INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue XII, December 2023

Optimizing Waste Collection Efficiency by NodeMCU enabled Ultrasonic Trash Can Surveillance and ThingSpeak Dashboards

A. Salleh, N. R. Mohamad, N. M. Z. Hashim

Center for Telecommunication Research and Innovation (CeTRI), Fakulti Teknologi Kejuruteraan Elektronik dan Komputer (FTKEK), Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia

DOI: https://doi.org/10.51583/IJLTEMAS.2023.121202

Received: 30 November 2023; Accepted: 08 December 2023; Published: 04 January 2024

Abstract: The use of inflexible route schedules for garbage collection results in inadequate waste disposal, posing environmental risks and incurring high operational expenses, including fuel costs and landfill fees, even when the waste containers are not completely full. This study utilizes a cost-effective Internet of Things (IoT) monitoring system to facilitate dynamic routing. The aim is to enhance the efficiency and frequency of waste collection by optimizing it based on real-time fill levels, rather than following fixed cycles. The prototype employs an ultrasonic distance sensor in conjunction with a NodeMCU ESP8266 micro-controller to detect the fill level of a trash can. The collected data is then transmitted to the ThingSpeak cloud platform. Real-time visualization dashboards display live data on waste levels in different containers, providing guidance for collection scheduling. The estimated scope entails conducting circuit simulation using Proteus, optimizing PCB layout, and developing an integrated IoT prototype connected to ThingSpeak for IoT analytics. Ultimately, integrating cost-effective IoT edge sensors such as ultrasonic ranging with cloud analytics dashboards greatly enhances effectiveness, sustainability, and intelligent allocation of resources in public trash collection. This results in economic and environmental advantages by reducing landfill overflow through the digitalization of smart cities.

Keywords: smart waste management, ultrasonics sensor, NodeMCU, ThingSpeak, IoT

I. Introduction

The handling of waste in urban settings has emerged as a pressing issue due to the significant rise in waste production caused by the fast urbanization and population expansion. Consequently, it is crucial to enhance the efficiency of waste collection in order to reduce the negative environmental and public health consequences of uncontrolled waste. Conventional waste management methods frequently encounter difficulties in efficiently monitoring and controlling waste collection procedures, resulting in inefficiencies and higher operational expenses [1], [2].To address these difficulties, there has been an increasing focus on utilizing modern technologies like the IoT, machine learning, and real-time monitoring systems to improve waste management procedures [3]–[5]. These technologies have the capacity to transform waste management by allowing for live monitoring of trash cans, predictive monitoring of waste levels, and the creation of smart waste management systems enabled by the IoT [3], [4], [6]. Despite notable progress in utilizing IoT and machine learning in waste management, there is still a lack of study on combining NodeMCU-enabled ultrasonic trash can monitoring with ThingSpeak dashboards to enhance waste collection efficiency.

The present state of trash management requires the creation of inventive and comprehensive solutions that can effectively tackle the challenges of rubbish collection in urban settings. Prior research has emphasized the significance of citizen involvement, advanced learning, and IoT based machine learning algorithms in the processes of trash segregation, prediction, and monitoring [3], [7]. Moreover, researchers have investigated the possibilities of utilizing blockchain technology and context ontology in smart waste management. They have highlighted the importance of developing comprehensive waste management solutions that are aware of the surrounding context [2], [8]. Moreover, the incorporation of IoT technology into solar-powered systems and the implementation of real-time monitoring has been suggested as a progressive step in smart city development. This highlights the diverse strategies employed to enhance waste management efficiency [9], [10]. Nevertheless, there is a lack of extensive studies in the literature regarding the merging of NodeMCU-enabled ultrasonic trash can monitoring and ThingSpeak dashboards. This integration has the potential to provide a fresh and efficient method for enhancing garbage collection efficiency.

The primary insights drawn from the current body of literature emphasize the capacity of IoT technology to fundamentally transform waste management procedures. Research has shown that machine learning algorithms based on the IoT are successful in forecasting garbage levels. Additionally, smart waste bins equipped with real-time monitoring features have been developed [7], [11]. Moreover, the incorporation of IoT technology into solar-powered systems has demonstrated potential in monitoring garbage in real-time, hence facilitating effective waste management in urban areas. Nevertheless, there is a significant deficiency in the existing body of knowledge concerning the utilization of NodeMCU-enabled ultrasonic trash can surveillance and ThingSpeak dashboards. This combination has the potential to provide a thorough and unified method for enhancing the efficiency of waste collection in urban settings.

In this work, the primary objective of this work is to create a monitoring system for garbage cans that utilizes sensors to track the current fill levels in real-time. This is made possible by employing NodeMCU micro-controllers and ultrasonic sensors to accurately measure the volume of trash. The primary outcome is the integration of ThingSpeak dashboards for centralized visualization and analysis of trash pickup data, patterns, and metrics.

II. Literature Review

The utilization of IoT technology to enhance waste collection efficiency has attracted considerable attention in recent years. In their study, [12] performed a survey focused on solutions for managing solid waste using IoT technology. The study highlighted the importance of effective trash management in urban settings. In a similar vein, [13] concentrated on constructing an Internet of Things (IoT) framework for waste management in smart cities. They emphasized the significance of utilizing IoT to enhance waste collection efficiency. In addition, [4] introduced a waste management system that utilizes IoT and machine learning techniques. Their study showcases the capability of machine learning and graph theory in enhancing the efficiency of garbage collecting procedures. These studies emphasize the increasing interest in utilizing IoT and machine learning to improve trash management in metropolitan areas.

Research has emphasized the significance of citizen engagement in garbage management, alongside IoT-based solutions. [14] introduced a sophisticated trash management solution specifically designed for residents, with a focus on including individuals in the waste management process. This is consistent with the results of a study conducted by [15], which examined dynamic models for the collection of high priority waste in smart cities. The study emphasized the significance of citizen participation in waste management methods. These studies highlight the importance of focusing on citizen-centric techniques to maximize the efficiency of waste collection.

Furthermore, the incorporation of cutting-edge technology such as cloud computing and big data analytics has been investigated in relation to waste management. [16] introduced a smart city platform that was designed to establish an automated waste collection system. The focus was on utilizing cloud computing and data collection to improve waste management procedures. [17] emphasized the interconnectedness of IoT, cloud computing, and big data analytics in protecting environmental health. They emphasized the promise of new technologies in waste management.

Moreover, the utilization of IoT enabled dashboards for trash management has been a topic of fascination. [18] performed a comprehensive analysis of existing literature to examine the necessary conditions and obstacles associated with dashboards, thereby illuminating the potential of dashboards in the field of waste management. Furthermore, [11] examined the deployment of IoT technology in garbage monitoring systems, showcasing the practicality of IoT-powered dashboards in the field of waste management.

III. Methodology

The primary procedure of the system entails the fabrication of hardware utilizing an ultrasonic sensor, NodeMCU micro-controller, and servo motor, the simulation of circuits using Fritzing software, and the design of schematic and PCB layout using Proteus software, in conjunction with programmable using Arduino IDE. The hardware development will involve incorporating an HC-HR04 ultrasonic sensor, to detect the level of waste, a NodeMCU for transmitting data, and a servo motor to control the lid of the trash can. By implementing this technology, it will be possible to continuously monitor the amount of garbage in real-time and automatically open the lid for waste collection. This has been demonstrated in studies conducted by [19], [20]. Fig. 1 shows the block diagram of proposed system.

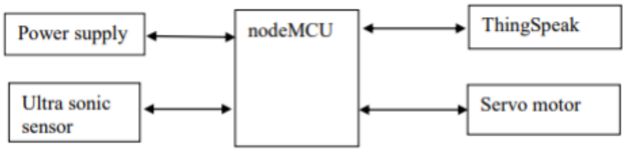

Fig. 1 Block diagram of system

The ultrasonic sensor can accurately and reliably measure distances ranging from 2 cm to 400 cm. This is accomplished by emitting ultrasonic waves at a frequency of 40 kHz, which then bounce off an object and return to the sensor. The sensor precisely determines the distance to the object by evaluating the time difference between the emission and reception of the sound waves.

Servo motors are a feedback control system comprising of three primary elements; a motor, a position sensor, and a control circuit. The motor initiates the motion of the servo. The position sensor, usually in the form of an encoder, relays information to the control circuit on the angular position of the motor shaft. The control circuit subsequently compares the current position to the desired position indicated by the input signal, typically a pulse width modulated (PWM) signal. The sensor is calibrated to measure distances ranging from 0 to 27 cm above the lid. When the ultrasonic sensor detects an object crossing a specific area, it activates the micro-controller to activate the servo motor located underneath the lid. The servo rotates by 90°, causing the movement of a linkage that is attached to the lid. This results in the hinged lid immediately pivoting outward. Fig. 2 shows the flowchart of automatic open lid.

The NodeMCU is a freely available IoT platform that facilitates quick prototyping and advancement of WiFi-connected electronic applications. The fundamental component of the device is an ESP8266 WiFi System-on-Chip (SoC) that incorporates a 32-bit Tensilica microprocessor and a wireless transmitter. The NodeMCU firmware is compatible with the Lua scripting language and can also support other languages through customized builds. The development board provides access to a variety of general purpose input/output pins from the ESP8266 for connecting to sensors and other devices. The board is equipped with an on-board USB-Serial converter and a 5V regulator, which enables convenient power supply and programming. This may be done by simply connecting a micro USB connection to a computer or charger.

Fig. 3 shows the system circuit in Fritzing software. The utilization of Fritzing software enables the virtual examination and verification of the hardware design, guaranteeing its operational effectiveness and compatibility with the NodeMCU and ultrasonic sensor components [19], [20].

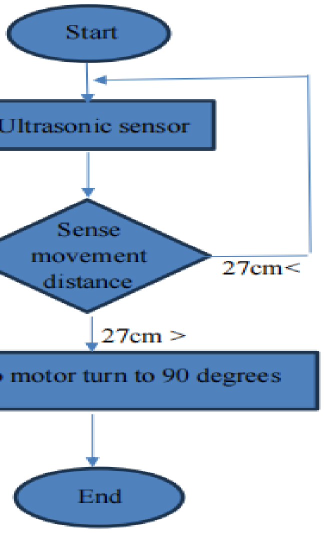

Fig.2 Flowchart of automatic open lid

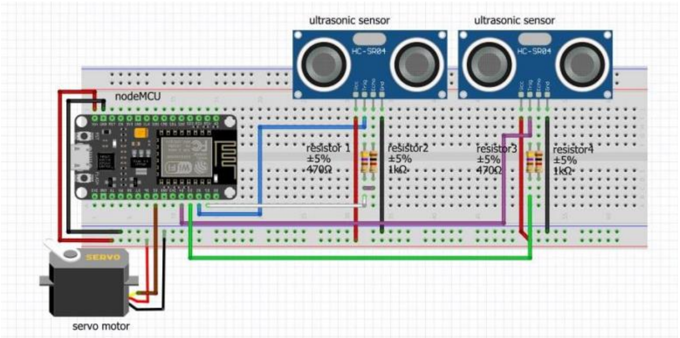

Fig.3 Circuit of system

Proteus is a popular electronic design automation software that offers powerful features for both schematic capture and PCB layout. It enables the creation of PCB layouts by automatically routing traces between placed footprints in an integrated editor.

This is done once the schematic layout (Fig. 4) is finished, including all components and connections that constitute the actual circuit. In addition, the use of Proteus software allows for the creation and visualization of the electronic circuit's schematic and PCB layout (Fig. 5). This enables the development of a compact and efficient PCB layout for the hardware components.

Furthermore, the programming with Arduino IDE will include writing code to connect the ultrasonic sensor, NodeMCU, and servo motor. This will allow for data collection, transmission to ThingSpeak dashboards, and control of the lid based on waste level measurements. The code will be developed to facilitate efficient connection between the hardware components and the ThingSpeak platform, enabling real-time viewing and analysis of data.

Fig. 6 shows the flowchart of system operation. The ultrasonic sensor, installed within the lid of the trash can, is the primary element that facilitates automated waste level monitoring. It consistently emits high-frequency audio pulses towards the trash surface and monitors the duration of the echo reflection. The microprocessor can determine the distance between the sensor and the surface level of the trash by using calculations based on the time it takes for sound to travel and the speed of sound. As the amount of garbage increases, the distance decreases proportionally since the trash is filling up. Calibrating ultrasonic levels to waste fill status is possible by examining the correlation between shifting distance readings and rubbish volume. The NodeMCU development board, equipped with built-in WiFi, utilizes internet access to relay the fill-level meters to the ThingSpeak cloud IoT platform. ThingSpeak collects and combines live data from sensors into customisable channels and displays it on visual dashboards. The NodeMCU

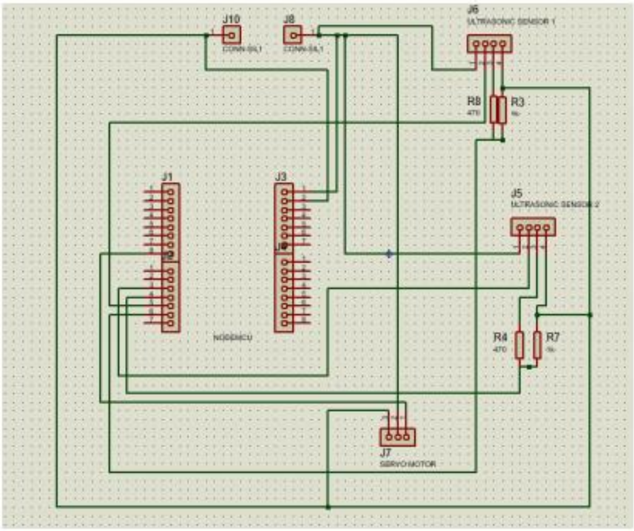

Fig.4 Schematic circuit of system

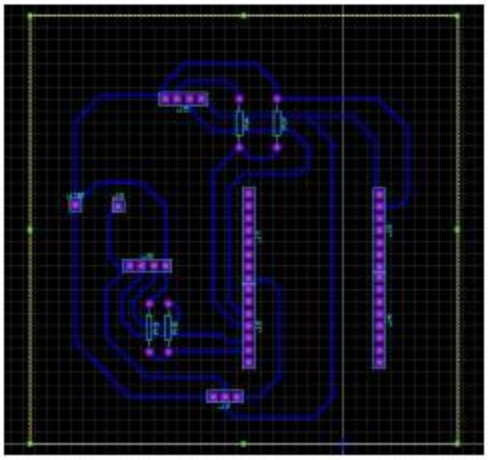

Fig.5 PCB layout of system

transmits updates over HTTP to a specified channel, which then generates a graphical depiction of the current level of trash fill. Exceeding certain threshold values can activate events such as email/SMS notifications to waste management teams, indicating that dustbins are approaching their maximum capacity. Utilizing automated telemetry enables the centralized planning of cleaning routes and timetables through ThingSpeak, eliminating the need for manual physical inspection. After the collection, when the dustbin is emptied, the ultrasonic sensor will reset to the maximum distance from the lid. This will indicate that the bin is empty and the information will be displayed on the ThingSpeak dashboard, thereby completing the operational loop.

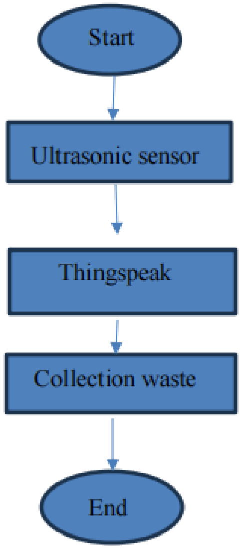

Fig.6 Flowchart of system operation

The programme code of overall system is summarized based on pseudo-code:

```
Setup:
  1.Initialize GPIO pins, servo, WiFi, ThingSpeak and ultrasonic sensors
  2. Connect to WiFi network
Main Loop:
  1.Trigger ultrasonic sensor 1 and calculate distance to trash
  2.Print trash level distance to serial monitor
  3.If trash distance <= threshold (can is full):
      1.Trigger ultrasonic sensor 2
      2.If path is clear:
      1.Open lid servo
      2.Wait 3 seconds
      3.Close lid servo
  4.If > 5 seconds since last update
      1.Update trash level on ThingSpeak
  5.Repeat main loop
```

From the Pseudo-code, the key functionality are continuous trash level monitoring, check trash full and clear path status, open/close lid when full and path is clear and regular updates to cloud.

IV. Result and Disscusion

Fig. 7 shows the prototype of system. The ultrasonic sensing device comprises two distinct ultrasonic range finding sensors. The primary sensor is positioned in a downward direction towards the waste bin to gauge the distance between the top of the bin and the surface of the accumulated garbage. It emits ultrasonic pulses and measures the time it takes for the echo to return in order to determine distances based on the speed of sound. Prior to measurement, the sensor undergoes calibration to determine the distance of the empty bin. As the garbage accumulates, the measured distance will decrease in proportion to the level of filling.

The sensor micro-controller monitors the fill level of the bin continuously and can be configured with a certain threshold distance value that signifies when the bin has reached its maximum capacity and is ready for collection.

Fig.7 Prototype of system

For instance, a bin with a depth of 100 cm may have a threshold set at 20 cm. The fullness condition is triggered when the measured distance decreases to less than 20 cm as a result of waste accumulation. When a full bin is detected, the secondary ultrasonic sensor is triggered to scan the area above the bin where the lid will open by swinging. This process examines for any obstructions, such as branches at a low height, electrical cables, and other potential hindrances, that could impede the proper functioning of the lid opening mechanism. If there are no obstructions in the forward space, the signal is given to start the sequence of opening the bin.

The servo motor module, capable of generating sufficient torque to raise the bin lid, is currently operational. The shaft servo revolves by 90° in order to raise the hinged lid. The garbage collection personnel can subsequently evacuate the filled bin as necessary. Additionally, the system has the capability to transmit notifications to the appropriate waste management teams regarding the specific bin that needs to be emptied. Once an adequate amount of time has passed for the bin to be emptied, the lid is securely closed by turning the servo back to its original pre-programmed position. This sequence operates autonomously, requiring no operator intervention whenever the container becomes full.

During the whole operation, the principal ultrasonic sensor consistently gives real-time measurement updates regarding the current levels of fill in the bin. The real-time data is relayed via WiFi to the ThingSpeak cloud IoT platform, where it stores historical records of the rate at which each bin fills up over time. The ThingSpeak dashboards efficiently display this time-series data for each bin and offer analytical tools to extract practical insights regarding garbage generation patterns as shown in Fig 8. The graph on the left (a) displays the variation in garbage levels over a specific timeframe, presumably collected using a smart trash sensor that consistently measures the amount of waste in a bin. The y-axis represents the percentage of the fill level, which ranges from 0% to 100%. The graph illustrates the fluctuation of trash levels, ranging from around 20% to 80% capacity, throughout the collection cycle. The right side (b) provides a real-time numerical depiction of the current fill state. All components of the system are functioning properly, particularly the ultrasonic sensor.

The garbage fill measurements displayed here offer valuable information for enhancing pickup efficiency, strategizing disposal logistics, and analyzing waste generation patterns at the monitored location. The real-time display, in particular, might be linked to autonomous collection vehicles, alerting them to empty containers when they reach a certain maximum capacity. Data-driven enhancements to collection efficiency and sustainability can be achieved by integrating the analytical skills of ThingSpeak with the capabilities of smart garbage sensors.

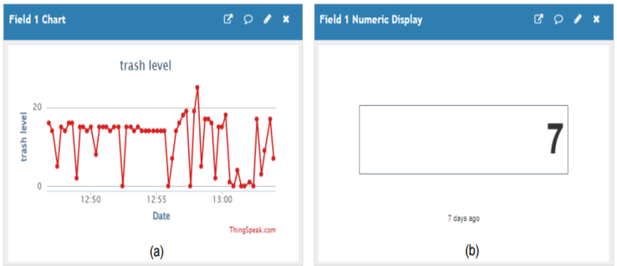

Fig.8 ThinkSpeak result: (a) Thrash level, (b) Current thrash level (%)

V. Conclusions

This paper presents a prototype IoT garbage monitoring system that utilizes NodeMCU and ultrasonic sensors to detect trash levels. The main finding indicates that by using ThingSpeak dashboards and real-time data to continuously monitor garbage levels, trash collection may be optimized by strategically scheduling collections based on high fill thresholds. This prevents excessive accumulation and enhances efficiency compared to predetermined timetables. The fill metrics additionally offer data for analyzing waste patterns and determining the appropriate bin sizes. Although the small-scale prototype was effective, future endeavors could enhance surveillance by implementing a sensor network over the full infrastructure of a smart city. Implementing further measures to provide automated notifications to collecting vehicles based on certain real-time data thresholds would elevate this monitoring system to a fully automated optimization process. The promise of data-driven dynamic collection systems, as demonstrated here, justifies the need for additional research and pilot studies to explore their feasibility for large-scale application, especially considering the growth of cities and the increasing amounts of waste.

Acknowledgment

The author would like to thank Universiti Teknikal Malaysia Melaka (UTeM) for financial support.

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