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Development of IoT-Based Smart Waste Management Systems for Organic and Non-Organic Waste in Smart Cities

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Abstract

Public awareness of the importance of separating organic and inorganic waste and waste management is minimal, so there is a lack of public knowledge to distinguish between organic and inorganic waste. In addition, the slow transportation of garbage from the Temporary Disposal Site (TPS) to the Final Disposal Site (TPA) with a slow garbage truck can cause accumulation, so height monitoring that can be accessed remotely is needed. Based on these problems, it is necessary to have Organic and Inorganic Waste Detection tools and Internet of Things (IoT)-based altitude monitoring using infrared, capacitive, and inductive proximity sensors to distinguish between the two types of waste. This tool also monitors garbage height using ultrasonic sensors and the Ublox Neo 6mv2 GPS Module connected to the NodemCU ESP32 microcontroller to determine the longitude and latitude location point values. The altitude information will be sent to the Google Firebase server using WiFi and displayed on the App created using the MIT App Inventor.

A. Introduction

Waste is one of the environmental problems that is increasingly becoming a global concern; along with population growth and human consumption that continues to increase, especially in urban environments, has encouraged the need for efficient and sustainable waste management. Waste can be divided into two main categories, organic and inorganic, based on their physical and chemical properties [1]. However, even though garbage cans have been distinguished, namely organic and inorganic garbage cans, people still do not put garbage in its place. Public awareness of the importance of separating organic and inorganic waste and waste management is minimal, so garbage cans are still mixed during transportation. One of the causes is the lack of public knowledge on the distinction between organic and inorganic waste. Referring to data from the National Waste Management Information System of the Ministry of Environment and Forestry (KLHK) accessed on February 1, 2023, the amount of waste generated reached 18.3 million tons per year. The waste managed is 77.28 percent, with details of waste reduction of 26.73 percent and waste handling of 50.55 percent. Slow transportation of waste from the Temporary Disposal Site (TPS) to the Final Disposal Site (TPA) with a garbage truck can cause a buildup of waste that exceeds the capacity of the TPS [2].

Therefore, we developed an Organic and Inorganic Waste Detection and Internet of Things (IoT)-based altitude monitoring tool using NodeMCU ESP8266 as a microcontroller and NodeMCU ESP32 as a serial communication. Three sensors are used to distinguish between the two types of waste: infrared, capacitive, and inductive proximity sensors. When the community wants to dispose of garbage, the garbage can not open unless the garbage to be disposed of is brought closer to the type of waste sensor on this device. The LCD lights up will notify that the garbage is included in the organic or inorganic waste, and the servo motor will open and close the garbage can lid according to the type of sensor reading. In principle, a servo motor can work in two directions (Clockwise and Counterclockwise), where the direction and angle of the rotor movement can be controlled simply by setting the duty cycle of the PWM signal on the control pin [3]. This tool is also equipped with garbage height monitoring that can be monitored remotely by garbage haulers and the Ublox Neo 6mv2 GPS Module to find the longitude and latitude location point values, which will later be sent using the Android Application to convey information. With this tool, it is hoped that the community will not choose the wrong garbage can to dispose of their garbage. And, of course, it also helps cleaning officers to more easily find out the state of the full garbage cans without taking up much time.

B. Research Method

This research uses several stages, including literature review, system planning, system testing, and analysis and conclusions. The following are the stages of this research:

1. Literature Review

At this stage, a literature study was carried out by reading and understanding various journals and books related to this research. Some of the literature studied was related to waste problems and IoT devices used in tools, such as the NodeMCU ESP8266 and ESP32, sensors, and actuators to differentiate types of waste, and literature regarding software development. In addition, preliminary studies were carried out using observations. Observations were made on community behavior, in this case, when residents in residential areas threw away rubbish. From this preliminary study, we obtained the problems raised in this research and several solutions several researchers have offered, as in previous research.

In 2019, Yusuf Ari Bahtiar, Dedy Ariyanto, Muhammad Taufik, and Trie Handayani from the Department of Electrical Engineering, Yogyakarta National Institute of Technology conducted research on Organic Sorting with Integrated Inductive and Capacitive Sensors [4]. In 2020, Ali Wafi, Herry Setyawan, and Sofia Ariyani from the Department of Electrical Engineering, Muhammadiyah University of Jember conducted research on a Prototype of an IOT (Internet of Things) Based Smart Trash System with an Android Application [5]. In 2021, Memen Akbar, Sri Devi Anjasmara, and Kartina Diah K Wardhani from the Caltex Riau Polytechnic Computer Engineering Study Program conducted research on the design of organic and inorganic waste detection equipment using the Proximity Sensor and NodeMCU ESP8266 [6]. In 2022, Min Idznullah Said from the Faculty of Engineering, Hasanuddin University, Makassar, conducted research on Android-based Smart Trash Monitoring Systems in Office Buildings [7].

2. System Planning

The system design involves several key steps:

Block Diagram System

The system planning in working on this research is done based on the diagram blocks that have been created, as shown in Figure 1 below:

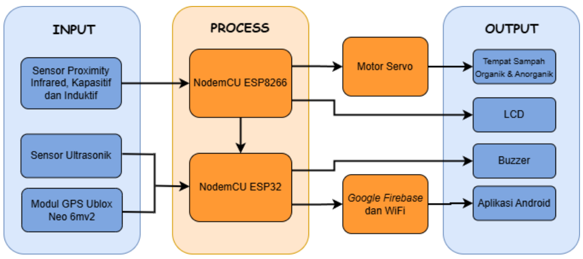

Figure 1. Block Diagram of Illustration

Based on the block diagram above explains the overall overview of the system made in this research. In this research, a tool was made to detect the height of waste and the types of organic and non-organic waste. The monitoring system of this tool uses NodeMCU ESP8266 and ESP32 as data transmission and is displayed on the smartphone. This board has WiFi features and open-source firmware [8]. The monitoring system of this tool is carried out automatically on the Arduino when the height of the garbage can is outside the standard, and a notification is sent on the smartphone if the height of the trash in the garbage can is outside the standard or full. The stages of making this tool are creating a box system, electronic hardware for the control system, and a system connected to Google Firebase and MIT App Inventor.

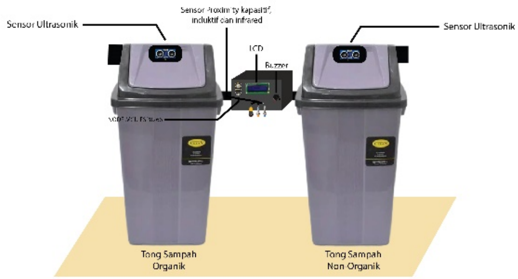

Figure 2. Prototype Hardware Design

In this system, it is planned that if the remaining volume of the trash can is below 10, the program will be detected as complete and will send a notification to the Android application "Trash is full," and a buzzer will sound, which will give a warning that the trash can is complete so it will close automatically and will not open again until the bin is emptied.

3. System Testing

Testing is carried out to evaluate the performance of hardware components such as Infrared Proximity Sensor, Capacitive Proximity Sensor, Inductive Proximity Sensor, HC-SR04 ultrasonic sensor, Ublox Neo 6mv2 GPS Module, Servo motor, and Buzzers are usually used as alarm signals [9]. Testing also includes integrating databases and Android apps to ensure that notifications and other functions operate correctly.

4. Analysis and Conclusion

Test results are analyzed to assess Android applications' system performance, sensor detection accuracy, and notification speed. The conclusion is based on an analysis to evaluate the success of the designed prototype.

Table 1. Main Device Specifications Used

No	Identity	*Type*	*Main Specifications*
1	Infrared Proximity Sensor	E18-D80NK	Power Supply 5 VDC, Maximum load current 100mA, effective from 3-80CM Adjustable
2	Capacitive Proximity Sensor	LJC18A3-B-Z/BX	Supply Voltage DC 6-36V, Current Output 200mA, Detecting Distance 8 mm.
3	Inductive Proximity Sensor	LJ12A3-4-Z/BX	Supply Voltage 5-36VDC, Current Output 300mA, Detecting Distance 4mm
4	Ultrasonic Sensor	HC-SR04	Voltage 5V DC, Static current < 2mA, Detectable distance 2cm – 450cm (4.5m)
5	GPS module	Ublox Neo 6mv2	Interface RS232 TTL, Power: 3-5V, Baudrate default: 9600bps

C. Result and Discussion

After planning and manufacturing the tool, this research will have several tests. The test was carried out in several stages. The first test is carried out separately, followed by the test as a whole or an integrated system and the data transmission time test.

1. Ultrasonic Sensor Testing

Ultrasonic sensor testing was conducted to determine the performance and compare the ultrasonic Sensor by calculating the ruler distance with the Sensor used simultaneously. The HC-SR04 ultrasonic sensor works by reflecting sound waves. The Sensor emits sound waves, which are reflected by objects in front of it and are received and processed to determine the distance between the Sensor and the object [10]; the following is a table of ultrasonic sensor readings compared to manual calculations using a ruler. The empty bin was 30 cm in size in this ultrasonic sensor test. The height of the garbage can starts from 4 to 25 cm with a high reading ratio using a ruler, and an ultrasonic sensor is not too far so that the test results in the bottom two columns have an ultrasonic sensor reading of <10 cm, then the garbage can is said to be full.

Figure 3. Ultrasonic Sensor Testing

2. Infrared Proximity Sensor Testing

Testing the Infrared Proximity Sensor E18-D80nk is a sensor used for obstacle detection. It can detect objects that have a distance of 13 cm—some samples used for household waste, such as screwdrivers, scissors, cans, etc.

3. Inductive Proximity Sensor Testing

Based on the test results, the inductive proximity sensor could detect objects made of metal, such as scissors, cans, screwdrivers, and spoons, but did not detect non-metallic objects, such as wood and rubber. Inductive sensors use coils (inductors) to produce high-frequency magnets. For example, if metal objects are close to the conversion magnet, contemporary objects will follow the flow within the object [11]. This follows the working principle of inductive sensors that only respond to metal materials through changes in electromagnetic fields. Meanwhile, as long as it is within the Sensor range, the proximity sensor can detect almost any material without distinguishing between materials, such as acrylic, wood, and rubber. However, inductive proximity sensors do not detect metal wrapped in plastic or at a distance beyond their capabilities.

Figure 4. Inductive Proximity Sensor Testing

4. Capacitive Proximity Sensor Testing

The test results show that capacitive and proximity sensors have different detection capabilities for waste types. Capacitive proximity sensors can detect materials with high dielectric properties, such as fruits, leaves, and wet food. However, these sensors cannot detect materials such as tissues, cardboard, and black plastics with low dielectric properties. On the other hand, proximity sensors can detect different materials within a specific range regardless of their properties. However, they remain ineffective for objects with thin or light surfaces, such as tissues, cardboard, and black plastic. Thus, integrating the two can be the optimal solution for applications that require detecting different types of waste, especially in conditions where wet organic matter is more dominant.

Figure 5. Capacitive Proximity Sensor Testing

5. System Integrated Testing

The test is carried out by observing the sensor output when the system has been integrated between hardware and software. The sensor data reading output results will be displayed through the Google Firebase database that was created. When the reading from the Sensor is not at the set point, it will send a notification to the Android Application [12].

This integrated system test is used to determine the reliability of the system that has been made. Testing the entire system is carried out by displaying the results of the ultrasonic Sensor from the output results. If the value of the ultrasonic Sensor is <10cm, it will notify the state of the full bin, and when the proximity sensor reads the type of garbage, the bin that was previously in full condition will not open until the bin is emptied.

Table 2. Integrated System Test Results

Conditions Met	Sensor Reading Value Ultrasonic Sensor	App Notifications	Buzzer
Ultrasonic Sensor < 10	1.93	Condition of Full Trash Bin	Turn on
	2.56	Condition of Full Trash Bin	Turn on
	3.25	Condition of Full Trash Bin	Turn on
	5.23	Condition of Full Trash Bin	Turn on
	6.87	Condition of Full Trash Bin	Turn on
	7.67	Condition of Full Trash Bin	Turn on
	7.89	Condition of Full Trash Bin	Turn on
	8.62	Condition of Full Trash Bin	Turn on
	9.23	Condition of Full Trash Bin	Turn on
	9.69	Condition of Full Trash Bin	Turn on

6. Application Testing

This system test is carried out based on system testing in several conditions that have been created. The results of the information the tool reads are then sent to Google Firebase, and notifications are sent to the App using MIT App Inventor, which the user later receives. App Inventor is an open-source web application originally developed by Google and currently managed by the Massachusetts Institute of Technology (MIT) [13]. In addition, it also shows the display of organic waste when it is <10 cm, then the Android application will send a notification that organic waste is full, and the buzzer will light up when the proximity sensor reads the Sensor so that the proximity sensor will not be able to read the object until the trash can is emptied. The following is an example of a notification when non-organic waste is worth <10cm [14]. The results of the Ublox GPS module sensor test in reading the location point of the garbage can show that this module can provide geographic coordinate data in the form of latitude and longitude accurately [15].

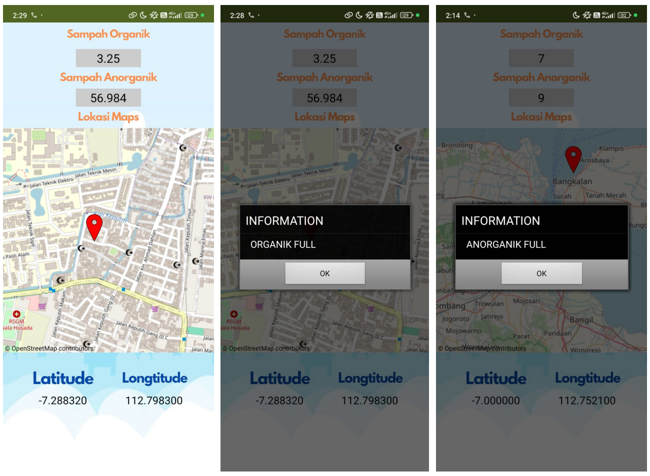

Figure 6. Notification Display When Organic and Non-Organic Waste is Full

D. Conclusion

After observations were made during the design, implementation, and testing of the tool and comparing the results of the data taken from the measurement process with supporting theories, as well as based on the data obtained, it can be concluded:

In the ultrasonic sensor test compared to the ruler, an average of 0.35% was obtained. Based on measurements and data collection, it can be seen that the results of the value reading from the Sensor can be said to be good because the difference between the ruler reading and the Sensor is only around 0.-0.3 cm. In the overall test, the integrated system can work well to detect the height of the volume of garbage with a value of <10cm, and then the ultrasonic Sensor will read the remaining volume space in the garbage can. Monitoring can be done through the Google Firebase database, which will be displayed on the Android application. The Proximity Sensor, namely Infrared, Capacitive, and Inductive, shows the ability to detect objects made of metal and non-metallic objects. If the Inductive Sensor does not read and the Infrared Sensor reads, the waste is included in the category of non-organic waste with a maximum testing distance of 13cm.

E. Acknowledgment

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