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The Design of the IoT-based Smart Bin System

Emanuel N. Madihlaba, Vusumuzi Malele, Pius A. Owolawi
Tshwane University of Technology, Pretoria, South Africa
emmanuelnoah35@gmail.com, vusimalele@gmail.com, owolawipa@tut.ac.za

Abstract
Waste management is one of the major problems facing the world today. The trash spillover from garbage/trash/dust bins and the waste handling facilities creates unnecessary waste that needs to be managed. For example, in certain areas, trash spillover generates pollution as well as various hazardous situations. In this regard, unmanaged trash may be the root cause of spreading various diseases as well as creating huge waste management and health issues. To overcome the challenges, as well as maintain public health and cleanliness, this paper proposes the design of an Internet-of-Things (IoTs) based garbage monitoring system that measures the level of garbage in the bins and alerts the relevant stakeholders. It uses an ultrasonic sensor, load sensor, Arduino board, GPS Module, buzzer, and a motor and trash bin (with lid) to design the system. A sensor network was used to collect the levels in the trash bins and remotely trigger the required controls using IoTs. An ultrasonic sensor is interfaced with an Arduino board to check the level of trash and display the data on a dashboard. The administrator will then execute the required notification and dispatch authorized action. In this regard, waste management will be efficient, and overspill managed.

Keywords: IoT-based bins, Smart bin, Smart Trash bin

1. Introduction

The issue of waste has been a challenge facing the world, especially in developing countries. Both public and private dwellings have increased the volume of waste, especially during the COVID-19 period where lockdown exacerbated the level of food consumption by people who did not have work. For example, during the COVID-19 period, the littering of gloves and wipes increased by double the amount in the initial stages of the pandemic; they subsequently fell after the facemask policies, which then led to an increase in littering of facemasks by double (Roberts, et al., 2022). The latter led to trash bins overflowing and the environment being littered. This affected the environment with a significant amount of personal, protective equipment (PPEs) - facemasks, gloves, and other protective wear (Hantoko, et al., 2021).

South Africa has successfully grown a recycling economy built on the hard work of an active informal waste sector (Malele, 2022). The informal waste sector stimulates job creation and enterprise development. For example, waste pickers will collect the necessary waste and re-sell it to recycling companies. Malele (2022) described the waste pickers' work and how much they make in a month. Surely, the collection of garbage/trash could put food on the table of unemployed people. The collection of trash or garbage in urban household areas is one of the most difficult and demanding tasks in certain areas across South Africa. It is because the trash generated day by day is unpredictable, and it is perceived that, in most cases, the waste space becomes bogged down due to irregular trash removal. This makes proper trash maintenance mandatory, and it implies that there is a need for a better smart trash monitoring and management system in urban areas for both municipal and industrial systems. Unfortunately, in most cases, the trash is overflowing creating a challenge for those who are supposed to remove it.

To other people overflowing trash bins create an opportunity for economic participation. For example, some people would use plastics to make carpets and sell them to tourists. In certain areas, trash spillover generates pollution (i.e., materials that could be recycled and non-recycled) as well as various hazardous situations and scenarios (i.e., bad smell, as well the unpleasant look and feel of the environment).

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This paper proposes the design of an automated Smart Bin Monitoring System that uses the Internet of things (IoT) as a contribution to addressing the waste management challenges, also known as The IoT-based Garbage Monitoring System. This paper is structured as follows: section 1 introduced the paper, section 2 will provide some similar studies and gaps, section 3 will provide the study methods, section 4 will provide the results, and section 5 will provide the conclusion.

2. Literature Review

The challenges of overflowing or spillover waste of trash bins and their day-by-day management issues continue to be a waste management and climate change issue. Different techniques for handling the spillover challenges have been proposed by different authors (Engelbrecht, et al, 2022; Malele, 2022; Ravi, et al, 2021; Aguila, 2019; Sharma, 2018; Ghadage and Doshi, 2017; Parkash, 2016; Kurre, 2016).

Although, the average waste generated by an individual is increasing daily and no one can control it, due to the number of start-up units aimed at using technology, this challenge could be combated (Parkash, 2016). Currently, different developers, designers and entrepreneurs are working on appropriate technology solutions aiming to manage the waste emanating from potential waste producers such as households, malls, dumping facilities, etc (Malele, 2022).

A system by Kurre (2016) facilitates the process of waste management using the dumpster level monitoring system, IR sensors and monitoring the level of the trash inside the bins using ultrasonic sensors placed on top of the bin. Unfortunately, IR sensors are not reliable, especially in sunlight areas.

Ghadage and Doshi (2017) proposed a system that solves issues faced in trash management by using infrared sensors, fire detection, and sensors for detecting moisture to separate dry and wet trash. Although, as an advantage, the system could alert the authorities if the fire is dictated on the trash. due to the use of infrared (IR) sensors, which cannot be used in the sunlight, the waste would be effectively managed.

Sharma, et al (2018) implemented a trash level monitoring system using an ARM controller and ultrasonic sensors and a fire sensor. The system also deals with the monitoring of harmful gases. The system alerts users based on four types of trash: domestic, paper, glass, and plastic. The system was designed such that when the sensor data value exceeds the threshold value, the updated data values and notification is sent to the Android through the GSM connection. This system also provides the bin with LEDs to indicate the status. The drawbacks of the implemented system were its components. For example, the speed of the ARM is limited, and it has limited calculation capacity. To solve the challenge, Aguila, et al., (2019) used the Arduino Uno.

A solution by Aguila, et al., (2019) monitors waste management in real-time to keep track of the bin's capacity. This application assists local government to properly manage waste. The system comprises an ultrasonic sensor to measure the volume of the bins, a load cell to measure the weight of the bin, and an Arduino Uno which controls the systems operation. The system alerts the municipality once the sensor reaches a particular level, and the signal is sent to the Arduino. The system by Aguila, et al., (2019), gives the users power to monitor the local government; however, in most countries local government is non-effective. Hence, a system proposed by Engelbrecht, et al., (2022) enables the user to be in control and receive rewards through their trash disposal.

Engelbrecht, et al., (2022) proposed a Smart Self-managing Recycling Bin system that is coupled with a rewards program to improve recycling awareness at the consumer level. A Raspberry Pi, strain gauges, a web application written in C# and a Dotnet core framework were used to develop this system. The system weight measurements with the strain gauges were 97 per cent accurate at 7 per cent tolerant. The system allowed users to be rewarded for recycling. Unfortunately, the Smart Self-managing Recycling Bin system focused a lot on the weighing side of the waste business, rather than on the consumer side.

This paper expands the Engelbrecht et al., (2022) work by including an IoT monitoring system and a separation technique using the weighing system for dividing the trash. This feature was not fully implemented in this paper, however, as the machine learning section was not included in this paper. Furthermore, it should be noted that the type of components used in all reviewed system

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solutions showed a disadvantage. For example, most systems used infrared sensors that, when exposed to light, are not reliable. This paper used reliable components such as an Arduino Uno controller instead of an ARM controller.

3. Methodology

The proposed system was developed and designed following the hardware and software designs. The research design used to complete the task is illustrated in Figure 1 with the following narrative. To determine which hardware components and related software were necessary, a literature review, particularly related work, was conducted. It yielded the gaps that needed to be addressed, and the types of software and material that could be used to develop the system.

Different software applications (Arduino Software (IDE), MySQL, JavaScript and PHP, and Fritzing) were developed and used to facilitate the smartness of the bin and allow the sensors to function well. The Arduino Software was used to construct and design the coding part of the system that, for example, would read sensor data and help with decision making (Badamasi, 2014). MySQL was used for creating the database that will log the system usage, and Java Scripts and PHP were used to create the system dashboard.

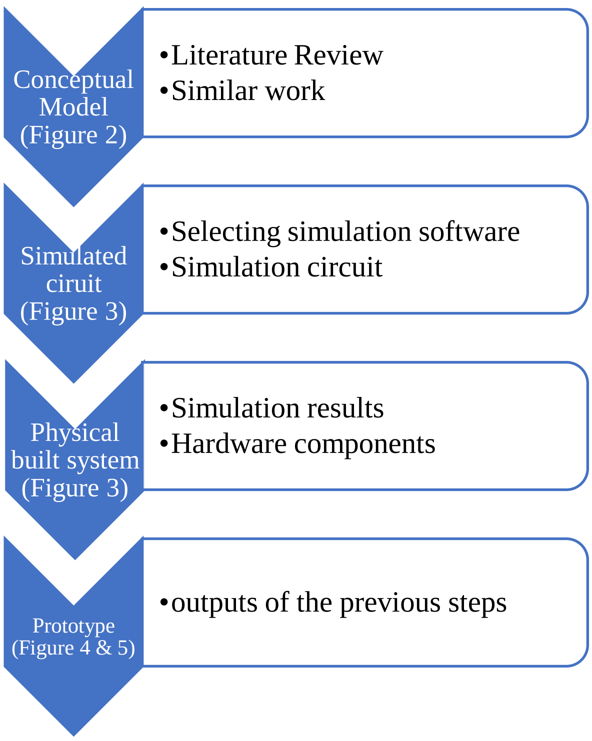

Figure 1. The proposed system research design.

The literature review work was followed by the conceptualization of the intended system which yielded a conceptualized model provided as a system block diagram in Figure 2. The system block diagram comprises the ultrasonic sensors, the Arduino microcontroller, and the GPS module. The Ultrasonic sensors are used to detect the level of garbage in the trash bin, and it will send this information to the Arduino, which is the system controller. The load sensor is used to detect the weight of the trash.

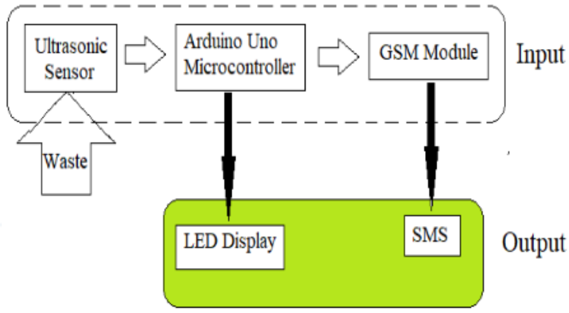

Figure 2. The proposed system block diagram.

Figure 2 was used to design a simulation circuit block diagram (see Figure 3). The simulation of the block diagram in Figure 3 was designed using Fritzing (an open-source electronics design software) and then it was simulated. The feasibility of the simulation task showed that if the physical circuit block diagram is built, it will operate effectively.

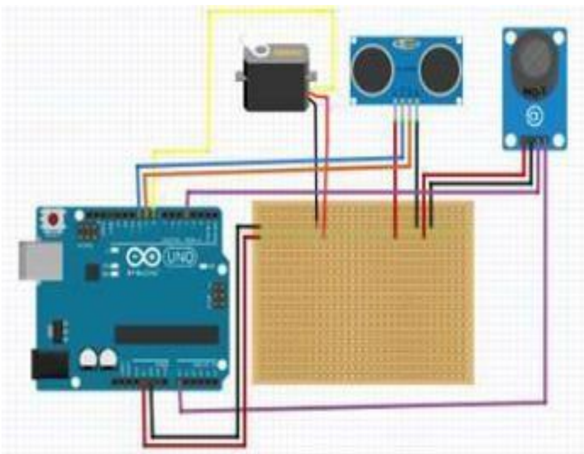

Figure 3. The simulation block circuit diagram

Using Figure 3, the physical circuitry of the IoT-based Smart Bin system was developed (see Figure 4). An ultrasonic sensor is connected to an Arduino board, the GPS Module, and the load sensor. The Arduino microcontroller is used to interface the sensor system with the GPS. This

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will help in managing garbage collection efficiently. Furthermore, the buzzer is connected to the Arduino board. A motor is also connected for closing and opening the lid.

The integration of the physical circuit led to the development of the prototype (see Figure 5). The circuit helped to develop a smart scale that was integrated with a bin to develop the IoT-based Smart Bin System. The scale was large enough to handle trash of about 10kg. The scale was connected to the buzzer to indicate any larger loads.

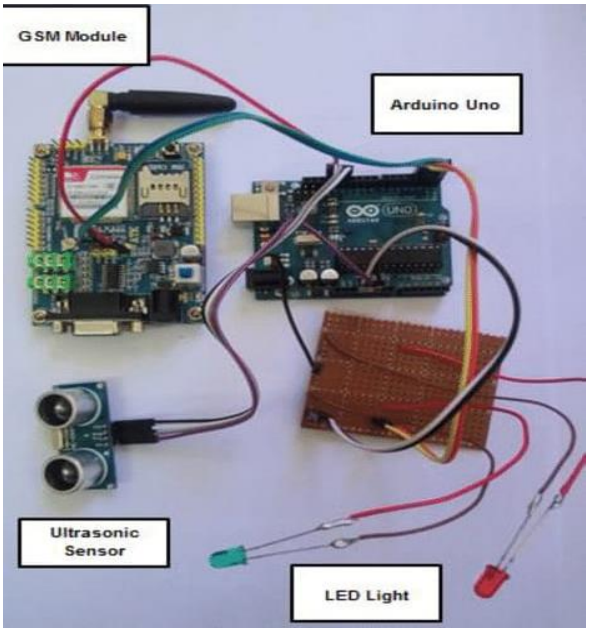

Figure 4. The physical circuit diagram of the proposed IoT trash bin system.

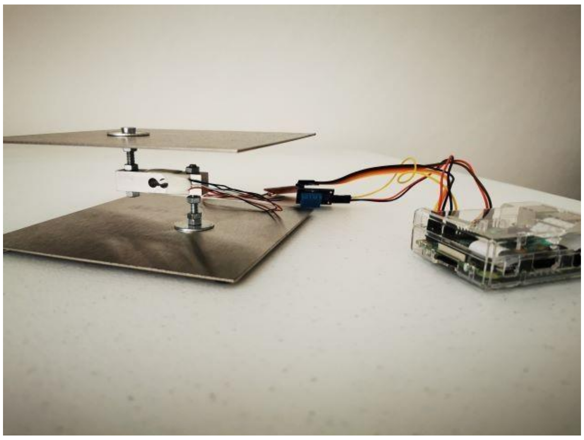

Figure 5. The IoT smart system prototype read for integrating the trash bin.

4. Results and Discussion

Figure 6 illustrates the final prototype, the IoT-based Smart Bin System. The level of garbage in the trash bin could be detected with the help of an ultrasonic sensor. When the measured value of sensors exceeds a certain threshold value, then the buzzer goes ON indicating that a dustbin is full; this information, with the GPS location where the trash bin is located, is then communicated to the dashboard for an administrator to view or monitor. The dashboard (Figure 7) will show in which area the trash bin is located by comparing coordinates, updating the location, and informing the concerned local authorities.

Figure 6. The IoT-based Smart Bin System.

The booting performance of the system is indicated in Table 1. After the start, the IoT-based Smart Bin System controller begin to sense the trash at 25cm when the lid was 90℃ open. At this degree, the motor will begin to run after a delay of 6 seconds. If the trash load is bigger than 10kg, then the system alerts the user by sending a SMS using the GSM module. Then, the system automatically sends the alerts to the user and simulates sending them to the authorities. Simulates because the first phase of the project was to design the system to focus first on the user side.

Table 1. The system booting and functionality method.

Condition	Performances
Arduino Controller = Working	Sensing Distance = 0 – 25 cm.
Motor = Working	Lid open = 90 Degree Delay open lid = 6 sec.
Ultrasonic Sensor = Working Servo	Delay close lid = 10 sec.

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Arduino Controller = Working	Initial Condition Load Sensor ON Buzzer OFF Lid Locked NO
Ultrasonic Sensor = Working Buzzer = Working	level Sensing Load sensor ON Buzzer OFF Lid Locked NO
Load Sensor = Working Lid = Working	Condition 100 garbage level sensing Load sensor ON Buzzer ON Lid Locked YES

Similar user alerts would be sent to the local authorities through e-mail. Unfortunately, that phase was not done, except for the allowance that the IoT-based smart bin user can send the e-mail manually. The capability of the system to send the e-mail automatically will give the local authority a chance to attend to the problem.

Table 2. The load for testing the IoT smart bin.

Item Name	Smart Bin Scale	Comment
1 kg bag of rice	1.0834 kg	No Buzz
Pieces of wood	10.077 kg	Buzz
Speaker System	3.7996 kg	No Buzz
Printer	2.7864 kg	No Buzz
6 bricks	13.869 kg	Buzz
Aluminium disc	15.849 kg	Buzz
Fan scraps	6.5036 kg	No Buzz
Pieces of Tyres	10.864 kg	Buzz
Car battery	14.308 kg	Buzz
Pair of Shoes	0.5261 kg	No Buzz
Weight vest	9.88 kg	Buzz

Table 2 presents the load that was used to test the IoT-based smart bin systems. When the ultrasonic sensors detect the load at 25cm while the lid is 90^o open, if the load is larger than 10kg, then the system will buzz. If the lid is less than 90^o open then it will be difficult to insert the load; however, if, in some method, the load is placed inside the trash and the lid is closed, the weigh system will measure the weight; if it is 10kg or greater, then the system will buzz and send the alert. The admin will notify the authorities and they will expect to send the local trash collecting truck.

Figure 7 illustrates that the system performance in Table 1 and the related communication are captured through Blynk–the system dashboard (Syufrijal & Rif'an, 2018; Gsangaya, et al, 2022). All values are shown on the dashboard even if the trash bin is empty or half full. For example, if the trash bin is half full, the dashboard will indicate "Smart Dustbin is 50 per cent Full" at the Blynk, and the yellow LED will light up once. The yellow LED lights five times to signal that the trash bin has reached a 75 per cent threshold, and this helps to avoid the trash overspilling. The red LED always lights up when the system has reached its capacity of 100 per cent. The latter leads to an actionable task of collecting the trash bins which is sent through an e-mail message.

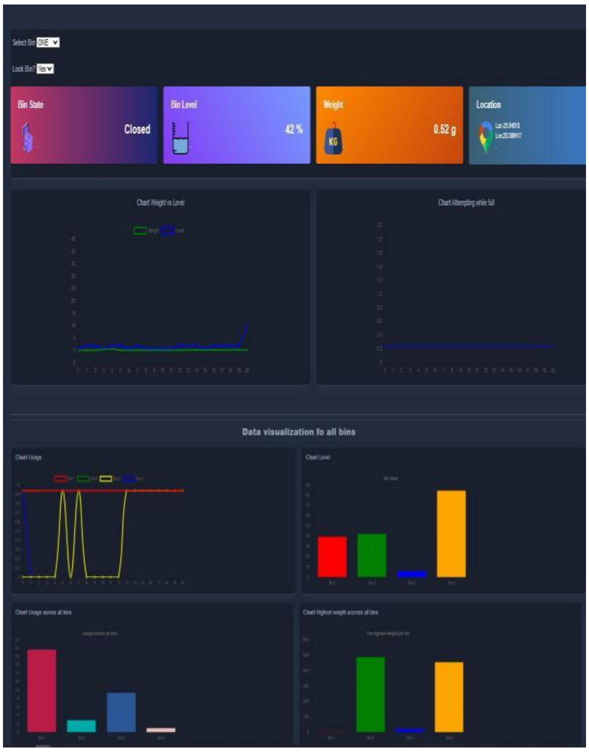

Figure 7. The IoT smart system Blynk dashboard Interface.

The dashboard was designed to represent the four Key Performance Indicators (KPI): (i) Bin State – represents whether the selected bin is either open or closed., (ii) bin level represents the current level of the trash in the selected bin., (iii) trash weight represents the weight in kilograms of the selected bin, and (iv) bin location represents the current location of the selected bin. Furthermore, the dashboards comprise three-line graphs and three bar graphs. Line graph 1 – indicates the breakdown of the relationship between the weight and bin level; Line graph 2 – indicates the breakdown of the opening and closing mechanism

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(the bin locks (closed) when it is not in use); and Line graph 3 – indicates the bin that is being used the most. Bar graph 1 – indicates the breakdown of the level of trash in the bins throughout; Bar graph 2 – indicates the combined usage of the bins; and Bar graph 3 – indicates the combined weight of the bins. The advantage of this IoT-based smart bin monitoring system was its ability to continuously measure the trash levels in the trash bins, place values on the dashboard for monitoring purposes and alert the concerned user. This makes the user a continuous part of the solution.

The limitation of this IoT-based smart bin monitoring system is the lack of a dashboard interface that could allow the authorities to see how many households have a full trash bin. The latter will allow the authorities to dispatch a truck for several households (instead of only one) with a full trash bin. To mitigate the risk of fruitless expenditure, by sending a truck toward only one house, the IoT-based smart bin monitoring system will be expanded to include a mechanism of automatic alert to the authorities and the trash dispatch unit. Once the authorities receive the alerts, the action that they will take will be sent back to the households (user).

5. Conclusions

The IoT-based Smart Bin System is based on an Arduino microcontroller. It is useful in improving the efficiency of trash management in developing countries, especially in areas where the trash is found to be overspilled from trash bins. The IoT-based Smart Bin System controller senses the trash at 25cm when the lid was 90℃ open. After a delay of 6 seconds, the motor runs and assists in measuring the load. For every load that was 10kg and more, a buzzer signals and sends a GSM module to send the alert message to the user. All the activities were recorded by the system dashboard, Blynk. The latter included the system performance as well. For example, all values are shown on the dashboard, even if the trash bin is empty or half full, e.g., the message that would reflect on the dashboard would be "Smart Dustbin is 50 per cent full" then the yellow LED will light up. If the trash bin is full, then the red LED will light up and the dashboard message will be "Smart Dustbin is 50 per cent full". The advantage of this system was its ability to continuously measure the trash levels in the bins and alert the concerned authorities. The latter helps to avoid overspilling and gives an actionable task of collecting the trash bins. Unfortunately, at the time of presenting this paper, no work was done to make sure the authorities, such as the municipality, are directly notified; only simulated work was carried out. In future, the dashboard for the authorities should be designed and be used to link the municipality for closing the IoT -based and smart aspect of the bin when viewed from the authorities' perspective. The latter should be noted as this paper presented the user perspective.

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