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Garbage Monitoring System Ready to Transport with Sensor LiDAR Based on Wireless Sensor Network

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A B S T R A C T

The transition of the waste management flow scheme from conventional to modern will be implemented in Indonesia as a whole, considering the national target of reducing waste to 70% by 2025 (Indonesia Presidential Regulation No. 97 of 2017). The high level of waste productivity makes the modern method of transporting garbage by truck (compactor) to each garbage node more efficient. This method has begun to be applied in various cities in Indonesia. However, this method is still dependent on service time, the number of trucks, and limited human resources (HR), which are the causes of the lack of efficiency in waste management in Indonesia. The result of this research is that the intensity of the waste from each node of the trash bin at the TPS can be monitored on the web. The reading data from the LiDAR sensor will be processed using the Time-of-flight method and then sent into ready-to-transport waste intensity data, which will be updated every second (real-time) by each waste node. The waste intensity is classified as complete if the sensor reading is 0-20 cm. marked red on the website, moderate waste intensity if the sensor reads 21-60 cm, marked orange on the website, and empty if the sensor reads 61-120 cm marked white on the website. The results obtained from monitoring the intensity of this waste can help parties and agencies that need information on the intensity of waste at each waste node to maximize waste management.

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1. Introduction

Indonesia is facing an increasing plastic pollution crisis. Plastic is a valuable material with a vital role in the economy, and the nation produces about 6.8 million tonnes of plastic waste annually. This figure is growing at 5% annually [1]. Citing the "National Policy and Strategy for Management of Household Waste and Types of Household Waste" contained in Presidential Regulation No.97 of 2017 [2], the Indonesian Government targets that by 2025 Indonesia will be clean of waste. This target is measured by reducing waste by 30% and handling waste by 70%. From these data, it can be seen that waste management has a vital role in realizing Indonesia's clean waste target.

Currently, trash cans in public places in urban areas are increasingly overflowing due to the increase in garbage daily. It creates poor health conditions by spreading several deadly diseases [3]. Smart Waste Management is a top priority in any smart city as it directly affects lifestyle, healthcare, and the environment [4]. To prevent negative environmental impacts, we need a system that supports the waste management process [5].

The main concern for waste management is deploying the necessary sensing equipment in the relevant area [6]. In this case, it is essential to develop a system that can monitor the level of waste in real time so that the relevant agencies can find out the actual status of the waste [7].

The strategy for handling waste (household waste and similar household waste) based on Presidential Regulation No. 97 of 2017 includes the application of environmentally friendly and efficient technologies. One of the appropriate technologies based on wireless sensor networks (WSN), WSN [8], has proven to be very effective in supporting the capture, analysis, and transmission of environmental data.

In this paper, a monitoring system is created that aims to monitor the intensity of waste at each Temporary Disposal Site (TPS) that is ready to be transported so that it is easily controlled by the party who will transport the waste. The data obtained from the LiDAR sensor is processed using the "Time-of-flight" method and displayed on the website with the REST API protocol. This is to classify the waste intensity at each node so that it can be known whether it is ready to be transported or not in real-time. REST API is one of several web interfaces that can be used to access data. The REST API uses a RESTful architecture to provide a direct and consistent interface. The main benefit of the REST API is that it does not require many tools to access data [9].

A study conducted by Fatimah, Y. A. et al. [10], under the title "A Sustainable Circular Economy Approach for Smart Waste Management System to achieve sustainable development goals: Case Study in Indonesia," proposed sustainable waste management through the use of the Internet of Things (IoT). as an integrator. A new intelligent and sustainable waste management design can achieve satisfactory economic, social and environmental waste management performance. Using ICT as the system's core, this system discovers the existing performance capabilities in waste management, which can achieve real-time, intelligent, flexible, and reliable waste management performance and information covering governance, economics, social, and environmental dimensions.

In previous research, a paper written by Zade, R. et al. [11] presents a system that monitors the trash can, informs the garbage collected in the bin through a web page, and alerts the user through a buzzer and LED. An ultrasonic sensor (HC-SR04) system is used to detect the level of waste placed on top of the bin, then compared with the depth of the trash. The hardware architecture includes Arduino modules, LCDs, sensors, and buzzers. The status of the level of garbage collected in the bin is displayed on the LCD screen. Remote system monitoring is carried out via a web page developed using the VISA tool in LabVIEW.

Researchers Abdulwahab, Mortada M., et al. [12] have designed a wireless monitoring system for waste bins, which helps reduce the risk of waste overflowing. The system is based on Raspberry Pi and consists of an ultrasonic sensor with an alarm circuit. In addition, the design provides wireless monitoring of trash in the trash via wifi technology. This system uses a database to store data. The system was experimentally tested in two operating cases: when the container was empty and when the container was full. The overall results show that the system is working correctly and are displayed on the web page. The results of the study prove that this monitoring system can help to reduce the problem of waste problems by providing continuous monitoring of the status of waste containers.

In her paper, Anitha A. [13] has built a system that can notify companies to dispose of waste on time. In this system, an ultrasonic sensor is installed above the trash can to detect the total amount of garbage in it according to the total size of the trash can. If the waste has reached the maximum limit, a notification will be made to the company office. Then the employee can take further action to empty the trash can. This system can help clean the city in a better way. By using this system, people do not need to manually check all systems because they have received notifications when the bin is filled.

In this research, a system that is integrated with the website is created to monitor the intensity of waste from each node of the trash bin at the Temporary Disposal Site (TPS) by utilizing a wireless sensor network connected to a single gateway using the Rest-API protocol. Each garbage node always updates data on the intensity of ready-to-transport waste. Updated waste intensity data can provide accurate information that the trash bins at the TPS are ready to be transported to the Final Disposal Site (TPA).

2. Material and Method

2.1. Wireless Network Communication Between TPS

Wireless Sensor Network (WSN) is a group of sensor nodes that are spatially dispersed, which are interconnected using wireless communication [14]. WSN consists of sensor nodes capable of calculating, collecting perceptual data, and communicating with other sensors connected in the network [15]. The following is the design of the wireless sensor network topology of the system that has been created.

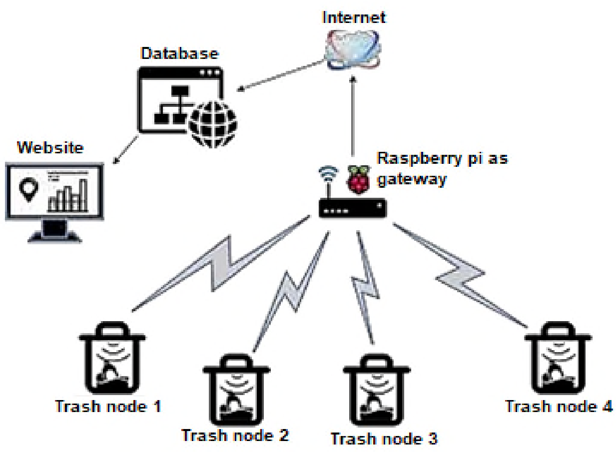


Figure 1 System Topology

Figure 1 shows that the topology used is a tree. Where the topology is most suitable for modeling wireless network communication between TPS, each trash node is controlled using an Arduino, a micro lidar sensor, and an NRF module. The communication protocol between nodes to gateway has become the default 24L01+ NRF module, which is enhanced shock burst. The enhanced shock burst protocol is a protocol that is based on packet communication and supports various modes from manual operation to the advanced autonomous protocol operation. nRF24L01 is a single-chip radio transceiver for the worldwide 2.4 - 2.5 GHz ISM band. The transceiver consists of a fully integrated frequency synthesizer, a power amplifier, a crystal oscillator, a demodulator, a modulator, and an Enhanced ShockBurst™ protocol engine [16].

2.2. Time-of-Flight

The TOF (Time-of-flight) method is categorized into direct (DTOF) and indirect (ITOF) forms, as depicted at Figure 2. The direct method shows the time difference between the transmitted pulse and the received signal [17]. The work of time of flight method is described at Figure 3.

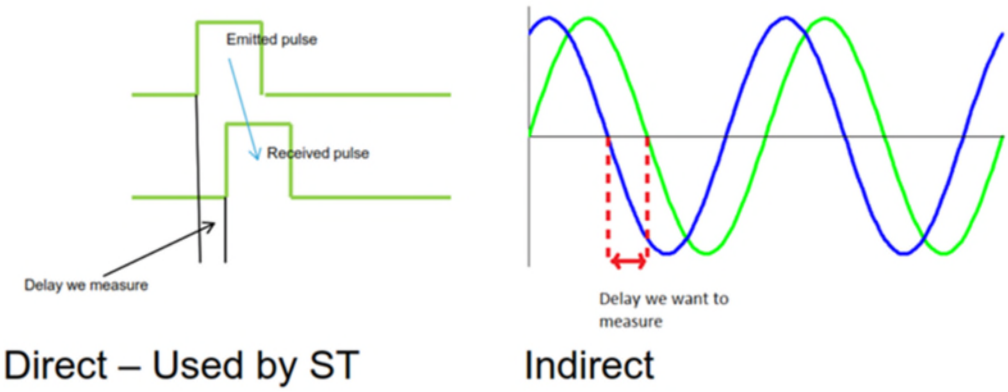


Figure 2 DTOF (Direct Time-of-Flight) and ITOF (Indirect Time-of-Flight)

As for the indirect method, a continuous modulated sinusoidal light wave is emitted, and the phase difference between the outgoing and incoming signals is measured.

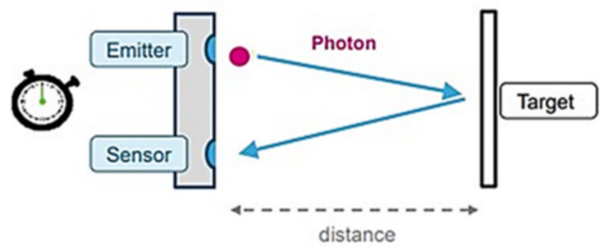


Figure 3 How Time-of-Flight Works

The distance values measured by the TOF method is calculated using Equation 1 [17].

$$Distance\ Value = \frac{Photon\ travel\ time}{2} X\ by\ speed\ of\ ligh \quad 1$$

The LiDAR sensor calculates the waste intensity, which is applied in this research. Some formulas and equations will be used, namely the Time-of-flight measurement method. Time-of-flight is a method of determining the distance between the sensor and the object in front of it based on calculating photons' travel time at the speed of light. The following is the direct time-of-flight formula [18] used to measure the intensity of waste at the garbage node.

$$d = \frac{c\,x\,t}{2} \qquad 2$$

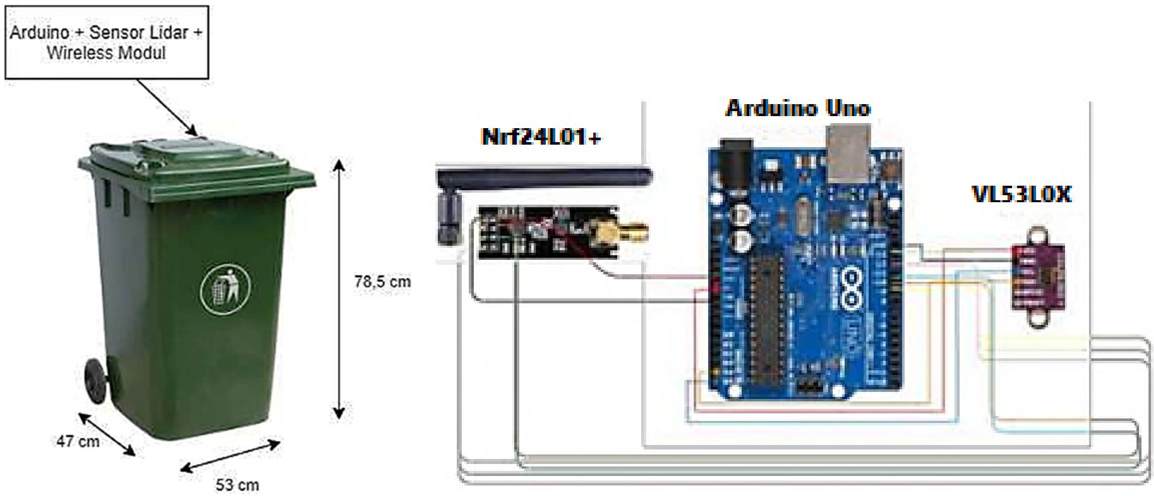
In Equation 2, the value of d is the distance of the sensor to the target or object in meters (m), c is the speed of light with a value of 3x 10^8 m/s, and t is the travel time for photons to return in seconds (s).

To calculate the sensor accuracy using Equation 3.

$$\%\,Error = \left|\frac{Sensor\ value - Measurement\ value}{Measurement\ value}\right| X\ 100\% \qquad 3$$

2.3. Garbage Node Models

The value of the Micro Lidar sensor contained in the garbage node will continue to change. This sensor value will be taken by Arduino, which will be used in data processing using the time-of-flight method. Figure 4 shows the placement of the sensor on the garbage node model that has been created.



(a) (b)

Figure 4 The Garbage Node Model That Has Been Created, (a) Model Garbage Node, and (b) Wiring Circuit

At each garbage node, there are three parts: the microcontroller, which processes sensor data retrieval and sends the data to the recipient/destination. An Nrf24L01+ module is a radio frequency-based communication module to transmit data to the receiver. And the Micro Lidar VL53L0X sensor is a sensor that collects waste intensity data periodically using the time-of-flight method.

The gateway receives data from the garbage node for further storage in the database. This data is used to identify whether the garbage node's intensity parameter is full. There are two components located at the gateway, namely the Raspberry pi three, which functions as a mini pc to process all data received through the nrf24l01+ module so that it is ready to be uploaded to the database via the wifi module owned in real-time. Another component is the Nrf24L01+ module which functions as a radio frequency-based communication module to transmit data to the receiver.

2.4. Sensor Data Processing

The VL53L0X Distance Sensor is a Time-of-Flight (TOF) range module with an accurate range of up to 2m, controlled via an I2C interface, and fairly low power consumption. It supports ultra-Low design for wireless and IoT applications [19]. The garbage in the garbage node will be processed into distance data by the Lidar VL53L0X sensor into waste intensity data by the time-of-flight calculation method. The following is a general description of converting data into a dataset, as shown in Figure 5.

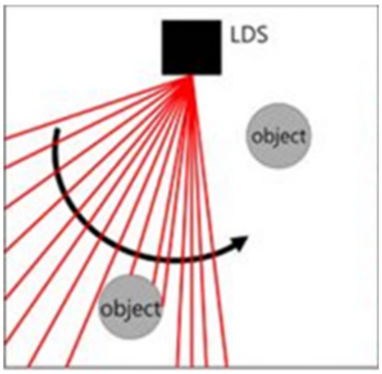


Figure 5 Sensor Reading Illustration

Each wave sent by LIDAR in Figure 5 has a specific speed and the travel time required by the wave from the sensor then hit an object until it returns to the sensor is called the time of flight (TOF). Measurements of the distances to environmental objects are based on the principle of Time-of-Flight [20]. So to calculate the distance between the object and the sensor [21], using Equation 4 and 5.

$$Time\ of\ Flight = \frac{2\,V_0\,Sin\,\theta}{g} \qquad 4$$

$$Range = \frac{V_0^2}{g}\,Sin\,2\theta \qquad 5$$

In Equations 4 and 5, Time of Flight is the time in seconds (s), V_0 is the initial velocity of the wave (m/s), and is the angle at which the wave is transmitted to the horizontal plane in degrees (°). G is the acceleration against gravity (9.8 m/s^2). The range is the object's distance to the sensor (m).

2.5. Website and Databases

As an information system technology, the web connects data from many sources and various services on the internet [22]. The website is a service for presenting data information in the form of indicators for each garbage node and its graph.

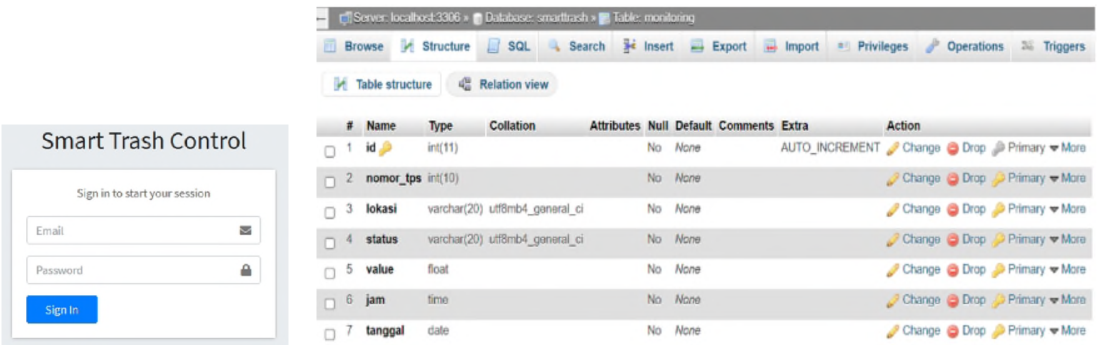


Figure 6 Login Page and Database System

The database is a place to accommodate data from the entire monitoring system for ready-to-transport waste. The data from each node consist of ID node, number of garbage collection points, and the location of them (latitude and longitude). The value represents the information on the height of garbage read by the sensor, the status represents the trash bin status, date and hour indicate the information about the hour and date when the system detects the status of the trash bin periodically. Th type and attribute of each parameter of sensor are shown at Figure 6.

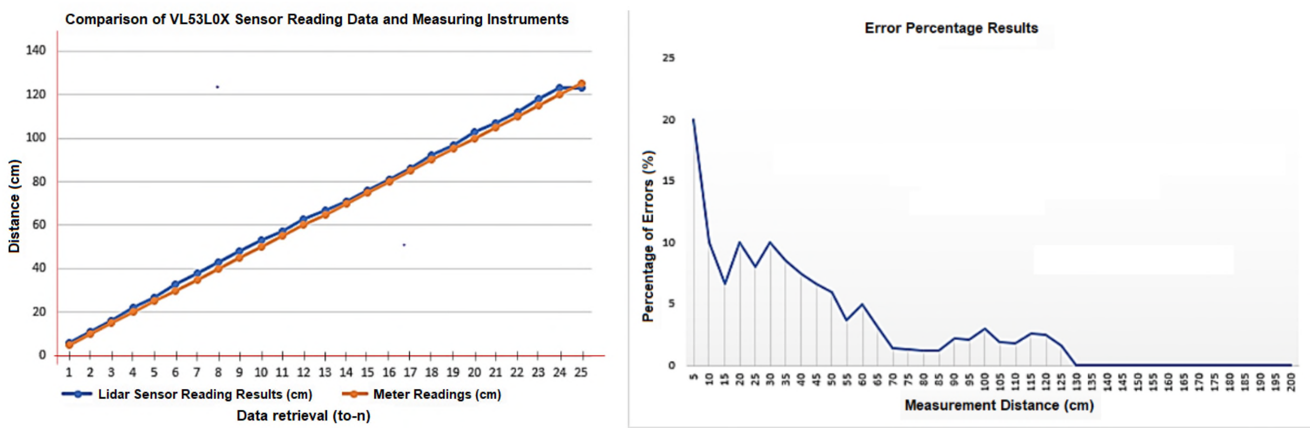
3. Result and Discussion

An experiment to collect data was carried out in the Pondok Mutiara Art Market, Banjar Bendo, Sidoarjo, East Java, Indonesia. Location as in Figure 7.

Figure 7 Location of Data Collection

3.1. Sensor Accuracy

The Experiments to test the suitability of the sensor accuracy distance. The results are shown in Figure 8.



(a) (b)

Figure 8 Sensor Data Reading Accuracy, (a) Sensor Data Graphs and Measuring Instruments, and (b) Graph of Error Percentage

The measurement results by comparing the meter measurements (orange color) and the readings of the micro lidar VL53L0X sensor (blue color) can be seen in Figure 8(a). In this figure, the comparison of the two values is not much different, so it can be continued in processing sensor data so that the percentage error of the Lidar VL53L0X sensor can be known. Before being used to measure the intensity of garbage at each garbage node. In the data from the VL53L0X micro lidar sensor test results using the time of flight measurement method, the accuracy results are obtained, as shown in Figure 8(b).

Figure 8(b) shows that the sensor accuracy value tends to be stable or effective in the value range of 10 cm - 125 cm. In comparison, readings above 125 cm are the maximum limit of the micro Lidar sensor reading ability. So ideally, it is determined that the trash can be said to be full when it touches a distance value of 10-15 cm from the sensor. With the approximately 10% error value, it can be said that the sensor readings can also be feasible for detecting the intensity of garbage at the garbage node.

3.2. Material test

Furthermore, material testing is a process to assure the accuracy of sensor detetion for garbage material. This test aims to observe the accuracy level of various materials found in waste composition in real conditions. This experiment was started by preparing seven materials that are commonly found in the composition of waste in general. The materials are plastic bottles, crackles, paper, cloth, glass, metal/cans, and wood. These materials are tested alternately in the trash, and data collection is carried out two times for material sampling so that the results are obtained in Table 1.

Table 1 Material Detection Test Data by Sensor

No.	Material	Sampling	Sensor Reading Results (cm)	Measuring Instrument Reading (cm)	Error Percentage (%)
1	Plastic Bottles	1	44	43	2.33
		2	45	43	4.65
2	Crackle	1	38	37	2.70
		2	39	37	5.41
3	Paper	1	41	40	2.50
		2	40	40	0
4	Cloth	1	32	30	6.67
		2	31	30	3.33
5	Glass	1	44	42	4.76
		2	43	42	2.38
6	Metal/Cans	1	39	39	0
		2	40	39	2.56
7	Wood	1	21	20	5.00
		2	22	20	10.00

From the sampling of 14 data above, the percentage error for material detection is less than 10%, with the highest error percentage for wood material.

3.3. System range test

In this test, the system has been integrated into the website by placing different garbage nodes and gateways. This tests the maximum distance that can be accepted and processed to be displayed on the website. After being tested for Line of sight (LOS), the maximum range is 700 meters. While testing at the Non-Line of Sight (NLOS) location to test the resistance if there is a lot of noise/obstacles in real conditions, the maximum range is 500 meters. The results of the NLOS test are shown in Table 2.

Table 2 System Range Performance

No.	Distance (Meters)	Garbage Node 1	Garbage Node 2
1	10	Received	Received
2	50	Received	Received
3	100	Received	Received
4	200	Received	Received
5	300	Received	Received
6	400	Received	Received
7	500	Received	Received
8	550	Lost	Lost
9	600	Lost	Lost

The results of the system's coverage distance performance on the website display are shown in Figures 9 and 10. The data received by the raspberry pi (gateway) programmed using the python language is then forwarded to the database using the wifi module embedded in the raspberry pi model 3b with the REST API protocol in real-time. So it can be seen in Figure 9. The smart trash indicator website display has three color parameters that classify the waste's height according to the transportation urgency. The white area indicates that the garbage node is still empty (parameter 61 cm – 120 cm). The orange area indicates the garbage node is almost full (parameter 21 cm - 60 cm), and the red area indicates the garbage node is full (parameter 0 cm – 20 cm).

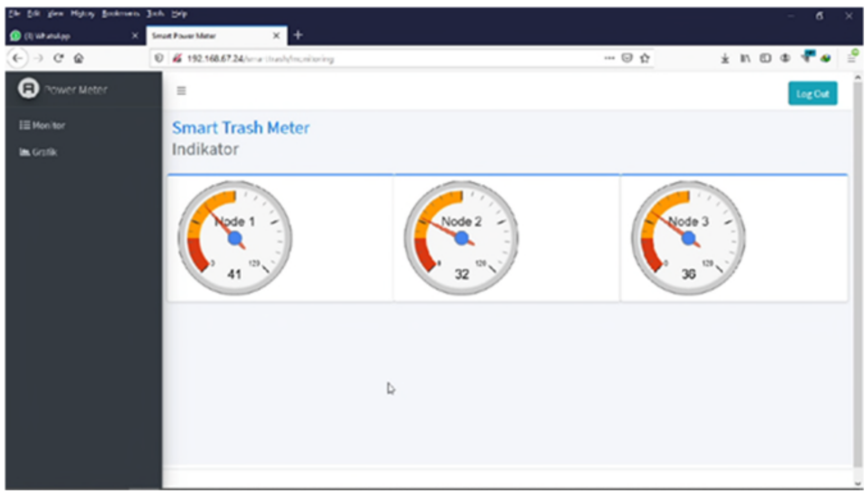


Figure 9 Smart Trash Website Indicator Pages

The display of the data received in real terms can be seen in Figure 10. in the form of a line graph. The x-axis displays the time the data was received, and the y-axis displays the intensity of data received.

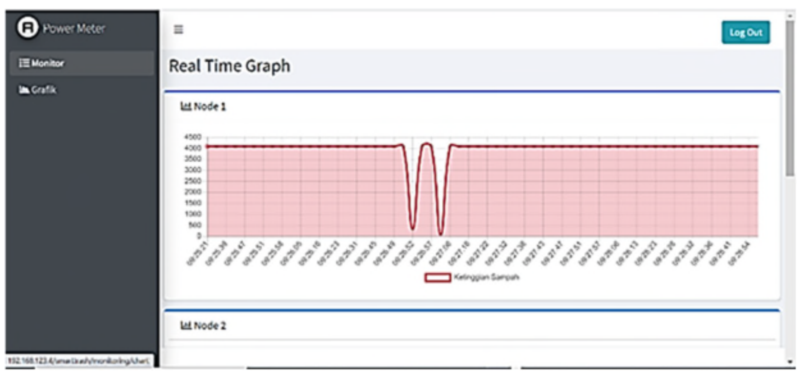


Figure 10 Smart Trash Website Real-Time Graph Page

Compared to the ultrasonic sensor used by previous researchers, the VL53L0X micro lidar sensor can detect seven different types of waste material usually found in a trash can. The micro lidar sensor can read intensity/distance data from the seven objects in the trash can. In this research, using the Nrf24L01+ Module as a wireless sensor network with radio frequency-based communication has the advantage of transmitting data between the garbage node and the gateway up to 500 meters to a distance of 700 meters under certain conditions. Monitoring with the website can find out the condition of the contents of each trash can or garbage node in real-time. So this information is very helpful for better waste management.

4. Conclusions

The level of accuracy of the lidar sensor on the garbage node using the time-of-flight measurement method has a maximum range of 125 cm with an error percentage below 10%. So it is ideal for the size of the trash in a tall TPS. The maximum is 75 cm to 125 cm. The lidar sensor detects paper, crackle, plastic, glass, wood, cloth, and metal/can waste materials. This material is quite representative of objects that are generally found in trash cans. The nrf24L01+ communication module has a maximum LOS range of 700 meters and an NLOS range of 500 meters. The process of sending and receiving data from many nodes to a single gateway can be done simultaneously (Multichannel) and in real-time. The smart trash indicator website display has three color parameters that classify the waste's height according to the transportation urgency. The white area indicates the garbage node is still empty, the orange area indicates the garbage node is almost full, and the red area indicates the garbage node is full. This ready-to-transport waste monitoring system can help parties and agencies that need information on the waste intensity at the garbage node to maximize waste management.

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