Design and Development of Smart Trash Bin Prototype for Municipal Solid Waste Management

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***Abstract*—This paper describe the design and development of waste management system intended for municipal areas. One of the classical city problems is the habits of its people who do not care about cleanliness of their environment. Awareness of how to throw and manage garbage in a good manner is still not become an important consideration. The government doesn't have yet the efficient waste management system. Waste management system based on information technology capable of handling waste management problems is needed to overcome this problems. In this work, a prototype of waste management system has been developed, especially for the solid waste, focusing on segregation and garbage collection phase. The system consists of three main subsystems: the hardware subsystem consist of trash bin equipped with sensors and communication system for monitoring the garbage status and controlling the garbage collection schedule. The other subsystems are data management and data visualization subsystem for management and analysis purposes. The prototype was built and tested. It shows that the system can operate well, their sensors can detect different type of garbage, also can send and display the garbage status to the management display station. The prototype can meet the needs that have been defined as part of urban waste management solution.**

Keywords—waste management, smart trash bin, solid waste, smart city, data management, data visualization

I. INTRODUCTION

Indonesia as the fourth most populous country in the world certainly has a lot of community social problems. One of them is the waste problem that continuously increase in line with the populations growth. It needs a smart solution and technology innovations to solve this waste management problems. Improper waste management can effect environmental problems as well as public health problems. Based on data derived from the State Ministry of the Environment (KNLH) it shows that from the total waste production in Indonesia, only 18.84% can be sorted for later reused or discarded [1]. By 2015, statistics data estimate that Indonesia will become the second largest waste producer after China with 187.2 million tons / year [2]. Java area became the largest contributor of the total amount of waste because of the high population. Increasing population and limited land to accommodate the rest of the consumption is one of the factors that cause the volume of garbage continues to mount.

According to Damanhuri [3], the waste management method consists of two types: waste reduction and waste management. In the handling of garbage there are several elements of work, namely: sorting, collection, transportation, processing, and final processing of waste. Either the waste reduction or waste handling, both still do not provide maximum results from predefined standards. It is estimated that only 60% of waste in major cities in Indonesia can be transported to final disposal site, whose main operation is landfilling [4].

Technological developments in the world today have reached an amazing stage. The current technology can be implemented in almost all elements of human life. Integration and collaboration between information technology with socio-environmental issues is something that is expected to provide output that can be a solution of the existing problems. Data and information on waste management can be a valuable resource in an effort to maximize management activities. With the application of information technology, it is expected that waste management activities can be monitored and controlled to be appropriate. Therefore, it takes a technology-based system that can provide solutions in order to increase effectiveness and efficiency of waste management.

This paper describe the design and development prototype of waste management system. The system consists of three main subsystems, i.e. hardware subsystem that consist of trash bin equipped with sensors and communication system for monitoring the garbage status and controlling the garbage collection schedule. The other subsystems are data management and data visualization for management and analysis. The paper consist five chapter. The following second chapter describe the related works of waste management system and technologies. Chapter three describe the system requirement analysis and system design process. The implementation of the prototype is described in chapter four, and the testing result is discussed in chapter five. The conclusion is described in chapter six.

II. RELATED WORKS OF WASTE MANAGEMENT SYSTEM AND TECHNOLOGIES

A. Condition of waste management in Indonesia

Waste management is still the main problem in Indonesia. Until now, the waste management paradigm used gather -

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transport and dump step [5] as illustrated in Figure 1. In practice, the main way of a city in solving its waste problem is eradication by landfilling. City managers assume that their landfill can solve the entire waste problem without having to pay proportional attention to the facility [4]. But it actually raises a new problem that is the formation of a disease nest in landfilling done.

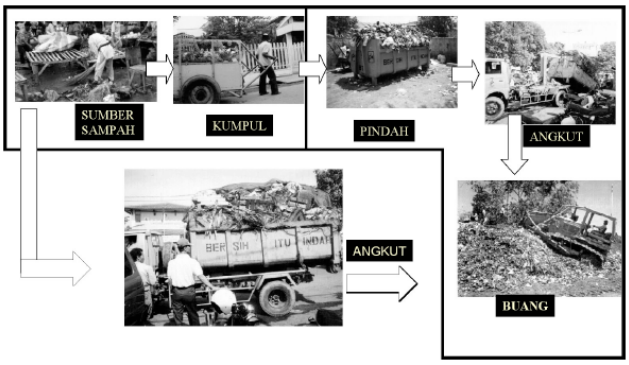

Figure 1. Gather-Transport-Dump Waste Management Concept

The way waste management with waste removal and eradication is most often applied in Indonesia due to the lack of effectiveness of other management alternatives. This method is also popular because of the low cost incurred and the ease of operation offered. However, this can lead to new problems of soil and groundwater contamination from leachate (waste water) generated, as well as air pollution in the form of a pungent odor from garbage heap [7].

In around 1980, the Center for Environmental Research (PPLH) ITB introduced the concept of Industrial Waste Areas at the regional level. This concept has a goal of minimizing waste transported to landfill as much as possible by involving community self-help in recycling waste [8]. Unfortunately, this concept does not go smoothly because of the need to change the mindset and community perspective in handling waste [3].

B. *Analysis of Integrated Waste Management Strategy – case study Semarang City, Indonesia*

The enactment of Law No. 18 of 2008 on waste management indicates that the municipal / district government should change the waste disposal system into a waste management system. Garbage that was initially transported and then disposed of to the landfill, must now be managed in advance at both the upstream and downstream levels. Community-based integrated waste processing can be implemented by reducing waste as much as possible by processing waste at the nearest location with the source of waste [9]. It can help to extend the life of the landfill, anticipate the limited use of landfills, optimize the operation of limited transportation facilities, reduce the cost of transporting waste from the Temporary Waste Disposal Site (TPS) to Final Waste Disposal Sites (TPA), increasing community independence as well as the community's active role in maintaining environmental hygiene through environmentally friendly waste management [10].

C. *Application of Waste Processing Technology and Its Utilization in Waste Management*

In general, the application of waste processing technology to urban areas can be illustrated in Figure 2. There are three types of technologies that are commonly applied in waste processing technologies such as waste composting, waste incineration, and waste recycling technology. Composting is the process of degradation of organic matter through the biological reaction of microorganisms under controlled conditions. Waste incineration technology can reduce the amount of waste that must be disposed to the landfill by 80%.

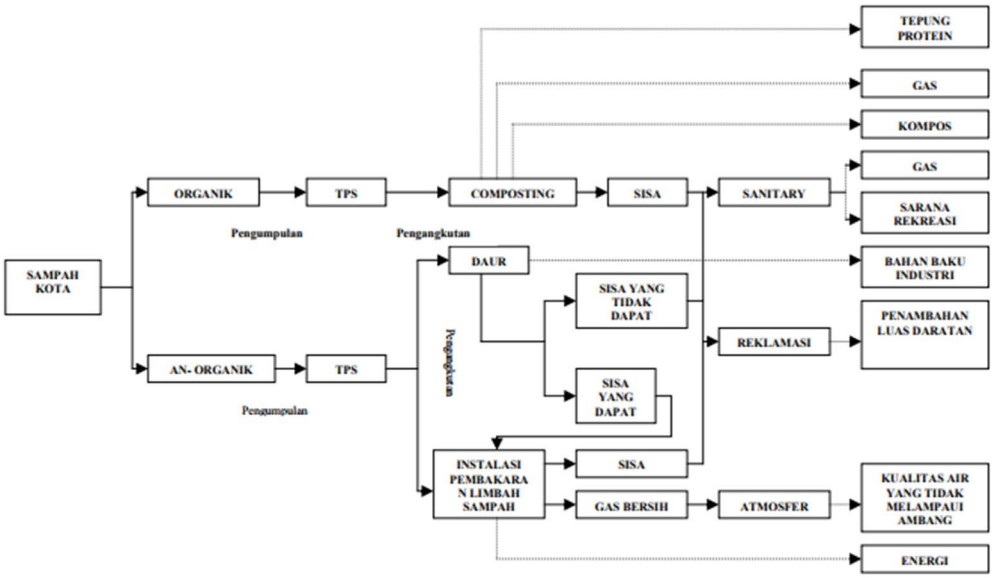

Figure 2. Urban Waste Management Diagram

The successful implementation of waste incineration technology depends on the physical and chemical characteristics of waste as well as the funding and management capability of the local government. Recycling technology utilizes waste components that have high economic value to be reused.

D. *Technological approach: A Smart Waste Management with Self-Describing Objects*

Radio Frequency Identification (RFID) is a technology that can be used in waste management by providing automatic and fast identification of the type of garbage when it is disposed of. In the research, a trash bin can identify the type of waste based on RFID Tags that exist on the packaging of the product. The waste to be identified is classified into 3 types, which are paper or cardboard, glass, and plastic waste.

In addition to using RFID Reader, the researchers also offer several alternatives in identifying waste types, including QR Code Barcode, and NFC technology. The workings of these alternatives are also similar, namely the process of scanning the tags placed on the packaging of these objects. However, there are differences in the scanning process if done using QR Code. The scanning process is done through the user's personal device which then raises the appropriate waste disposal recommendations.

From the results of the literature study, the problem of waste management that currently exists in the community is the lack of community participation in helping waste processing both in the upstream and downstream areas. Good waste processing in the upstream area will ease the final waste processing workload in downstream areas, i.e. in Final Disposal Site (TPA) [13].

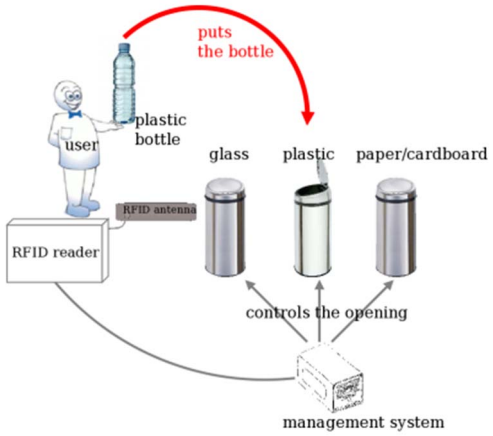

Figure 3. Trash Category Identification Schema using RFID [12]

Waste processing in the upstream area can be done by sorting waste in accordance with the characteristics established by related government agencies [3]. From the sorting, the waste that has been separated in accordance with the classification will be easier to be transported for later processed in accordance with the place of processing. In addition, from proper waste segregation, waste management process through Reduce, Reuse, Re-cycle concept can also be implemented effectively and efficiently. From an operational point of view, waste segregation carried out in the early stages of waste management can reduce transportation costs from garbage transport vehicles and also can reduce the workload and cost of landfill (TPA).

III. ANALYSIS AND DESIGN

A. *System Requirement*

System requirements are generated by identifying and analyzing the core of the problems. This waste management system has the needs to run in accordance with the requirements. A list of system functional requirements is presented in Table 1.

Table 1 System Requirements

ID	Requirements
SyR-001	System can perform trash type detection.
SyR-002	System can provide an indicator of the appropriate type of garbage to the user.
SyR-003	System can measure the volume and the weight of garbage contained in the trash bin.
SyR-004	System can transmit volume, weight, and volume percentage data to the server.
SyR-005	System can perform data processing from the sensor.
SyR-006	System is capable of displaying volume and trash weight data visualization on web pages.
SyR-007	System is capable of performing data management of the trash device.
SyR-008	System is able to perform user data management system.
SyR-009	System is capable of processing garbage weight and volume data in the database.
SyR-010	The system is able to create a written report about waste information.
SyR-011	The system is able to create a map marker at the location of the trash device that reaches a predetermined threshold.

B. *System Design*

Based on the general description and design specification of the system, the design of technology system of city waste management is shown in Figure 4.

The trash bin will send garbage data captured by the sensor wirelessly to the server, which then performs the data processing into garbage statistics on the website dashboard. It will also send notification about the current trash volume in the trash bin along with its location to the garbage officer through mobile application.

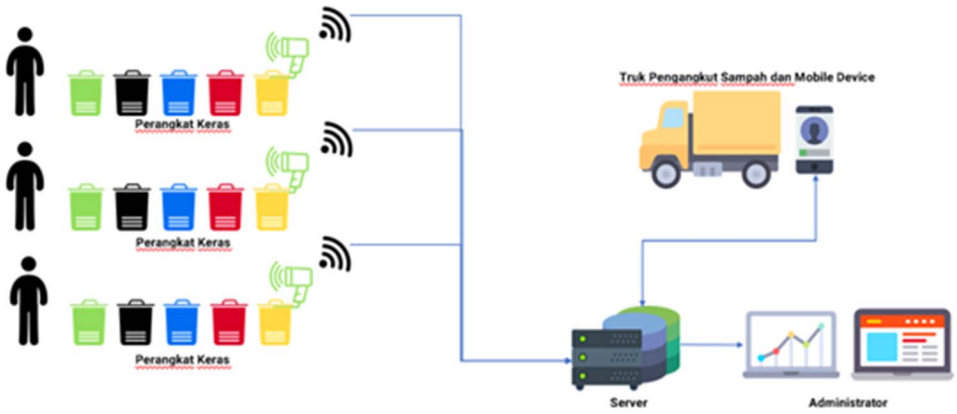

Figure 4. Waste Management System Design

The schema of the design of the system in more detail can be seen in Figure 5.

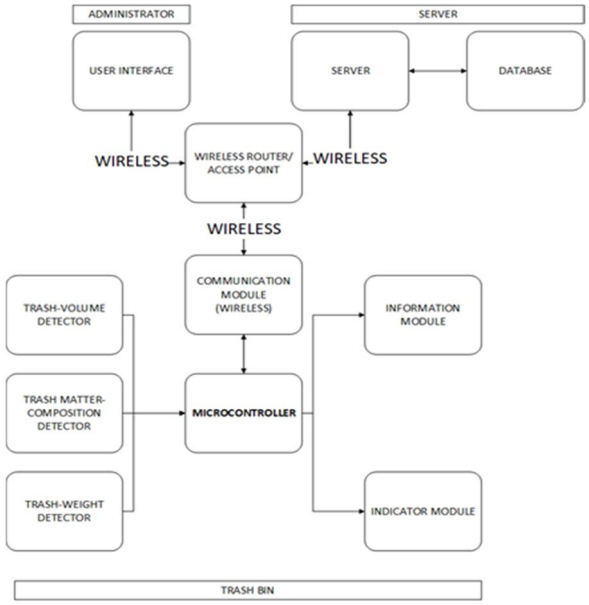

Figure 5. Hardware Design

C. *Hardware Design*

The following is the hardware design resulting from meeting the functional requirements of the system and based on the assessment of aspects of maintainability, performance, physical infrastructure, budget, and project goal achievement.

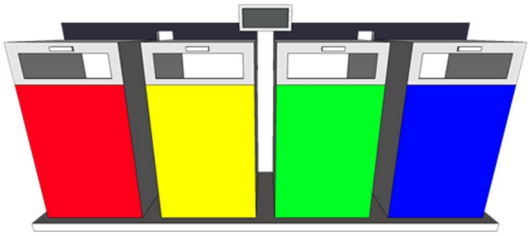

Figure 6. Mock-up Platform Design

D. *Software Design*

The software design is structured into a use case diagram that describes the activities that can be performed by the municipal solid waste management software. The diagram can be seen in Figure 7.

There are six major activities that the system can do: sorting waste, managing trash device data, knowing garbage statistics, managing administrator data, views garbage data report, and views the location of near-fully loaded trash bin.

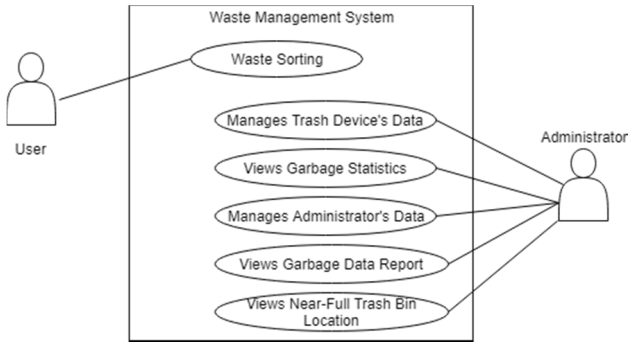

Figure 7. System Use Case

Sorting garbage is done on trash device. The device will process the values generated by the characteristic waste detecting sensors to produce an appropriate disposal container guide for the user. Managing trash device data allows the system to add, change, or remove the device's listed in the system. Garbage statistics information allows the system to provide an assistance in waste management decisions, especially to waste managers or environmental agencies. Managing administrator data allows the system to add, change or delete administrator data, both in-office and field staff. The system can also generate reports on garbage data into a file for printing purposes. The system can know the location of the fully-loaded trash can, so that it can be carried out by the officer immediately. This activity is directed to field officers and the location is known by using a smartphone.

IV. IMPLEMENTATION

A. *Hardware and Device Implementation*

Implementation of city waste management system and technology uses two microcontrollers as its core. The microcontrollers represent two sub-systems of the system as a whole. The sub-system is a solid waste sorting sub-system and a data management sub-system. Both sub-systems can be illustrated by Figure 8 and Figure 9.

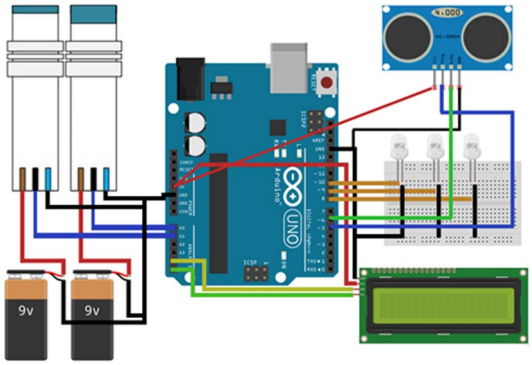

Figure 8. Solid Waste Sorting Sub-System

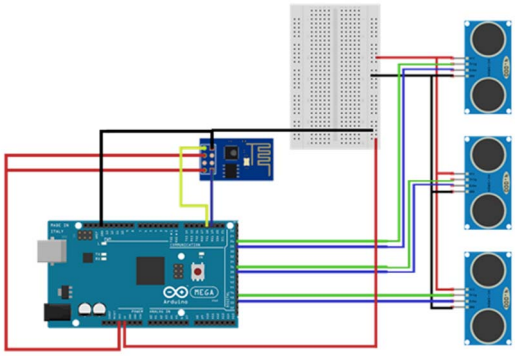

Figure 9. Data Management Sub-System

The components used in the implementation of this project are written in Table 2.

Table 2 Component for Implementation

Sensor Module	**Sensor Type**
Microcontroller	Arduino UNO
	Arduino Mega 26500
Volume	*Ultrasonic* Sensor HC-SR04
Waste Characteristics	Capacitive and Inductive Sensor
Communication Module	Esp8266-01
Notification Module	LCD 2x16
	LED

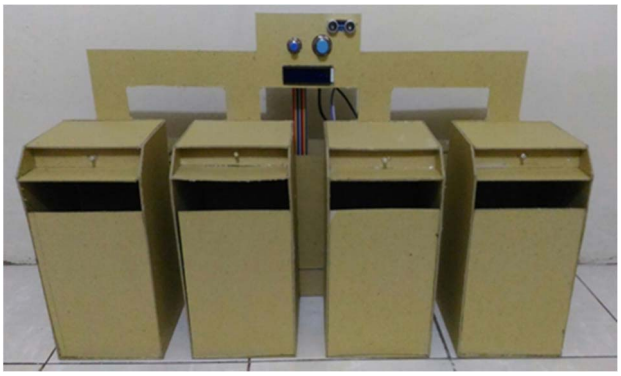

Figure 10. Hardware Mock-up

The device mock-up is based on the hardware design that has been designed in the previous section.

B. *User Interface*

The user interface on the website is designed in such a way that it is easy to use by administrators and information can be well conveyed. Figure 11 is one view on the website, the dashboard page. There is a navigation menu on the left side of the page that can direct administrators on the various features offered.

Waste information in the form of figures and diagrams can assist decision makers in waste management activities, such as priority development of infrastructure for managing certain types of garbage, the capacity of garbage transport vehicles, and the needs of the number of fleets and garbage officers

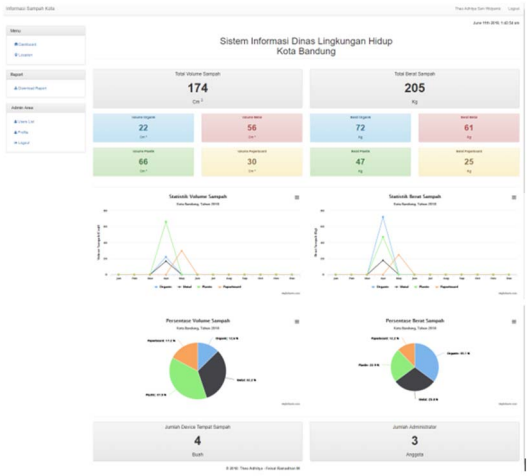

Figure 11. System User Interface

C. *Communication Schema*

Communication between hardware and software is connected using the MQTT (Message Queueing Telemetry Transport) protocol and Mosquitto as its broker. ESP8266 from hardware publishes data to broker, and accepted by MQTT WARN who acts as a client which subscribes to certain topic. MQTT WARN then pushes the received data to the database for further management. A more complete communication scheme can be seen in figure 12.

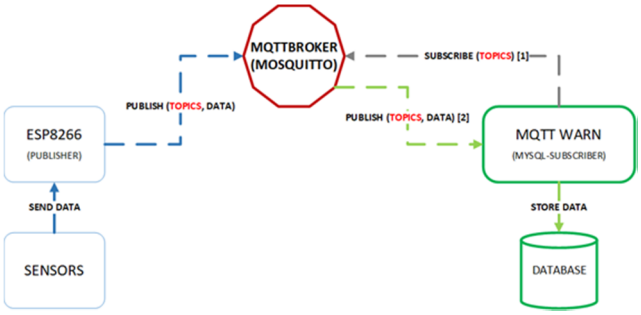

Figure 12. Communication Schema

V. TESTING

A. *Test Case and the Results*

Some test cases are made to test system functionality and its capacity to fulfil the goals.

Table 3 Test Case for Implemented System

ID	*Test Case*	Results
TC-001	*Starting-up system*	System can be started up
TC-002	Connectivity testing	The system can be connected to a configured network
TC-003	Cloud server testing	The system can be connected to a configured cloud server
TC-004	Detection module testing	The system can detect various types of waste materials
TC-005	Indicator module testing	The system can provide an indicator that matches the type of garbage dumped
TC-006	Information module testing	The system can provide information according to the type of garbage dumped
TC-007	Data gathering module testing	The system can collect data from waste containers
TC-008	Communication module testing	The system can transmit weight, volume, and volume percentage data over the network
TC-009	Garbage device data management module testing	The system is capable of performing CRUD functions for every trash device
TC-010	Garbage device mapping function testing	The software system is able to display a map with a marker for each bin listed on the system
TC-011	Visualization function testing	The software system is capable of processing data and displaying the appropriate garbage data visualization
TC-012	Fully-loaded garbage device marking function	The mobile app is capable of displaying markers on the map for the almost fully-loaded trash bin.
TC-013	Report generation function testing	The system can create reports that contain garbage information in PDF format
TC-014	Integrated system testing	Hardware systems with software systems can work well and are synchronized

B. *Explanation of the test results*

In general, the test cases that have been successfully tested and produce the appropriate results. It's just that for some test cases there are disturbances such as long delay time caused by disconnection of device communication network with broker, large response time due to bad data transfer through cable, and also delay time due to technical problem i.e. the accurate placement of the objects to be detected.

VI. CONCLUSION

City waste management system and technology is a system capable of handling waste management problems in Indonesia, especially the segregation and garbage collection activity. This system consists of three main subsystems namely the sorting subsystem, data management subsystem, and data visualization subsystem.

Testing for each test case produce the appropriate results, there are only a few obstacles such as communication delay, response time, and the accurate placement of the objects to be detected.

The system can be further developed by improving the quality of hardware used so that the readings of the sensor can be more accurate and data processing can be done more quickly. System development can also be done by extending the scope of management, for example adding the activities of transportation, processing, and final processing to obtain a comprehensive system in handling waste management.

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