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Smart Waste Management System: A Novel Approach to Waste Collection in Twenty-First Century Smart City

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***Abstract*— It has been observed that domestic household bins are still being manually collected by the municipality. This old method of trash removal has flaws. It is labour-intensive. In this paper, we design and implement a novel innovative domestic waste management system. To achieve this aim, specific objectives had to be achieved. These were to design and implement a motor driver controller (MDC), obstacle detection system (ODS), email notification system, trash status monitoring, internet time-based trigger (ITT), and finally, integrating all the systems together. The project was divided into two phases: the design phase and the integration phase. The finished prototype was tested and demonstrated to function according to the design specifications. When the bin is empty, the system remains at the origin. Only when the bin is full that the system moves to the disposal point. When an obstacle is detected, it stops and sends a push notification via email to the user. Once the obstacle is removed, the system continues its path until it reaches its destination. The design objectives were achieved.**

***Keywords*— Waste, Smart, Management, Disposal, System**

I. INTRODUCTION

It has been observed that the household domestic waste bins are still manually moved from the house to the collection point. This has been the trend for decades. It is a laborious exercise that needs a more efficient way of handling if there will be improvement in the waste management in twenty first (21st) smart cities.

This old method of waste collection has several flaws; firstly, it is more labour intensive, secondly, the forgetful tendency ingrained in the human nature makes this process less efficient because of high dependency relationship between the subprocesses involved. For example, if the bin is not taken outside on the waste removal day (Thursday for example) this will cause problems to both the municipality and the persons that stay in that particular home. The municipality would have wasted petrol, time and money paid to workers for no value returned.

Now, for the persons at home they will have to take the waste to the dumping area themselves, see to it that they minimize their waste in the following week or put in place some kind of waste management measure; the fact is this creates a problem for them too. The designing and implementation of a robotic intelligent domestic trash management system was carried out. A prototype model that will lead to practical solutions to the above-mentioned problems.

The aim of this project was to design and implement a prototype robotic intelligent domestic trash management system. The specific objectives of this project were:

i. To design and test the motor driver controller for the wheels,
ii. To design and test obstacle detection system,
iii. To design and test an email notification system for obstacle(s) detected on the path,
iv. To design and test a trash status monitoring system,
v. To design and test an Internet time-based trigger system.
vi. To integrate the above-mentioned systems seamlessly.

The project was designed and implemented to be internet time-based triggered and monitor the status of the bin. The developed product is to work automatically without any human intervention in the waste disposal process.

The developed product would be restricted to the following conditions:

i. If at Origin and EMPTY- There is no need to move to Disposal Point.
ii. If at Origin and NOT EMPTY – Move to Disposal Point.
iii. If at Disposal Point and EMPTY- Move back to Origin.
iv. If at Disposal Point and still NOT EMPTY – (Not Applicable) it is assumed, it will always be emptied.
v. If Obstacle Detected at Origin or on the way- Stop and send Push Notification and Email Notification

vi. If Obstacle Removed (Origin to Disposal Point)- Move to Disposal Point.
vii. If Obstacle Detected at Disposal Point or on the way- Stop and send Push Notification and Email Notification.
viii. If Obstacle Removed (Disposal Point to Origin)- Move from Disposal Point back to Origin.

Waste management systems effect society in a purposeful and meaningful way. This project in particular adds value to the knowledge area of designing and implementing waste management systems using low power consumption and low-cost components. This system presented in this paper does not have adverse health and environmental impact on humans and the environment; it has positive effects. The design is safe to use in a household setting because it uses low Direct Current and not Alternating Current. Exposed wires of the circuit, if touched unintentionally, will not be deadly. Finally, the design is legal as it does not violate any legislative laws.

II. RELATED WORKS

In [1], according to Neo-Hippocratic medicine, the contaminated environment and air are the significant reasons of excess mortality in urban societies. Even when the quantity of waste was still small, collection and discharge remained substandard. This led to the employment of new policies and waste management techniques.

In Ancient times, the first landfill record ever recorded (3 000 BC) was developed in Crete, modern-day Greece. Legend has it that large holes were dug to serve as refuse dumps. In the Middle Ages, dumping of wastes in holes, ditches and waterways was banned by the English parliament (1388). New Amsterdam (now New York City) passed the first anti-littering law.

During the Industrial Revolution, Ben Franklin started the first cleaning service of streets. Public Health Act of 1875 was passed, in which waste collection and prevention of mass scavenging were authorised. The garbage bin also first appeared this year. In the 20th Century, almost 300 incinerators operated in the US and Canada. In the 21st century, pay-as-you-throw programs began, and each household was charged based on the amount of trash it threw away (2000s). Advances were made in trash truck technology. This allowed trash to be packaged and hauled up to three times more waste than earlier models.

Research efforts have been made to solve waste management problems in recent years. Most of these works measured the level of garbage fill for monitoring purposes only. This is shown in Figure 1. Figure 1 shows how an ultrasonic sensor can measure garbage levels. The distance measured by the sensor is used to determine the garbage level. When the measured distance is at maximum, that is, total height, the waste bin is empty. The bin is full when the measured distance equals the garbage holding capacity (GHC)—provided that the measured distance is also not equal to the total height of the bin.

Authors in [2] proposed a smart green environment of the garbage monitoring system by measuring the garbage level in real-time and alerting the municipality whenever the bin is full based on the types of garbage. The proposed system consists of ultrasonic sensors which measure the garbage level, and an ARM microcontroller which controls the system operation. The authors categorized wastes into, domestic waste, paper, glass, and plastic. With the aid of LCD and ThingSpeak APP, the level of each bin containing different categories of waste is monitored in real-time to store the data for future use and analysis.

Authors in [3] constructed a sensible bin using an ARM microcontroller that was interfaced With UART and IR sensors. The IR sensor placed at each end of the trash bin. They work under AND operation. When the dust bin is filled, a message will be sent to the respective mobile lines displaying "Garbage is filled". It continuously alerts the specified authority till the rubbish within the garbage is removed.

In [4], the authors discussed the state-of-art technologies that have been employed in literature for waste management. Also, the authors proposed a novel architecture for waste management that utilizes the concept of IoT and image processing. The proposed architecture acts as a surveillance system to monitor garbage overflow and delivers a message to the concerned authorities to take the necessary and immediate action.

In their study, the authors of [5] aimed to explore the industrial waste management practices at Free Trade Zones in Sri Lanka to identify probable approaches to address the burning issues. The study was conducted using the case studies of three free trade zones which generated the highest industrial waste. Semi-structured interviews were conducted with four participants of each case responsible for industrial waste management. In addition, two expert interviews were conducted to verify the case study findings. Findings revealed that most people were not satisfied with the existing isolation practices of industrial waste management due to various issues visible in the existing industrial waste management process.

In [6], the authors described the development of a smart garbage monitoring system, which is based on an Arduino Uno microcontroller. It was found to be very useful in improving the efficiency of solid waste disposal management in residential areas where the garbage piles at the bins are one of the residents' major concerns owing to its ability to continuously measure the garbage level in the bin and alert the municipality for immediate collection. From the tests conducted, the authors opined that the device performed optimally according to the design specifications.

The author in [7] built a system which will notify the corporations to empty the bin on time. In this system, a sensor was put on top of the garbage bin which detects the total level of garbage inside it according to the total size of the bin. At the maximum level, a notification will be sent to the corporation's office, then the employees can take further action to empty the bin.

The idea of a network of dustbins was presented by the authors in [8]. ''Smart Bin'' was developed by integrating the idea of IoT with Wireless Sensor Networks. The authors proposed the idea of incorporating cloud computing and Machine Learning techniques applied to the sensor data

leveraged by the dustbin system to gain useful insights into improving the efficiency of garbage monitoring.

An IoT-based trash-checking system utilizing Arduino or Raspberry Pi board, an open IoT stage, was developed by authors of [9]. Their project framework included an Arduino microcontroller, an ultrasonic sensor, a Wi-Fi module and a DC battery. Information from the ultrasonic sensor and burden cell is gotten by the Arduino microcontroller. Utilizing an ultrasonic sensor, the profundity of the trash in the compartment is resolved and the energy consumption of the waste receptacle from the battery was estimated. LCD screen was used as a display monitor. With the aid of the Wi-Fi module, the displayed information was sent over the internet.

Authors in [10] tried to provide a solution to the problem of garbage pile-up by developing an intelligent garbage monitoring system. This system allows the city authorities to better manage their resources in collecting garbage and provide a platform that allows efficient garbage collection.

In [11], the authors proposed a solution to upgrade minor and essential components of the university waste management system in a Pakistani university. The proposed solution is a garbage basket and its management. The basic idea of this solution is to connect each garbage basket by using the Internet of Things (IoT) protocol with the main sweeper monitoring room to show the status of each basket and notify wirelessly.

The authors in [12] developed an IoT-based smart waste management system using sensor systems. An Android application was developed with desired information relating to the various level of waste dustbins which at different locations. The waste bins send notifications with their location details to the drivers of the trucks for collection once it is filled up. This system is powered by a solar panel, a renewable energy resource.

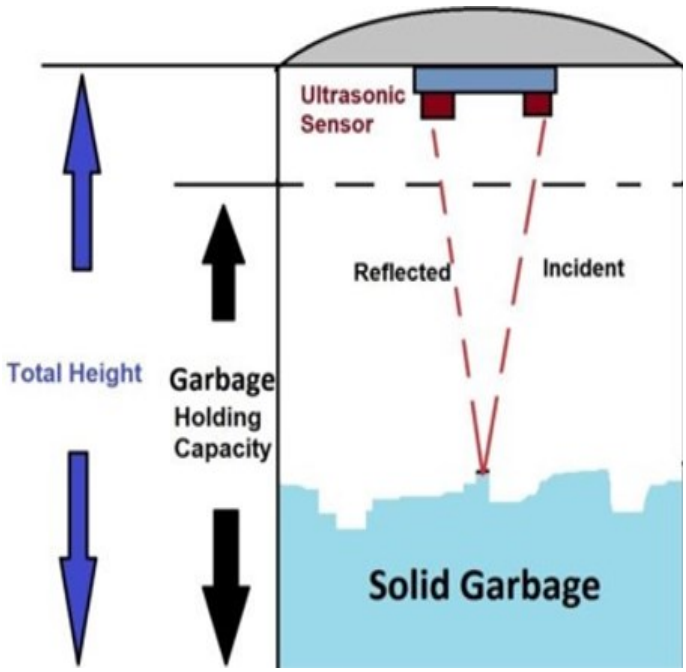

Fig. 1 Garbage fill level measured using Ultrasonic sensor.

Figure 2 shows the design of the waste bin with intelligence. To detect the level of garbage, they also used an ultrasonic sensor. The DHT11 sensor was used to monitor trash conditions. For example, it was convenient to control the state of the waste. The flame sensor was used to detect the presence of flames as some deposits of incandescent waste, such as cigarette waste, can result in smoke and fire. In this work, the authors used the Arduino MKR Fox 1200 microcontroller [10].

Robots have several advantages when it comes to doing repetitive tasks. With the rise in the use of artificial intelligence (AI), sooner or later, robots will take over the world.

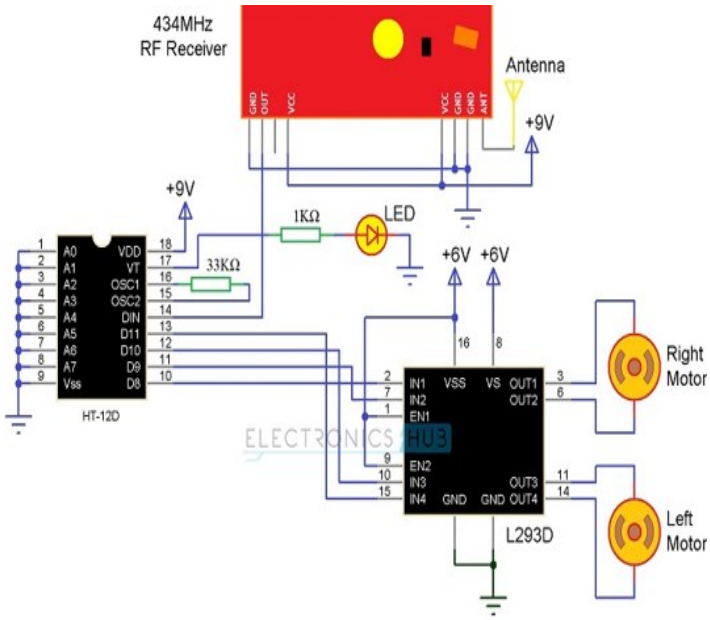

Fig. 2 RF Controlled Robot without a microcontroller.

The RF-based system in Figure 3 uses a commercially packaged motor driver (L293D) to control the wheels. A motor driver was designed from the first principles. The other components of the circuit the HT12D (RF decoder) and RF receiver are of no use. The motor driver uses the H-bridge configuration to control motors. This concept was used to design the motor driver.

Another project is the smartphone dual tone modulation frequency (DTMF) robotic vehicle. It also operates without a microcontroller. It has a DTMF tone decoder, motors and a motor driver. The DTMF has 18 pins. When a button is pressed from the smartphone, a tone is generated. The decoder decodes this tone into a binary sequence. Via this sequence, the robot is controlled.

On the other hand, the line follower robot follows a predetermined path indicated by a dark line of a particular width. The circuitry has an 8051 microcontroller, motors, IR sensors and a motor driver. The robot follows the path by following a line detection protocol.

The remote-controlled spy robot can capture video and audio and sends the data to a remote area. Its controllable range is about 125 m via the remote control. It uses a charged-coupled

device (CCD) camera. The data is sent to a receiver through an RF wireless communication.

The SMS-controlled robot uses GSM technology to control the robot. Direction instructions are sent to the robot by means of an SMS from a cell phone. The 8051 microcontroller is interfaced with GSM SIM 300. Universal Asynchronous Receiver-Transmitter (UART) protocol is used for communication between the microcontroller and the GSM modem.

III. DESIGN METHOD AND CONSIDERATIONS

In designing the system, appropriate platforms were used to design a reliable system that can be easily operated and accepted as a new household electronic device. Before the design, conscious choices had to be made concerning selecting suitable platforms and hardware components. Priority was given to open-source platforms and low-cost, reliable and flexible components.

There are various platforms over which the system could have been implemented. ESP8266 microcontroller was found to be appropriate. This was due to their low cost and availability in the market.

The diode 1N4148 was chosen because it is one of the cheapest protection diodes. This diode is parallel to the Relay to prevent damage to the transistor, which is susceptible to high voltages produced when current flow is interjected or disturbed.

The transistor (BC546B) was chosen because low voltage (3V) from the ESP board can be used to trigger it. from our experience working with the ESP microcontroller, this is thus far the easiest solution to control a high voltage (12V) with a low voltage (3V).

The 12V relay was not intended to be used in this work, but because the 5V relay was out of stock, the 12V relay was bought and used for the project to continue. This did not affect the performance of the Motor Driver. Higher voltages lead to higher speeds, and low voltages to low speeds.

The design algorithm is described in the following steps below:

Initialize variables (flag=0, fflag=0, bflag=0) and pins

1. *Check the status of the bin and send results to Blynk.*
2. *Check if it is time for waste disposal (5 to 20 seconds).*
   YES
   i. *If NOT EMPTY, NO OBSTACLE and* $\boldsymbol{fflag} \leq 2$ *-> Move 1/3 to disposal point-> increment* ***fflag*** *(Forward flag) -> Exit to 1.*
   ii. *If NOT EMPTY and OBSTACLE -> Send Push and Email Notification to owner-> delay for 3 seconds -> Exit to 1.*
   iii. *If EMPTY -> Set* ***flag*** *(Empty flag) to 1 -> delay for 100 micro-seconds -> Exit to 1.*
   iv. *If FULL, NO OBSTACLE and* $\boldsymbol{fflag} \leq 2$ *-> Move 1/3 to disposal point-> increment* ***fflag*** *(Forward flag) -> Exit to 1.*
   v. *If FULL, OBSTACLE and* $\boldsymbol{fflag} \leq 2$ *-> Send Push and Email Notification to owner-> delay for 3 seconds -> Exit to 1.*

   NO
   i. *Go to 3*
3. *Check if it is time to move back to Origin (40 to 55 seconds).*
   YES
   i. *If EMPTY, NO OBSTACLE,* ***flag*** *is 0 and* $\boldsymbol{bflag} \leq 2$ *(Backward flag) -> Move 1/3 back to Origin -> increment* ***bflag*** *-> delay for 1 second -> Exit to 3.*
   ii. *If EMPTY, NO OBSTACLE and* ***flag*** *is 1 (Already at Origin)-> delay 100 micro-seconds -> Exit to 3.*
   iii. *If EMPTY, OBSTACLE and* ***flag*** *is 0 -> Send Push and Email Notification to owner -> Exit to 3.*

   NO
   i. *Go to 4.*
4. *Check if time to RESET Flags (56 to 59 seconds).*
   YES

   i. *Set* ***flag, fflag*** *and* ***bflag*** *to 0 -> Exit to 4*

   NO
   Go to 1 (Restarting the 1-minute cycle).

Fig. 3 Waste Management System Prototype

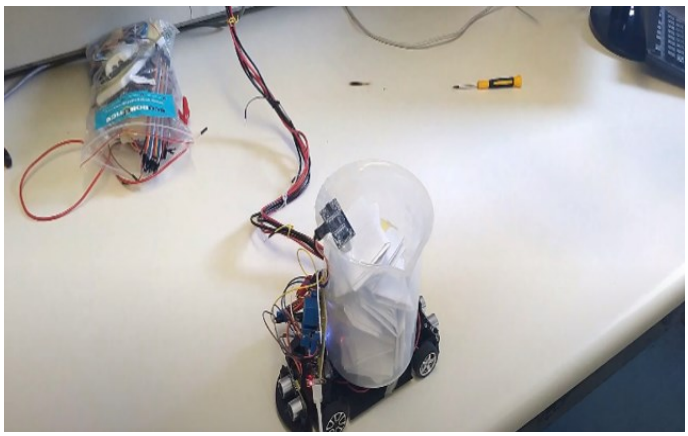

Fig. 4 RF Full Waste Bin

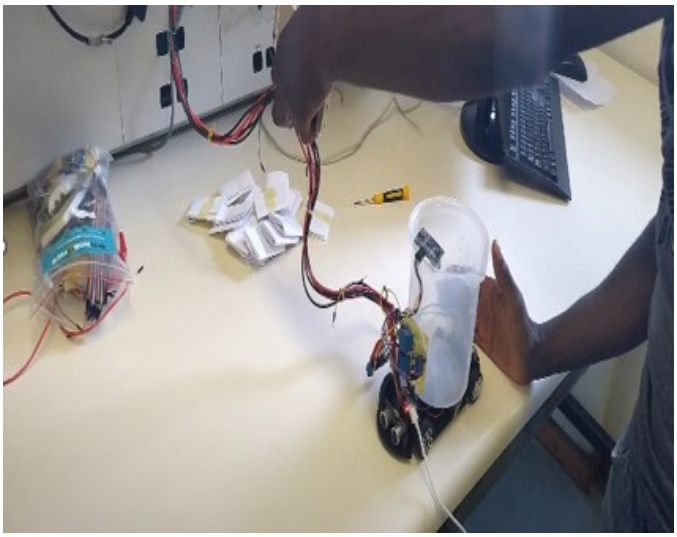

Fig. 5 Detection of obstacles on the bin's path

IV. Conclusions

In this paper, we designed and implemented an innovative domestic waste management system. With the aid of a robotic system, an intelligent waste collection and disposal system was achieved. Incorporated in this system are a motor driver controller (MDC), obstacle detection system (ODS), email notification system, trash status monitoring, and internet time-based trigger (ITT). These various features were integrated together to produce a robust system with high-performance efficiency. The prototype was tested and demonstrated to function according to the design specifications.

However, for future improvement of the system, a manual mode of operation could be introduced to allow users to control the robot remotely over the internet. Furthermore, the high-resolution camera could be incorporated to identify the robot as it navigates easily. Training the robot using artificial intelligence for pathfinding will be an attractive feature to be incorporated for future improvement. Finally, is to develop an IoT mobile application that can perform all functionalities to do away with Blynk mobile application as it cannot be used for commercial purposes.

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