin or a segregation flap.
Battery with BMS:	9V pack, voltage regulator.
Jumper wires and a breadboard	For making connections between components.
Resistors, capacitors, switches	Resistors, capacitors, and switches regulate current flow, stabilize voltage, and control power in the circuit.
Arduino Mega (Nano)	It is a central processing unit of the smart security device.
H-bridge (consisting of mosfet diodes and transistors)	These are the microelectronic components for current and signals transfers.
Structural support	This is made of the metal/wood which act as a mounting support for the waste bin and electronic systems.

Waste bin.	A standard bin made of durable plastic.
Lid mechanism	Hinges, a thread/lever system to connect the servo motor to the lid.
Housing/Mounting materials	Cardboard, Plexiglas/acrylic sheets, metal bars, screws, nuts, cable ties, and a glue gun for assembly and securing components.
Wires/auxiliary accessories	Used for components interconnectivity.

3.2. Method

3.2.1 Conceptualization.

The smart waste bin is meant to automatically open on sensing motion movement of a user and then the lid is actuated to open. The user proceeds to use the waste bin by disposing wastes into it after which the lid closes after a pre-determined period of time with no obstacle around the lid or sensor which may inhibit its operation or actuate an opposing command. The schematic of the proposed smart waste bin is shown in the Figure 3.1.

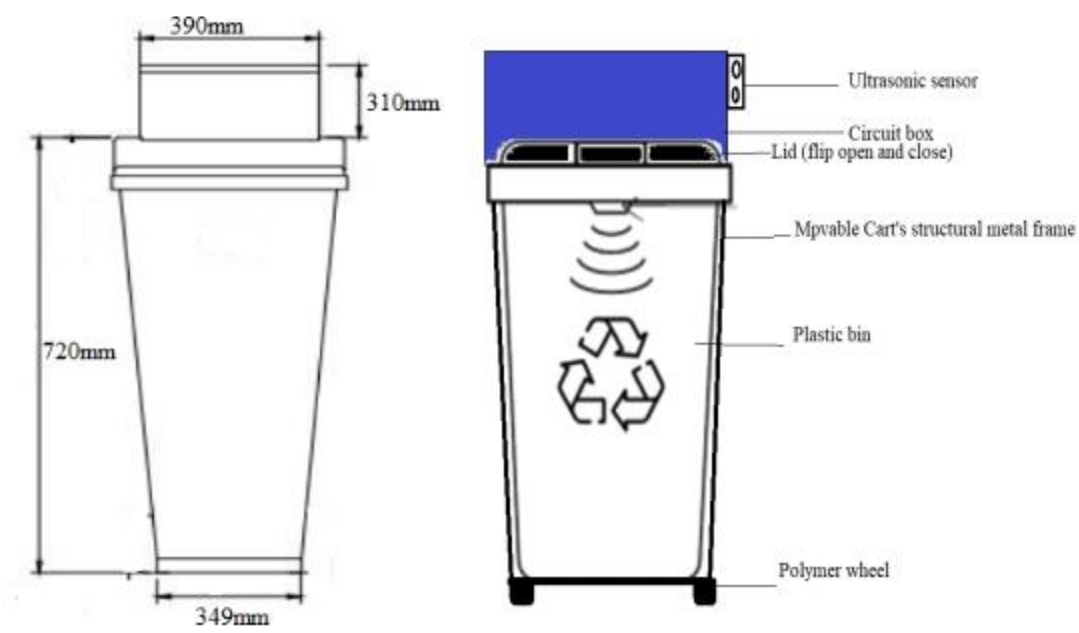

Figure 3.1 Schematic of Smart Waste Bin

The block diagram of the smart waste refuse bin is shown in Figure 3.2

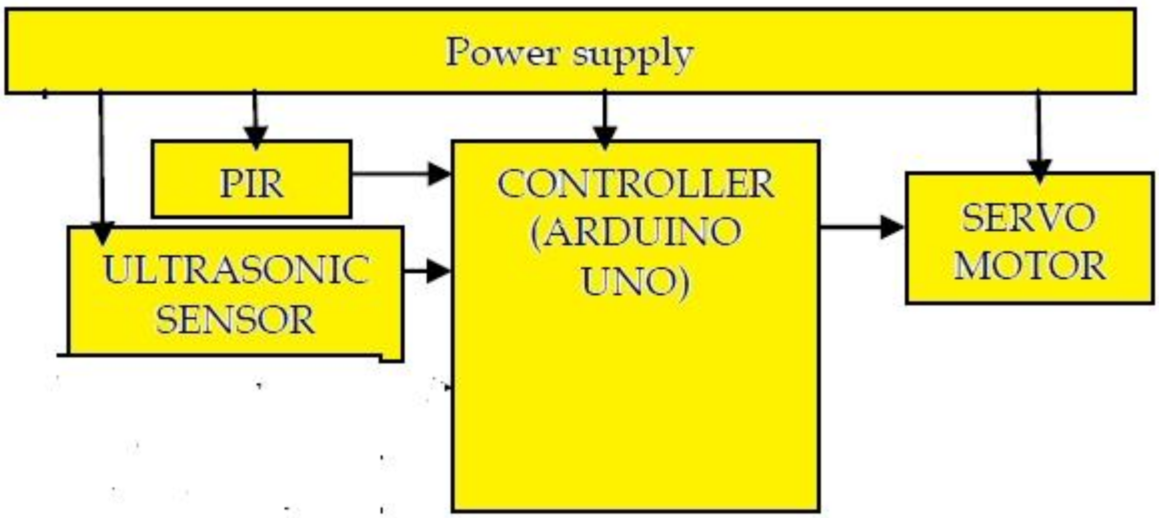

Figure 3.2 Flow diagram of the smart waste bin

3.3 Detail System Design

To implement the smart waste bin design, several electronic components were considered. The choice of any component depends on their characteristic which is considered relevant to the proof of concept. Other factors which include cost, efficiency and reliability were also considered in the use of various components. The synthesis of the proof of concept is executed under two sub sections which are

1. **Hardware**

In designing the system hardware, the system comprises the state sensors, output display, load driver, acting load, communication module and control unit. The state sensors were implemented using limit switches and proximity sensor. These help the controller to know the state of the system. There are two states of the system: Smart bin door is open; the Smart bin door is closed.

The Load Driver was used to drive the load and it was implemented using relays interfaced to the controller via ULN2003. The ULN2003A is an array of seven NPN Darlington transistors capable of 500mA, 50V output. It features common-cathode fly back diodes for switching inductive loads. In broader applications it can also be used for interfacing with stepper motor, where the motor requires high ratings which cannot be provided by other interfacing devices. The Load represents the motor that drives the door mechanism of smart waste bin management system. A DC motor is any of a class of electrical machines that converts direct current electrical power into mechanical power. The module is supplied with continuous energy (between 3.4 and 4.5 V) and absorbs a maximum of 0.8A.

2. **Power Supply**

The power supply circuit diagram is shown in Figure 3.3. Its design and installation is achieved by stepping down voltage from 230V AC to 15V AC.

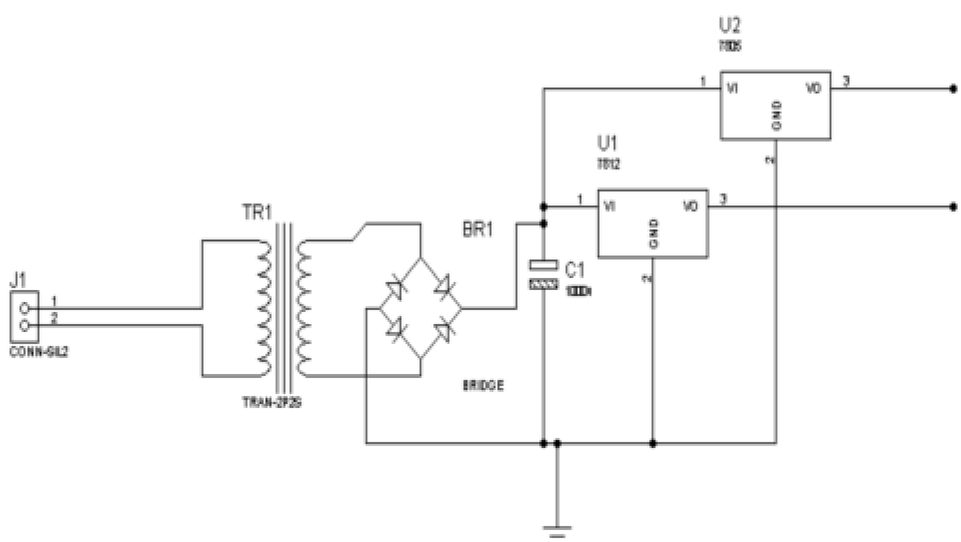

Figure 3.3 Circuit diagram of the power supply

The 15V AC generated by the transformer (TR1) is then converted to DC via the use of a rectifier (BR1). Afterwards, 1000uf capacitor (C1) is used to filter off ripples. 12V voltage regulator (7812) is used to generate standard \12V and 5V voltage regulator (7805) is used to generate 5V. The 12V generated is to power the Arduino Uno and the 5V is to power the servo motor, PIR, ultrasonic module and the voice recognition module. Alternative power source to the system is the AC current bypass and the use of a 9V solar battery connected directory to the sensor and driver ports.

3. Ultrasonic Sensor

A 5V powered ultrasonic module HC-SR04 shown in Figure 3.4 was used as the signal sensing for the actuation of the waste bin lid.

Figure 3.4 Ultrasonic sensor module

The module can have varying dimensions which ranges between 2cm to 400cm with an accuracy of 3cm. The feature makes it a good choice to measure the distance between the user and the bin so that waste is properly disposed without spilling to the ground. The device has four pins which are Vcc, Ground, Trigger and Echo. Vcc and the Ground are used to power the module while Trigger and Echo are connected to the Arduino Uno to operate it. To use the TTL (transistor transistor logic) device, a pulse 10usec wide is sent to the trigger pin. Automatically, the module will transmit eight 40KHz burst. If an obstacle is detected the burst will be reflected back and the Echo pin goes high for the time taken to send and receive the burst. The ultrasonic sensor and Arduino board connection circuit is shown in Figure 3.5.

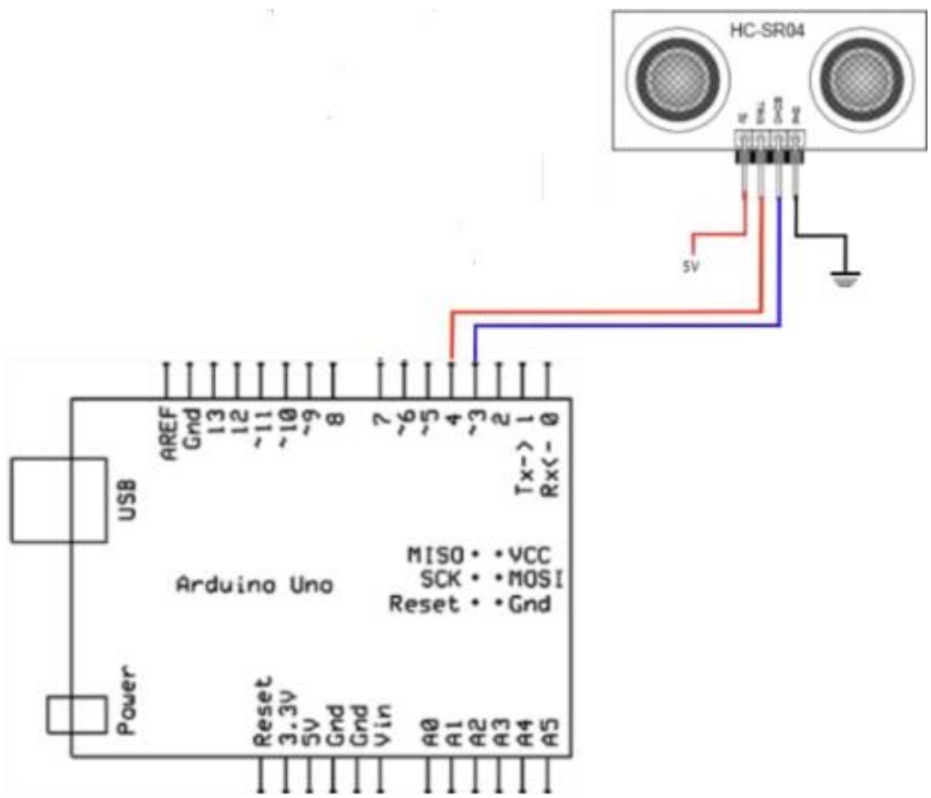

Figure 3.5 Circuit diagram of ultrasonic Sensor-Arduino baud interconnection

The sensor head emits an ultrasonic wave and receives the wave that is reflected back from the target within a set distance. This distance can be calculated with the following formula expressed as: (Uko and Anazondo, 2024)

$$\text{Distance} = \frac{1}{2} * T * C \qquad (3.1)$$

where: T is the time between the emission and reception, and C is the speed.

4. **Microcontroller (AT89S52)**

The AT89S52 microcontroller was chosen for its low power consumption, high performance, and cost-effectiveness. It operates at a 12 MHz clock speed, has 8KB of memory, and comes with 15 digital I/O pins. The microcontroller's interfaces with the motor which actuates the smart bin's lid. ULN 2003 is the driver that drives the load through the dc relay. ULN 2003 eliminates the use of transistors and free will diode configuration in driving the load. The relay is a 12V dc. The terminal voltage of the motor is expressed as:

VL= Vm = 12V dc

5. **Arduino Mega (the MCU)**

The Arduino Mega shown in Figure 3.6 is a microcontroller board based on the ATmega2560 microcontroller.

Figure 3.6 Arduino Mega (the MCU)

The Arduino has 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.

It can be used to develop a variety of electronic devices. The Arduino Mega has a number of digital and analog input/output pins, as well as several other hardware features.

The specific specs of the Arduino Mega are as follows:

Microcontroller: ATmega2560

Operating Voltage: 5V

Input Voltage: 7-12V

Digital I/O Pins: 54 (of which 14 can be used as PWM outputs)

Analog Input Pins: 16

DC Current per I/O Pin: 40 mA

DC Current for 3.3V Pin: 50 mA

Flash Memory: 256 KB of which 8 KB used by bootloader

SRAM: 8 KB

EEPROM: 4 KB

Clock Speed: 16 MHz

LED_BUILTIN: 13

Length: 101.52 mm

Width: 53.3 mm

Weight: 25 g

In addition to these specs, the Arduino Mega also has a number of other hardware features, including 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. These features make it easy to connect the Arduino Mega to a variety of external devices, such as sensors, actuators, and other electronic components. The various pin configurations of sensors, actuator, and the driver on the Arduino UNO R3 microcontroller board used for implementing the smart waste bin is presented in Table 3.2.

Table 3.2 Pin configurations of components interconnection to Arduino UNO R3

Devices	**Device type**	**Pin(s) used**
Ultrasonic Sensor 1	Sensor	Digital Pins 2 and 4
SG 90 Servo Motor	Actuator	Digital Pin 9
MQ 4	Sensor	Analog Pin 0
MQ 135	Sensor	Analog Pin 1

Devices such as the ultrasonic sensors, MQ series sensors and Servo motor are connected to the 5V and ground (GND) on the Arduino MCU board. The ESP8266 module require 3.3V from the Arduino board or an LM 317 voltage regulator connected to a 5V power supply or even a lithium polymer battery of 3.3V (Mehta, 2015). Other connections include the echo and trig pins of ultrasonic sensor which are connected to pins 2 and 4 on the board, the echo and trig pins of the second ultrasonic sensor connected to pins 7 and 8 on the board, the servo signal pin connected to pin 9 on the board and the MQ series sensors connected to analog pins 0 and 1.

6. **The container and frame**

The container for collection of refuse is a plastic receptacle (polyethylene). It is resistant to chemicals and physical damage. The container features a lid to contain odors and prevent pests from accessing the waste. Additionally, it is equipped with a handle and wheels for easy transportation. The waste container is mounted on a frame made from mild steel.

Power Supply Unit

Battery with BMS: The battery capacity shown in Figure 3.7 varies, with common options including 2000mAh or 3000mAh. The Battery Management System (BMS) includes crucial protection features such as overcharge protection, over-discharge protection, and short-circuit protection.

Figure 3.7 Battery with BMS

The peak secondary voltage, $V_{peak} = \sqrt{2} \times V_{rms}$ (3.2)

A bridge rectifier diode rectifies the 14V from the secondary of the step down transformer. The full-wave bridge rectifier 5W001 was used because it has a peak inverse voltage of 50V and can pass a peak current of 2A which is suitable for the circuit design.

$V_{L(peak)} = V_{(max)} - 2V_{d(on)}$ (3.3)

For a suitable filter capacitor value to be employed the following calculations was considered

$V_r = \frac{I_O}{2f_c}$ (3.4)

where

Vr = ripple voltage =1v

F = frequency = 50hz

I_o = regulator output current = 250mA

The capacitance C of the capacitor is therefore expressed as:

$$C = \frac{I_0}{2fvr} \quad (3.5)$$

7. **Energy Audit for the electric power requirement of the smart bin**

Total power requirement for the system = 3 PIR MSD x 10 = 30W

Auxiliary accessories = 30W

Arduino-Uno Water pump = 8W

Ultrasonic sensor 5W

Driver = 6W

Battery Selection: The method for selecting the battery involved calculating the overall daily energy use and the number of days of autonomy (1 day) needed during peak usage periods (8am-4pm)

Battery Capacity (Amp-hours) = Daily Energy Consumption

(Watt-hours) x Number of Autonomy Days / Battery Voltage

Battery Capacity (Amp-hours) = 29.8 Wh x 1 day / 3.7V = 8Amp-hours (Ah)

Arduino Uno:

A Microcontroller shown in Figure 3.4 is used ATmega328P. Its operating voltage is 5V. Digital I/O Pins is 14 (of which 6 provide PWM output) and Analog Input pins: 6. A Flash Memory is32 KB (of which 0.5 KB is used by the bootloader) and Clock Speed is 16 MHz.

Light emitting diode (Indicator).

Figure 3.4 Adruiono Uno

A LED is connected in the circuit to indicate that there is power in the circuit. A resistor is connected in series with the light emitting diode. The resistor limits the amount of current entering the LED. The value of the resistor is determined as follows:

$$V = V_d + IR \qquad (3.5)$$

Where;

V = supply voltage

V_d = voltage of LED

I = allowable current through the LED

Sensors and Detectors:

The toilet seat and doors terminals are parts of the input unit which consist of the motion sensors which are mounted at specific points at the access and or exit locations through which user interface. The motion sensor senses if there is a movement in the toilet area. When selecting and integrating IR sensors shown in Figure 3.5 into smart toilet systems, understanding their specifications is crucial to ensure optimal performance and compatibility. Typical Range: 850 nm to 950 nm (infrared light).

Figure 3.5 IR Sensor

Typical Range: 10 cm to 15 cm (adjustable). Operating voltage is Typical Range: 3.3V to 5V. The sensitivity of the sensor which is expressed as the output electrical quantity y as a function of the physical quantity x.

Mathematically:

$$y = S\,x, \qquad (3.6)$$

where:

S = sensitivity.

Servo Motors:

Servo motor shown in Figure 3.6 is used to control the position of objects, rotate objects, move legs, arms or hands of robots, move sensors etc. An Operating Voltage: 4.8V to 7.2V. Servo motors have three wires: power, ground, and signal.

Figure 3.6 Servo motor

8. **Limit switch:**

Limit switches are used to detect the presence or absence of an object. A limit switch shown in Figure 3.7 is an electromechanical device operated by a physical force applied to it by an object.

Figure 3.7 Limit Switch

Relay Module:

A 12V relay module shown in Figure 3.9 is designed to control high-voltage devices using a 12V DC control signal. It features electromechanical relays capable of handling currents up to 10A and voltages up to 250V AC or 30V DC. The module typically comes with multiple relays, ranging from 1 to 8, allowing for versatile switching capabilities. It is often used in automation systems and can be controlled by low-voltage signals from microcontrollers or other digital circuits. Indicator LEDs on the module provide visual feedback on the relay status.

Figure 3.8 Relay Module

9. The Transmitters

Two transmitters are selected with different frequencies. These frequencies are distinctly different to avoid jamming of signals, because environmental noises oscillate at frequencies the receiver could be picked up if not conditioned (Wayne et al, 2012). Timers are configured as stable multi-vibrators, infra-red LEDs and transistors as drivers. A stable multi-vibrator is to generate a tone frequency and then modulates the infra-red beam, to generate modulated beam. The pulses are connected to infrared diodes through a pair of Darlington transistors to give the required signal amplification. The light beam emitted from the IR diode is focused to the receiver.

The transmitter range is expressed as:

Min RX level + RX antenna gain - RX transmission line loss +TX antenna gain -TX transmission line loss + TX power= Free Space Path Loss (maximum acceptable). (3.7)

The range equation relates the received RF signal power to the transmitted signal power, as a function of frequency with wavelength expressed by the Friis equation as:

$\lambda = \frac{c}{f}$ and distance (D) between transmitter and receiver antennas.

$$Pr = \frac{P_t G_t G_r}{1} \left[\frac{\lambda}{4\pi D}\right]^2 \quad (3.8)$$

where:

Pr = the power received at the receiving antenna in watts

Pt = the power transmitted from the transmitting antenna in watts

Gt = the gain of the transmitting antenna

Gr = the gain of the receiving antenna

lambda = wavelength of the signal in meters

D = distance between the transmitting and receiving antennas in meters

Receivers

The infrared receiver is implemented using infrared receiver module developed for frequencies reception between a range of frequencies. The receiver consists of infrared receiver photodiodes, AGC (automatic Gain Control), Band pass, and a demodulator. The receiver absorbs the infrared emission from the transmitters and converts it to electrical signal, which is forwarded to the central console of the smart system.

The receiver power is expressed as:

$$R_p = \frac{G}{f^2 \ x \ D^2} \quad (3.9)$$

where:

G = antenna gain by the transmitted power,

f = frequency

D = propagation distance.

74151 Multiplexer

These 74151, 8 to 1 line multiplexers are used in the central console unit for power and reset functions, respectively. The multiplexer input terminals are scanned sequentially at a frequency dependent on the clock in order to pick up the signal on its line. The power multiplexer is used to detect the ON mode of the different terminals. The signal multiplexer is used to ascertain which of the terminal picked up a breach.

The equation for the multiplexer can be represented as:

$$Y = S_1S_0I_0 + S_1S_0I_1 + S_1S_0I_2 + S_1S_0I_3 \quad (3.10)$$

The number of selection lines required for a multiplexer with N input lines is:

$\log_2(N)$ selection lines 1.

i. Software design

The Software section primarily focuses on the design and implementation of the software components that control the bin's automated lid opening and closing. Input variables for material selection. The smart waste bin system is driven by embedded software, which controls the hardware components like sensors (ultrasonic) and the servo motor for automated lid movement. The programming is done using Arduino microcontrollers, where the code interacts with hardware components to process data and executes actions based on input from the sensors. The software includes algorithms for error detection and correction, ensuring that sensor data is accurate and reliable. the system performs periodic calibration to ensure accuracy over time.

3.3 Bill of Engineering Materials and Evaluation

The bill of engineering materials and evaluation of the smart waste bin is presented in Table 3.**3.**

Table 3.3 Bill of Engineering Materials and Evaluation of the Smart Waste Bin

S/N	Materials	Description	Quantity	Unit cost (N)	Total cost (N)
1	Structural frame	Composite	Lump sum	50000	50000
2	Wood pallet		Sum	15000	15000
3	Arduino-Uno micro-controller		1	22000	22000
5	Lipo DC Battery		1	4000	4000
6	Relay module		1	4500	4500
7	Xt60 female and male plug		5	300	1500
8	Bread board		1	3000	3000
9	Jumper cables		Lump	7000	7000

10	Adruino uno programmable board		1	3000	3000
11	Limit switch		1 set	6000	6000
12	Rollers		2	1500	1500
13	Servo motor		2	2500	5000
14	Labor	Lump sum		50000	50000
15	Miscellaneous			25000	25000
14	**Total**				201000

The constructed smart waste bin is shown in Figure 3.9.

Figure 3.9 Fabricated Proof of Concept of Smart Waste Bin

3.4 Construction and Testing of the System

The smart waste bin was constructed in accordance with the circuit and flow diagrams in section 3.1. The design was simulated on an electronics work bench. The testing followed the modular pattern used in the design with each functional block being tested. Various workshop production techniques such as welding, cutting, machining, filing, bracing, soldering were used in carrying out the entire fabrication process.

3.5 Testing of the Smart Waste Bin

The testing of the smart waste bin was commenced by system initiation where the power was switched on and all components verified to be in good working condition. Users were instructed to use the smart waste bin at random to evaluate the performance of the individual fixtures of the device. The amplifier stage was tested for the output voltage level. The entire circuit was tested for short circuit and open circuit faults that could result into problems. The results documented were obtained for sensitivity with respect to distances sensitivity of ultrasonic sensor, time for lid opening and closing, and user acceptance.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Result

After the construction of the smart waste bin, the entire system was subjected to a series of tests to evaluate its functionality, responsiveness, and reliability. The purpose of the testing was to verify that each component, namely the ultrasonic sensor, Arduino microcontroller, and servo motor all performed as expected and that the complete system operated in accordance with the design objectives.

The system was powered using a regulated DC supply. The ultrasonic sensor (HC-SR04) was tested to determine its sensitivity and accuracy in detecting proximity at varying distances. The servo motor was monitored for consistency in angular displacement and time response when opening and closing the lid. The Arduino microcontroller was evaluated to ensure accurate signal processing and coordination between the sensor input and actuator output.

Testing was carried out in both controlled laboratory conditions and in a real-world environment to examine how ambient factors such as lighting, temperature, and motion affected sensor performance.

The result obtained from the testing of the smart waste bin is presented in the Table 4.1

Table 4.1 Smart Waste Bin Operation Sensitivity

Distance (mm)	**Response sensitivity**	**Waste bin lid opening time (sec)**	**Waste Bin lid close time (sec)**
0.2	Sensor activates	4.2	4.1
0.4	Sensor activates	4.1	4.0
0.6	Sensor activates	4.2	4.1
0.8	Sensor activates	4.1	4.2
1	Sensor activates	4.2	4.1
1.2			
1.5			
1.8			

The results indicate that the ultrasonic sensor consistently detected objects (such as a hand) within a range of approximately **0**.2 to 1.0 meters, with optimal response between 0.4 and 0.8 meters**.** Beyond 1.0 meter, the sensor no longer triggered the servo motor, confirming the designed operational threshold.

4.2 Discussion

Field Observation and User Evaluation: For the purpose of evaluating the real-world performance, the smart waste bin was placed for a temporary period of one week in the Faculty of Engineering, University of Benin as mobile observation points. The system worked well during this period with little to no maintenance necessary. The system had performed well as per the testing done. The lid opening and closing movements took an average of about 4.1 and 4.0 seconds, respectively. The open command slightly delayed probably as the servo motor consumed more power to lift the lid against gravity.

Observation study results also showed noticeable user engagement in attentiveness towards the automatic lid and its encouraging role on hygiene disposal behavior. The interactive & contactless design of bin inspired many people to use it.

From the hygiene point of view, there was absence in hand contact by using contactless mechanism to prove safe and prevent disease transmission—particularly precious in the post-COVID 19 era when hygiene and touch-free technologies are essential (WHO, 2020).

4.4 Summary

This chapter presented the testing procedures, experimental results, and performance analysis of the smart waste bin system. Results showed high sensor accuracy, consistent servo actuation, and significant user acceptance. The design successfully met the objectives of achieving contactless, hygienic, and efficient waste disposal.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this project, the automatic smart waste bin works in an easily accessible way to help make maybe one of the oldest and most inconvenient human activity, which is trash disposal, more efficient as well as hygienic. This system does not require any physical buttons, making it more sanitary and convenient to work with as an ultrasonic sensor works in conjunction with an Arduino microcontroller and servo motor.

Moreover, being it a smart dustbin they come equipped with sensors which lets the users enjoy more convenience and cleanliness none of these efficient handling attentive solution fulfils either at home or in offices or public places. It does not only serve its purpose, but it also changes people’s minds about thoughtlessly throwing their waste by using technology that promotes minimal waste with user-friendly design. The smart waste bin designed herein will be implemented to the Department of Production Engineering for utilitarian purposes.

The results of the tests showed that the system was operated according to the expectations placed on its design. It showed consistent sensor detection, precise motor function, and autonomous lid management. The performance of the different trials showed that the smart waste bin can safely be used in homes, offices, schools and other public facilities.

The specific goal of the project, which was to create and build a smart waste bin, has been fully met. Likewise, the particular objectives which include: system conceptualization; material choice; components assembly; circuit design and performance test was accomplished successfully. This establishes that the smart waste bin developed is a cost-effective, sanitary, and simple solution towards modern-day waste management issues.

5.2 Recommendations

The recommendations below have been developed from the experience and outcomes of this research:

1 More work can be done to create a flexible version of the smart watste bin with the inclusion of IoT. This will help in monitoring a bin on real time basis,it also automatically notifies when the bin is full and manages waste collection centrally using web or mobile application.

2 Another way we can develop the smart bin is by using different types of sensor, for example infrared or capacitive proximity sensors to compare the response time and accuracy, as well as sensitivity.

3 A solar-powered design can also be created for improved energy efficiency that would allow the system to become self-sustainable outdoors or in off-grid areas.

4 It can even be enhanced with features such as LED indicators, buzzer alarms for alerts or automatic waste segregation module.

These improvements would make the smart waste bin more efficient, eco-friendly, and seamless for use in a smart home, office and public waste disposal systems.

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