IOT-BASED FRAMEWORK FOR A CENTRALIZED MONITORING OF SOLID WASTE DISPOSAL FACILITIES

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ABSTRACT

With the latest advancement in technology, this study attempts to address the problem of optimizing the cost necessary in solid waste management, specifically on the logistics of solid waste collection, and efficient management decision processes. Concisely, this study serves as a theoretical paper on developing an implementation framework for building an IoT based Framework to guide the actual development of a Centralized Monitoring System for Solid Waste Disposal Facilities. Disciplines and techniques used in Software Engineering have been employed in this study to arrive at and describe the resulting implementation framework for building a working prototype of the IoT framework. The paper also includes comparisons of key IoT enabling technologies in order to identify the best suitable tool for the specific use case necessary in solid waste management. Also, at the latter parts of this paper, results are presented using Software Engineering diagrams and are discussed accordingly in detail to serve as a basis in the actual development of the IoT framework. The implementation framework is projected to have a very low implementation cost while offering several opportunities for optimization and cost reduction.

Keywords: *internet of things, centralization, monitoring, waste disposal, framework*

1.0 Introduction

As the reach of technological modernization expands in the Philippine landscape, solid waste management still prevails to be one of the most basic yet relatively under innovated facet of governance present in every part of the society. Generally, solid waste management systems involve three aspects referred to as

Collection, Treatment and the Recycling of solid waste. As a pre-defined constraint, the conduct of this study focuses on innovating the aspect of collection of solid waste management in rural areas of the Philippines. At present, waste management systems employed by the Philippine government, are implemented using manual processes that require constant physical monitoring and handling of at least a hundred solid waste drop-off sites per city. With this, several challenges are encountered which include the logistics of planning and executing cost efficient waste pick-up routines on drop-off sites, prevention of excessive accumulation of solid waste at drop-off sites, and strategic planning of solid waste management pertaining to future projections and preparations.

In efforts to gain background and contribute to the dilemma, several studies in the field of solid waste management and existing innovations have been reviewed to provide better context and foundation for the conduct of this study. In a study conducted by (Guerrero, et.al, 2013), it has been found that manual implementations of solid waste management systems are costly due to unavailability of vital information during the decision making process of the management, which in turn leads to decisions that invite opportunities for further optimization. Furthermore, there are also notable attempts to reduce solid waste management costs, and modernized the decision making processes on solid waste management as documented in the works of (Ghose, et.al. 2006), implementing a Geographic Information System (GIS) based model for solid waste management. With the developed transportation model, the management is equipped with the capability to better analyze and arrive at a more optimized route for the logistics of solid waste pick-up on various dump sites. A broader study by (Harmon, et. al. 2015) on Smart cities and the Internet of Things have also acknowledged that a large part of efficiency is contributed by having vital information available. This claim is further confirmed by the study of (Mulas, et.al. 2016) on developing a framework for growth and sustainability of urban tech innovation ecosystems of which also stated that, the capabilities of IoT provides a game changing advantage of targeting sustainability through real-time data collection made by ubiquitous IoT devices.

As a synthesis of the conducted literature review, existing studies show that it is safe to imply that, although there have been attempts to optimize and minimize the cost of solid waste management, a better solution can be created using the latest technologies prevalently utilized in various smart systems. Although there has been an existing study for the efficient logistic implementation of solid waste collection using the GIS solution, limitations that can be eliminated were found in the existing solution as it did not account for the actual status and weight capacities of involved solid waste disposal sites. With these arguments in place, it can be stated therefore, that there is a need to re-innovate the present solutions used in solid waste management. Also, it has been found that there is no existing or at least formally documented study, which directly address real-time monitoring, and detailed measurement of solid waste data and activity on solid waste drop-off sites using IoT and centralized information systems.

In response, this paper attempts to address existing gaps by leveraging the capabilities of modern IoT technology, to develop an implementation framework for building an IoT Framework for the Centralized Monitoring of Waste Disposal Facilities. With the IoT framework, the management would be equipped with the capability to; accurately monitor the status of waste disposal drop-off sites that are full and recommended for pick-up; accurately monitor the amount of waste in kilograms per drop-off site allowing the management to easily map waste disposal activity per area. These capabilities are targeted to enhance if not optimize the decision processes of solid waste management by providing a real-time and data-driven information system for planning optimal logistic routes for collecting solid waste on drop-off sites. Potentially, with the volume of real-time data collected, stored and made electronically available by the IoT framework and information system, the solution also serves as a key contributor in producing future studies through the data it collects, of which is implied to open a wider array of possibilities for analysts, researchers and innovators to address issues on solid waste management.

2.0 Conceptual Framework

This study is anchored on the theory of (Verhulst, 2015) which states that cities have options to utilize four asset classes identified as people, data, infrastructure and technologies of which are capable of interacting in a more fluid and synergistic manner through the Internet of Things. With the stated theory, a concept has been formulated based on the theory to address the efficiency problems encountered in solid waste management. In order to define the guiding concept of this study, a diagram of the conceptual framework is provided below in figure 2.1.

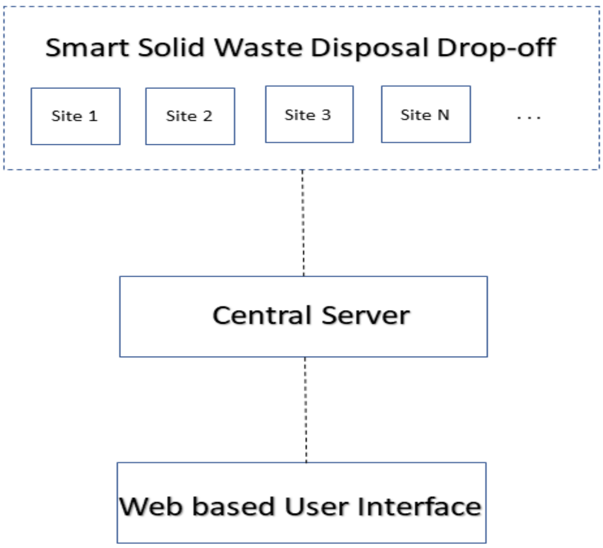

Figure 2.1: Conceptual Framework

The diagram is composed of three components identified and depicted in the diagram as Smart Solid Waste Drop-off Sites, Central Server, and the Web based User Interface. In the diagram, Smart Solid Waste Drop-off represents a collection of known solid waste drop-off sites formally referred to as IoT nodes registered within the system's scope of operation. This collection also refers to the working collection of IoT nodes to be centralized and monitored by the IoT framework. The collection of IoT nodes may be scaled to house *(n)* any number of IoT nodes as long as it fits the capacity of the employed hardware specification during actual implementation. Furthermore, this component is composed of several sub-components labelled as "Site *n*", these symbols refers to an individual node in the collection, each node is equipped with mechanisms allowing it to detect the weight of the site and when a site is full. The Central Server refers to a dedicated computer server hardware that houses the IoT driven information system responsible for storing and making electronically available the weight and status data sent from the collection of IoT nodes from the actual solid waste drop-off site. The Web User Interface refers to any computer terminal equipped with a web browser, an internet connection and or direct local area connection to the server, which would be operated by concerned personnel in charge to access the IoT based information system.

3.0 Research Methodology

Research Design

The study follows a descriptive method in addressing the gap presented in the area of solid waste management. The methods of Software Engineering will be used to design and arrive at an implementation framework for the development of an IoT based Framework for a Centralized Monitoring of Solid Waste Disposal Facilities.

Research Method

The conduct of this research is sub-divided into 4 steps to determine key requirements, suitable technology for implementation and an efficient implementation framework. The following are the steps taken to arrive at an implementation framework:

a. Identify hardware requirements
b. Identify communication requirements
c. Identify software requirements
d. Development of the implementation framework

4.0 Results and Discussion

After the actual conduct of the study methodology, results regarding the best fit hardware, communication and software requirements have been identified and are discussed accordingly on the sub-sections 4.1 up to 4.3. A final implementation is also presented and discussed to describe how an actual prototype of the IoT framework should be built which is found in the last sub-section 4.4. Along with this, it is defined in the area of IoT that bidirectional communication, mobility and localization services are key requirements for implementing IoT technology, these factors have been included in evaluating the requirements of the IoT framework. Also, minimizing the power consumptions of these devices is prioritized to enable longer uptimes and battery life in remote areas.

4.1 Identified Hardware Requirements

In order to satisfy requirement of mobility and localization in IoT, this study has examined six (6) of the top modern microcontroller hardware widely used in the field of hardware interfacing. A table showing the comparison of microcontroller technology has been provided below in Table 4.1.1 containing both technical specification and cost information.

Table 4.1.1 Comparison of Microcontroller Technology

Microcontroller	**Processor Frequency**	**Voltage**	**General Purpose IO Pins**	**SRP Price**
Raspberry Pi 3	1.2Ghz 64-bit quad-core	5 V	25	1,800 Php
Arduino Uno R3	16 MHz	5 V	14	1,400 Php
Intel Joule 570X	1.7 Ghz quad-core	12 V	48	30,000 Php
S7 Synergy Starter Kit	240 MHz	5 V	3	4,300 Php
Freedom Board	40 MHz	5 V	3	1,000 Php
ESP32	240 MHz dual core	3.3V	36	450 php

As shown on the table, a list of microcontrollers along with their respective specifications on processor frequency, voltage, number of general purpose IO pins and its retail price are presented to provide a visual means of comparison. The highlighted row on the table indicates the best microcontroller technology that fits the requirements for building an IoT sensor control. The ESP32 microcontroller was found to be the best fit for the specific requirement of applying IoT on the use case solid waste management. Although other microcontrollers have higher processor frequencies implying greater processing power, the selected 240 Mhz cpu frequency fits best in the IoT framework as no heavy processing is done in the IoT nodes itself, with this the design can avoid the need for a large capacity power source as it is capable of running at full processing speeds using only 3.3 volts of electricity. The number of IO pins also exceeds the minimum requirements for implementation, making it more suitable for mounting sensors. Budget wise, the selected technology also prevails to be the most cost effective among all other choices.

4.2 Identified Communication Requirements

In order to satisfy requirement of bi-directional communication in IoT, this study has examined five (5) of the top modern communication protocols widely utilized in the field of telecommunications. A table showing the comparison of communication protocols and technology has been provided below on table 4.2.1.

Table 4.2.1. Comparison of Communication Protocols and Technology

Communication Technology	Frequency	Bandwidth	Range	Power Consumption
Bluetooth	2.4 GHz	720 kbps	10 m	low
Zigbee	2.4 Ghz/784 MHz/868 MHz/915 MHh	250 kbps	300 m	low
Wifi	2.4 GHz/5.8 GHz	54 Mbps/1.3 Gbps	100 m	high
LoRaWAN	430 MHz/433 MHz/868 MHz/ 915 MHz	0.3Kbs to 50Kbps	15-30 km	low
Wimax	2.5 GHz/3.5 Ghz/5.8 Ghz	80 Mbps	50 km	high

As shown on the table a list of communication technologies along with their respective specifications on frequency, bandwidth, range and power consumption is presented to provide a visual means of comparison. The highlighted row on the table indicates the best communication technology for IoT communication, identified as the LoRaWAN with a minimum frequency of 430 Mhz and a maximum of 915Mhz, a bandwidth capable of communicating 0.3Kbps up to 50kbps worth of data in the range of over 15 to 30 kilometers while having a low power requirements. A lower frequency is ideal for implementing the IoT framework since it requires less power to emit its transmission signal, thus eliminating the need for large power packs to be attached on the devices. Also in communication disciplines lower frequency transmissions are capable of reaching farther distances as proven by how AM radios work. The small bandwidth also suits the requirements of IoT since data being transferred back and forth towards the server are miniscule, there is no need for excessive bandwidth support which also contributes to lowering the power consumption of the device.

The LoRaWAN stands for the communication protocol referred to as the Long Range Wide Area Network communication protocol. The communication protocol is secure as it utilizes the implementation of the encryption algorithm referred to as the Advanced Encryption Standard (AES), in order to ensure the integrity of data passing through the communication lines. The design principle of the AES encryption is based on a substitution–permutation network, a combination of both substitution and permutation, and has been tested to be effective in both software and hardware. Illustrated below in Figure 4.2.1 is the visualization of the AES encryption algorithm used to secure the exchange of communication between two devices.

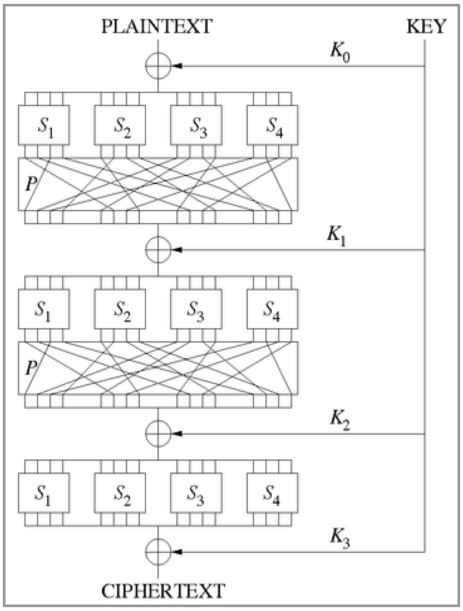

Figure 4.2.1: Visualization of the Substitution-Permutation Network

Generally, the Substitution-Permutation Network works by taking a block of the plaintext or target data and a key as arguments, and performs several alternating "cycles" of substitution boxes labelled as S-boxes and permutation boxes labelled as P-boxes to generate the block of ciphertext. Sub-blocks of input bits are transformed by the S and P boxes resulting in output bits. The key is used during each cycle, usually in the form of "cycle keys" derived from it. In order to decrypt the ciphertext the same procedure is executed backwards using the inverses of the S and P boxes and applying the cycle keys in reverse order.

4.3 Identified Software Requirements

In order for the system to be able to archive, the collected data by IoT nodes, an Entity Relationship Diagram has been designed to describe how data is stored on the central server as shown on figure 4.3.1.

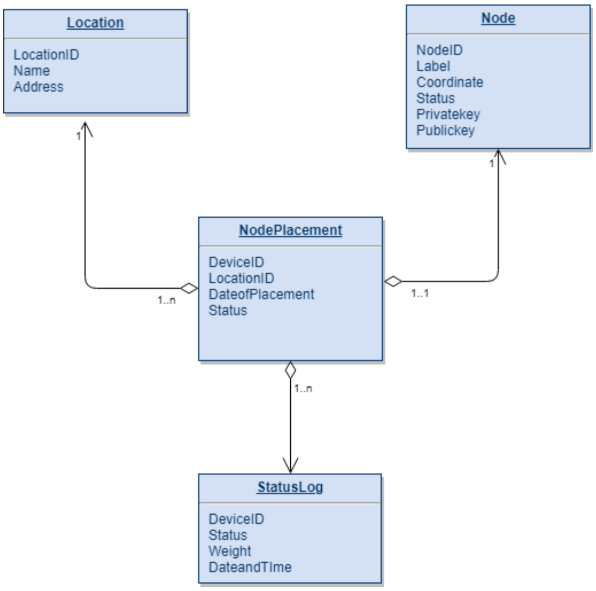

Figure 4.3.1: Entity Relationship Diagram

The entity relationship diagram involves four (4) entities to be used in the implementation of the system identified as Location, Node, Node Placement and Status Log. The Location entity is used to store data pertaining to the deployable locations of IoT nodes. The Node entity is used to store information on the actual solid waste drop-off site, including the map coordinates and encryption details. The Status Log entity is used to store information pertaining to the content status and weight of solid waste per IoT node. The Node Placement entity is used to store the placements of individual IoT nodes while associating the data of the first three entities.

4.4 Sensor and Microcontroller

A final implementation framework has been developed based on the specific requirements of the IoT framework applied to address solid waste management monitoring and centralization. The diagram depicted in figure 4.4.1 shows the systems' IoT node Sensor and Microcontroller Implementation Diagram.

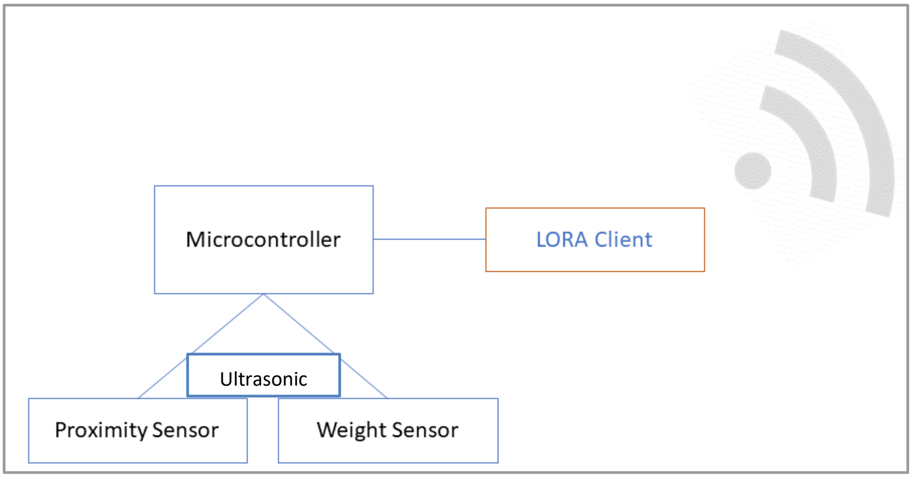

Figure 4.4.1: IoT node Sensor and Microcontroller Implementation Diagram

Each solid waste drop-off site will be equipped with an ESP32 microcontroller that has an attached ultrasonic sensor and weight sensor. The role of the ultrasonic sensor is to get the distance between the top lid of the waste bin and the bottom of the waste bin. When the distance between the lid and the contents of the waste bin reach at a certain threshold a notification data will be sent from the microcontroller to the central server via the LORA client. The role of the weight sensor is to measure the actual weight of the contents of the waste bin, when a measurement has been done the data is then sent from the microcontroller to the central server via the LORA client module.

5.0 Conclusion

Based on the conduct of this study, the result implementation framework for an IoT based framework is projected to be financially and technically feasible given that the selected environment for deployment is within the technical scope of LoRaWAN technology.

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