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Enhancing Waste Collection Activities Using IoT-Based Smart Waste Management System

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ABSTRACT

This study emphasized the need for efficient waste management systems in our communities in order to prevent disease and wastage of resources. Survey of existing solutions that leverage on IoT technologies was carried out. A simple low-cost smart waste management system that uses ultrasonic sensor to determine the level of refuse in bins is proposed. The refuse level can be monitored remotely via any web app that supports MQTT protocol. A dedicated android mobile app is also developed for the purpose of seamless refuse level and location monitoring. The system can be used by municipal authority to monitor and analyze waste generation and collection in near real-time. The system is also useful for truck drivers to optimize routes for refuse collection. It is also recommend for private solid waste collector for optimization of facilities and smart waste collection practices.

Keywords: Waste management; Internet of Things; Ultrasonic Sensor, Remote Monitoring

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1. INTRODUCTION

The number of people living in cities around the world is anticipated to continue to rise exponentially and this is causing a significant environmental consequence in most cities of the world especially developing countries (Adeniyi et al, 2022). One of environmental effects of continuous growth of cities population include solid waste generation. As a result, modern cities are face with challenges of how to manage varieties of waste generated. Solid waste management comprises of activities such as generation, storage, sorting, collection, transportation, disposal, treatment and cost recovery (Adeniyi, 2019; 2022). Of all the activities involve in solid waste management storage is very important as properly stored waste determined how convenience the collection and transportation will be.

Solid waste collection and transportation consume significant portion of budgeted allocation for municipal solid waste management by the authority of government who directly responsible for urban waste management. Inadequate facilities, lack of financial resources, and lack of proper planning are some of the challenges militating against proper waste management especially in developing countries (Imran & Kim, 2020). A lot of resources are being wasted in the course of garbage collection in some selected areas as most bins are left uncollected for long time while some are collected when partially filled up. Serious health issues have been linked to many instances when waste bins are left

unattended. To address these problems, there is a need to leverage enabling technologies to monitor the refuse level in near real-time.
In this way, information about the status of bins such as the location and volume of refuse bin could be monitored from waste management office or any place in preparation for actual collection and transportation exercise. This research work proposes a low-cost smart waste management system that provides a near real-time level of refuse in a municipal refuse bin using Internet of Things (IoT). The solution enables waste management and recycling companies to optimize their collection operations and maximize the use of resources. The system enables efficient management of waste collection assets, waste production analysis, and generation of optimized routes for truck drivers as well as the required volume of dustbin to be place in different location.

It is the intention of this study to develop simple and low-cost hardware for remote monitoring of waste level, and development of mobile app for remote monitoring using IoT. It also aims to develop seamless geo-located data gathering infrastructure that can interoperate with numerous data visualization and analytic tools.

2. LITERATURE REVIEW

In recent times, several research works have been carried out on various aspects of waste management system. The focus of the studies varies from sensing technologies, actuation methods, communication protocols, user interactions, evacuation route optimization techniques, waste collection planning and implementation, routing methods according to the type of waste; recycling and preparation for re-use, etc. Review in this study will be limited to research work that leverage on IoT for waste management. Generally, The IoT architecture consists of four parts namely end device, gateways, cloud server, and end-user. The end device uses sensors to measure the level or weight of the refuse bins, a microcontroller to carry-out local data processing, and a radio link to establish wireless connectivity with base stations or gateways. The gateway or base stations are used to establish connectivity between the end devices and the cloud server.

The Cloud Servers are used to provide flexible, scalable and secure authentication process. The end-user, who may be an employee of waste management company or a government worker, uses a web or mobile app to remotely view or analyze the refuse bins' filled level. A Web-based Decision Support System (DSS) for waste lube oils collection and recycling is proposed by Repoussis *et al* (2009). A model which allows intra-city and inter-city dynamic routing incorporating real-time operational constraints is proposed. The aim of the research was to develop efficient and effective management system for waste lube oils collection and recycling. Dynamic routing utilizes shortest path and hybrid meta-heuristics models. The proposed DSS introduces an Enterprise Resource Planning (ERP) system which allows the utilization of specific functional models and the combination with other scheduling tools. The study provides online monitoring of the waste collection procedure and the developed Web interface allows the platform independent approach for wireless telecommunication. The proposed model was applied to practical industrial environments, and is reported to enhance productivity and competitiveness on reverse supply chain management.

Tao & Xiang (2010) proposes capacity, temperature, weight, humidity and chemical sensors for solid waste collection. The study developed a municipal solid waste platform utilizing recycling information collected using IoT Technology. The research work presents a model for waste collection, transportation, recycling and processing. A management information platform that leveraged on IoT platform is presented to serve as a waste collection model in the city of Wuhan. The outcomes of the study are reported to help community authorities and make efficient usage of the information produced in every stage of the waste collection process possible.

Similarly, a combination of proximity and weight sensors is proposed in Catania & Ventura (2014) to obtain the status of trash bins (i.e., weight and filled level). A Raspberry Pi microcomputer is used as the gateway to transmit the measured data to the smart-M3 platform. The approach is used for optimized handling of solid wastes in urban areas. Though, the approach is used for optimized handling of solid wastes in urban areas, notwithstanding, additional gateways are required to increase its wireless range of the system. In the same vein, Folianto, Low, & Yeow (2015) proposed a smart bin system that utilizes a mesh network to monitor the level of fullness of the trash bin. The network uses low-power radio at the 2.4 GHz band. The collected data are then sent to a remote server for proper analysis and waste collection route optimization. The work of Tambare & Venkatachalam (2016) is on IR sensor-based smart waste management system using Internet-of-Things (IoT). The trash bins' filled levels are sent to an Intel Galileo Gen 2 board through RF modules. The study also compared the proposed system with some of the existing systems. Most of the systems evaluated use short-range communication technologies like Wi-Fi, Zigbee, LoRa, RF, etc. The short-range communication technologies involve deployment of repeaters to increase their wireless range, and their power requirements are not comparable to the low power consumption nature of IoT nodes.

Waste management optimization using IoT architecture in the context of Smart Cities is proposed by Cerchecci *et al.* (2018). This study describes a unique sensor node design utilizing low-cost and low-power components. All the sensor nodes are fitted with a microprocessor, an ultrasonic sensor to measure the fill level of trash bins, and a LoRa transmission module. A LoRaWAN network is set-up to evaluate the performance of the system. Also, attempt is made at increasing battery life by reducing power consumption via hardware and software optimization with focus on energy-saving technologies and strategies for the nodes. A waste monitoring and management system for rural areas is also proposed by Lozano (2018). In the research work, a low-power wireless node prototype is built to estimate the weight, filling level, and temperature of the refuse bin. The monitoring architecture facilitates the collection and analysis of filling data for each refuse bin, with the ability to generate notifications in the event of an incident. The system helps in determining the most proficient waste collection routes. The proposed system builds routes dynamically based on data acquired from node on sites, thereby saving energy, time, and other valuable resources.

Beliatis, et al. (2018) developed an IoT-based waste management system. The approach leveraged on LoRa network for deployment and evaluation of an economically viable digital waste monitoring system for Industry 4.0 and smart cities. The study identifies the fact that the primary challenge to successful commercialization of many of prototypes developed for waste management is the cost of the sensor and accessories. The study uses ultrasonic sensing system, since reliable waterproof sensors appropriate for outdoor environment are expensive. In the study carried out by Addabbo *et al.,* (2019), the suitability of waterproof ultrasonic sensors for measuring the level of waste within a trash bin is investigated. The proposed sensing node was evaluated in the laboratory to demonstrate its effectiveness. The value of the refuse level inside the bin is computed with an accuracy of 2–3 cm- this accuracy is acceptable since the waste is not uniformly spread inside the bin. A waste management network consisting of five sensor nodes interfaced to a single-channel LoRa gateway is developed to work in real-time after the initial test and validation.

A LoRaWAN-based solid waste management system with incorporated energy-harvesting sensor node is proposed in Ramson, et al. (2021). The system was deployed to work in real-time. An intelligent user interface was developed to locate the bins with respect to the level of refuse in the bin; and various evaluation metrics are provided to establish the feasibility of the work. In a related study, customized sensor node and gateway based on LoRa technology for accurate estimation of level of refuse inside bins is presented in Akram et al (2021).

This work evaluated energy consumption of the system by simulating it using the Framework for LoRa (FLoRa) platform while varying a number of important LoRa communication parameters. The study also provides relevant evaluation metrics for the LoRaWAN network such as range, data rate, time on-air, sensitivity, link budget, and battery life. In a study carried out by Vishnu et al. (2021), practical compatibility issues between the short-range and long-range communication protocols in dual network architecture is investigated. The research work selects a LoRaWAN for public trash bin monitoring, and WiFi network for residential trash bin monitoring. In addition, the custom-made sensor nodes were evaluated with objectives of determining power consumption and energy harvesting capabilities of the system.

In a recent survey (Vishnu, S. et al., 2022) detailed analysis of RFID, WSN, and IoT-based approaches in solid waste management systems was presented. The authors analyzed each category with typical system architecture. The significance and limitations of the categories are discussed, and recommendation is made on suitable communication technology for IoT-based solid waste management systems. The approaches used in the survey are considered relevant for this study. RFID Based Solid Waste Management Systems are normally designed - to obtain information on the waste collection area and the respective collecting time; to develop a system for monitoring and tracking of waste bins and waste collection trucks; and to obtain information on the quantity of solid waste inside the refuse bin. A typical system architecture for RFID-based solid waste handling system is shown in Figure 1.

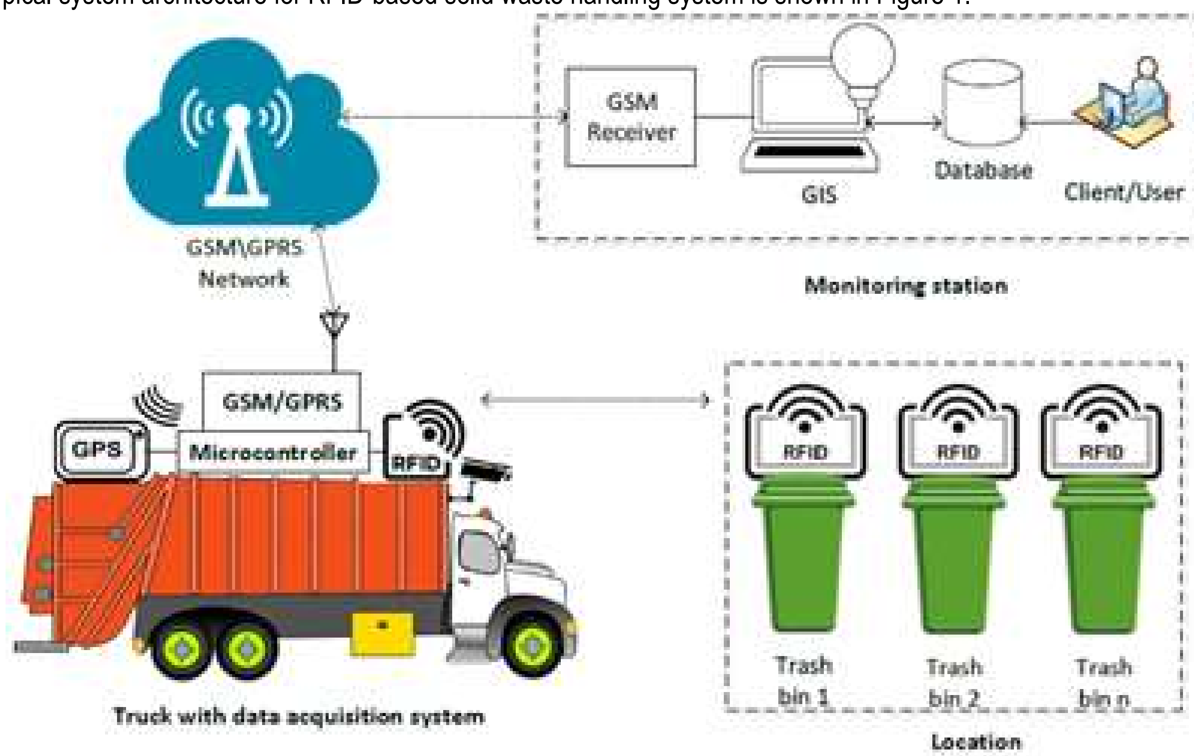

Figure 1: RFID-based Solid Waste Management System architecture (Vishnu, S. et al., 2022)

Vishnu, S. et al., (2022) submitted that RFID-based systems are unable to provide continuous real-time monitoring of the bin's filled level; Trash bins are monitored only when the truck is within the range of RFID tags; RFID tags are using

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to identify the bins uniquely and they do not provide any data on the filled levels of the bins; and that additional infrastructure is required to obtain the filled levels of the trash bins. Wireless Sensor Networks (WSN) Based Solid Waste Handling Systems are also deployed in real-time solid waste management systems. WSN approach is characterized by inherent ability to deal with node failures; Optimal for battery-powered, mobile and heterogeneous nodes; and ease of scaling to a very large distribution level. A typical WSN architecture for solid waste management system is illustrated in Figure 2. The architecture comprises clusters, base station, and central monitoring station. Each cluster includes many trash bins fitted with sensor nodes, and all these sensor nodes are inter-connected to a coordinator node. The coordinator nodes of different clusters are then linked to the base station, which act as processing unit for the WSN. The base station uploads data to a server to enable remote monitoring via internet.

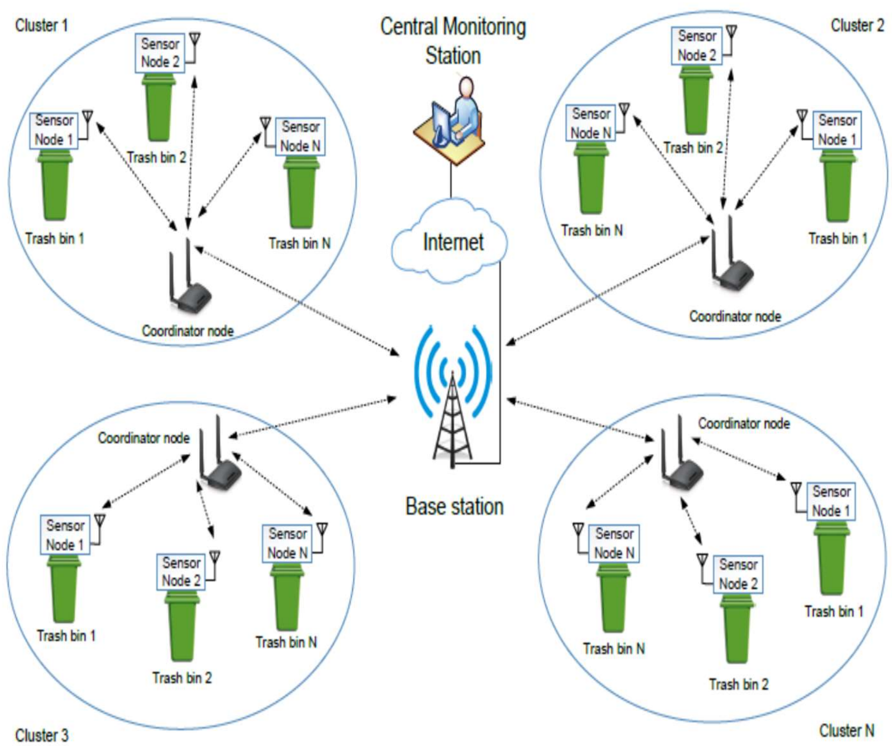

Figure 2: Wireless Sensor Networks Based Solid Waste Handling Systems (Vishnu, et al., 2022)

IoT-Based Solid Waste Management Systems are presented as a very robust approach for refuse management systems since the data recorded from the smart bins assist in reducing missed pickups. The authorities will be automatically notified if the sensors detect that the garbage container is filled-up. Then, the IoT waste management system enables the scheduling of next pickup for this location. This simplifies the process of waste management and reduces overflowing garbage cans. The approach is also good for route optimization as real-time information provided by the smart trash bins can be used to decide on the best paths for refuse collection.

Moreover, waste production analysis can easily be carried-out. This is possible since the connected devices keep track of how quickly the bins fill up and how often they empty in different locations thorough the day. The insight into these data can be used for improved trash bin distribution, and eradication of improper waste disposal techniques. A typical IoT architecture for waste management system is shown in Figure 3.

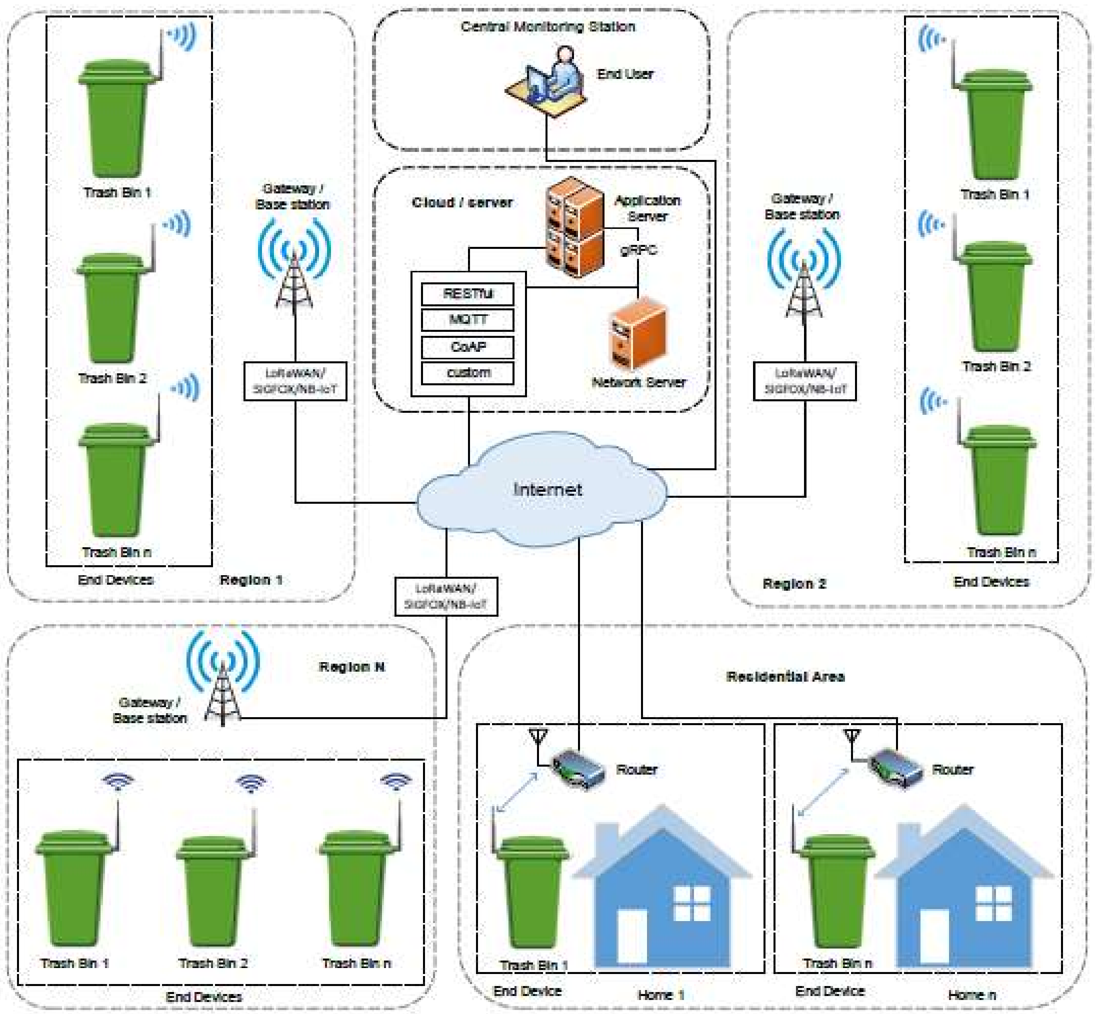

Figure 3: A general IoT architecture for waste management system (Vishnu, S. et al., 2022).

3. MATERIALS AND METHODS

3.1. System Architecture

This section provides overall System Architecture of the proposed Smart Waste Management System. General overview of the system is as follows:

a. The main microcontroller is ATMEGA328P, interfaced to ESP8266 WIFI module (thorough serial port) for internet connection.
b. An ultrasonic sensor (HC-SR04) is used to determine the refuse level in the dustbin.

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c. A GPS Module (MT3329) is incorporated into the system to determine the geographical location of the refuse bins.
d. An android app is developed for remote monitoring of refuse level, battery voltage, and geographical coordinate of the dustbin via an existing IoT platform.
v. The device is powered by a lithium battery which is charged by solar power.
e. System calibration, diagnostic, and troubleshooting are aided with integrated Liquid Crystal Display (LCD), Push Buttons and Light Emitting Diodes.

The block diagram of the proposed waste management system using IOT is shown in Figure 4. The main circuit diagram of the system is shown in Figure 5.

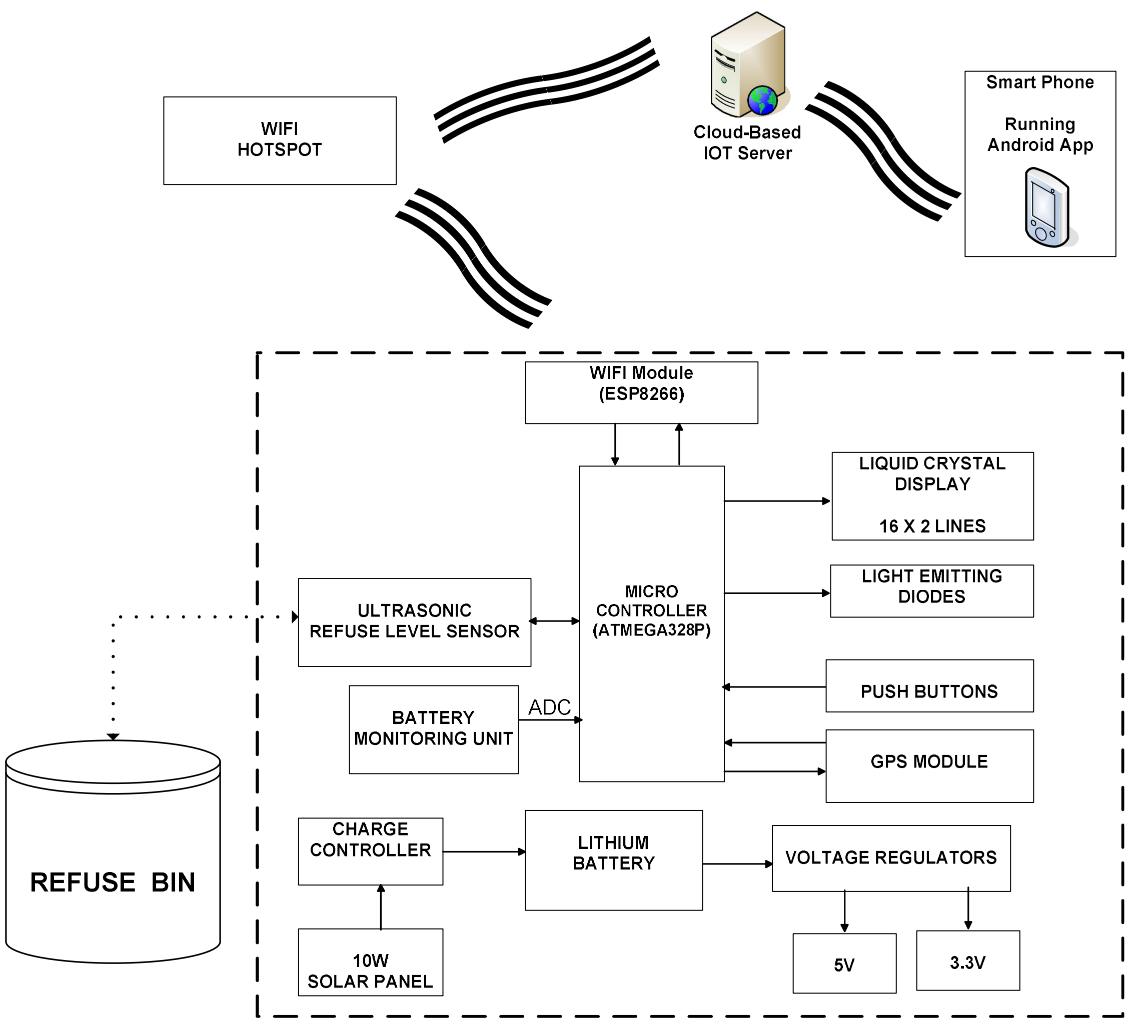

Figure 4: Block Diagram of the proposed Waste Management system using IOT

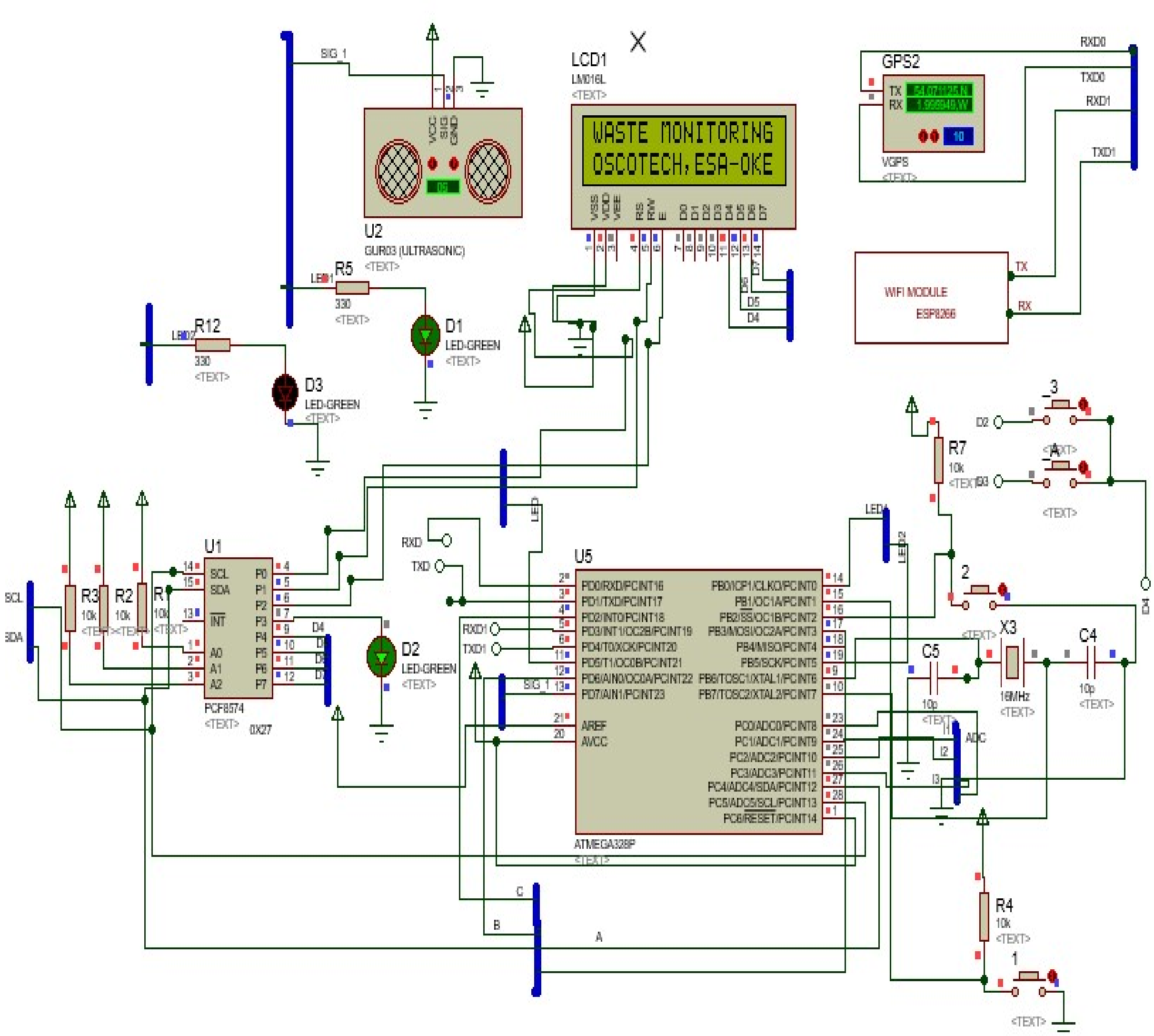

Figure 5: Main circuit diagram of the Proposed Smart Refuse Bin

3.3 Hardware Overview

3.2.1. Microcontroller

The microcontroller used for the system is ATmega328P - an 8-bit single-chip microcontroller from Atmel with a modified Harvard architecture RISC processor core. It combines 32 KB ISP flash memory with read-while-write capabilities, 1 KB EEPROM, 2 KB SRAM, 23 general-purpose I/O lines, 32 general-purpose working registers, 3 flexible timer/counters with compare modes, internal and external interrupts, serial programmable USART, 6-channel 10-bit A/D converter, a byte-oriented 2-wire serial interface, SPI serial port, programmable watchdog timer with internal oscillator, and 5 software-selectable power-saving modes. The device operates between 1.8 and 5.5 volts with maximum throughput of 1 MIPS/MHz.

3.2.2 Wifi Module

The Wifi module used for the system is ESP-07. The module's core processor is a low power 32-bit microprocessor unit. The module integrates the antenna switches, RF balun, power amplifier, low noise receive amplifier, filters, power management modules, and thus requires minimal external circuitry. The module supports standard IEEE802.11 b/g/n protocol, complete TCP/IP protocol stack. The module provides unparalleled ability to embed Wi-Fi capabilities within other systems, or to function as a standalone application- at low cost, and minimal space requirement. Wireless internet access can be added to any micro controller-based system with using SPI, I2C, or UART interface.

3.2.3. GPS Module

A high-performance single chip GPS module, MT3329, is used to obtain geographical coordinate of the waste bins. The module which contains powerful ARM7EJ-S CPU has in-built CMOS RF, digital baseband, and an optional embedded flash. It has high levels of sensitivity, accuracy, and Time-to-First-Fix (TTFF) with very low power consumption. With an on-chip integrated LNA, MT3329 delivers a total pre-ADC receiver noise figure of 4 dB. It also has an on-chip automatic centre frequency calibration band pass filter; therefore does not require external filter. The integrated PLL with Voltage Controlled Oscillator (VCO) provides excellent phase noise performance and fast locking time. The module supports up to 210 PRN channels. With 66 search channels and 22 simultaneous tracking channels, MT3329 acquires and tracks satellites in the shortest time. It supports various location and navigation applications, including autonomous GPS, DGPS, and AGPS.

3.2.4 Ultrasonic Sensor (HC-SR04)

An HCSR04 ultrasonic ranging sensor is used to determine the level of refuse in the bins. The ultrasonic sensor uses sonar to determine distance of an object. It provides 2cm - 400cm non-contact measurement function with up to ranging accuracy of 3mm. The modules includes ultrasonic transmitters, receiver and control circuit. The basic principle of its operation is as follows: When IO trigger is received for minimum of 10us high level signal, the module automatically sends out eight 40 kHz; and detect whether there is a reflected pulse signal. If the signal is reflected back, the time, t from sending ultrasonic to returning is the duration of time the output IO is high. Object distance can be computed as follows:

Speed of sound, V = 340 m/s = 0.034 cm/μs

$$\text{Object distance (cm)} = \frac{t}{2} * speed = \frac{t}{2} * 0.034 = 0.017t \qquad 1$$

The refuse level inside the bin can be computed as follows:

The height, *h* of the bin is 80 cm.

$$\text{Refuse level in \%} = \frac{(80\text{ cm} - \text{Object distance})\text{ X }100\%}{80\ cm} \qquad 2$$

$$\text{Refuse level in \%} = \frac{(80\text{ cm} - 0.017\text{t})\text{ X }100\%}{80\ cm} \qquad 3$$

3.2.5. Power Management Unit

The primary source of power for the system is a 7.4V, 4200mAh Lithium battery. A 10W Solar panel is connected to the battery via a versatile battery charger IC, MP2615. The MP2615 is a high efficiency switch mode battery charger suitable for 1- or 2- cell lithium-ion applications. It regulates the charge current and full battery voltage using two control loops to achieve high accuracy constant current (CC) charge and constant voltage (CV) charge. It is can deliver 2A of charge current programmable via an accurate sense resistor over the entire input range.

The microcontroller, LCD and ultrasonic sensor require +5V operating voltage, while GPS and WIFI module require 3.3V to operate. To meet these requirements, two linear regulators, LM2576-5V and MIC2930 are used to regulate battery supply voltage to +5.0V and +3.3V respectively. The battery status monitoring system is implemented using a potential divider, connected to the ADC input of the microcontroller thorough MCP6004, a general purpose operational amplifier connected as voltage buffer. MCP6004 has a 1.0 MHz Gain Bandwidth Product (GBWP) and 90° phase margin. It operates from a single supply voltage as low as 1.8V, while drawing 100 µA quiescent current. A buffer is required for the network to ensure low impedance into the ADC input. Figure 6 below shows the circuit configuration used for battery monitoring system. To select the resistors to use for potential divider, the following computations are carried out.

$$V_{out} = \frac{R1}{R1+R2}\text{Vbatt} \qquad 4$$

With the assumption that the battery terminal voltage cannot exceed 10.0V, Vbatt is taken as 10.0V, R_1 as 10kΩ. Since maximum voltage that can be tolerated by the ADC pin of the microcontroller is 5.0V, the V_{out} is taken as 5.0V.

The required value for R_2 is computed as follows:

$$R_2 = \frac{R1(Vbatt-V0)}{V_o} \qquad 5$$

R_2 = 10kΩ (10-5)/5 = 10kΩ

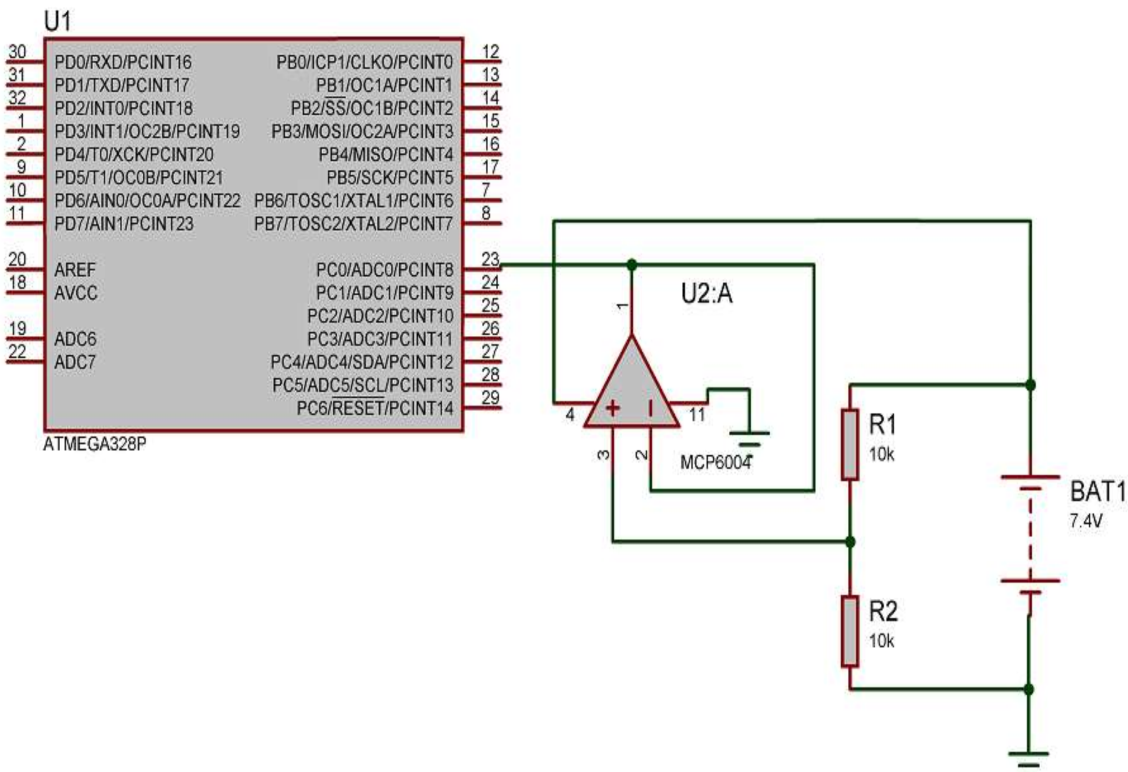

Figure 6: Battery Monitoring Unit

3.3 Firmware and Software Development

3.3.1 Principle of Operation

At power on, the system measures the level of refuse in the smart bin using the ultrasonic sensor, and the coordinate of site location using the GPS module. The battery voltage is also measured using the battery monitoring unit. The data obtained – Location coordinate, Refuse level, and Battery voltage- are converted into a string and sent to the WIFI Module (ESP8266) via the serial port. The WIFI Module (ESP8266) connects to a pre-configured WIFI hotspot to send the data to MQTT server (hivemq). At an interval of 30 seconds, the system measures all the three parameters (Location coordinate, Refuse level, and Battery voltage). The data upload to MQTT server will then be carried out if there is up to 10 % change in the value of any of the measured parameters. This approach is adopted to extend battery life, minimize traffic to the server, as well as optimize internet data usage.

3.3.2 Data Packet Format

The data from the Smart refuse Bin is packed in JavaScript Object Notation (JSON) format, which is a lightweight format for storing and transporting data. The data format uses Key/Value pair approach, and it is fast, efficient, and supported by many browsers. The structure of data packet from the Smart refuse Bin is illustrated in Figure 7.

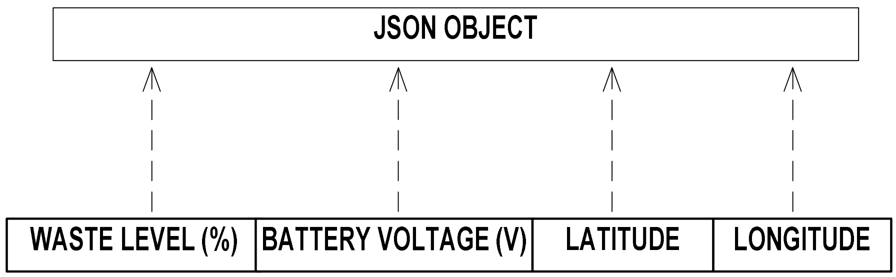

Figure 7: Format of JSON Data from the Smart Bin

The flowchart for the system firmware is shown in Figure 8. It illustrates the system mode of operation and data uploading to the cloud server.

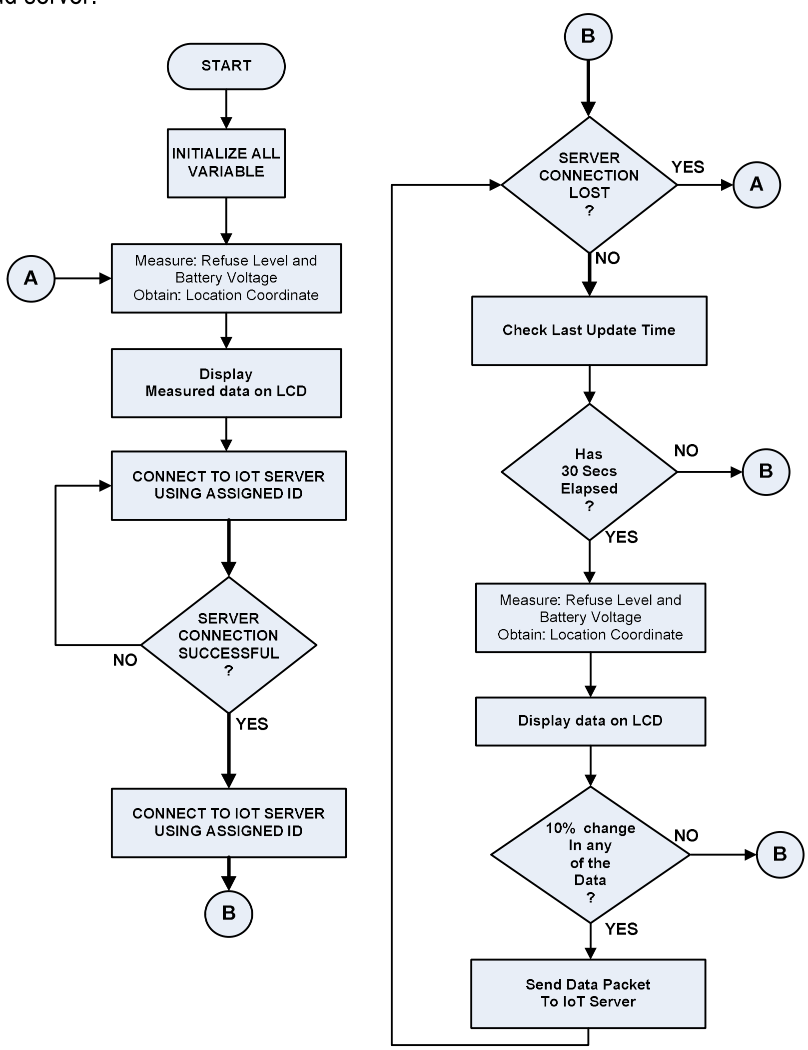

Figure 8: Flowchart of the Firmware

3.3.3 Mobile App Development

The mobile app for the Smart Waste Management system was developed in Android Studio Environment. The Flowchart for the mobile app is illustrated in Figure 9.

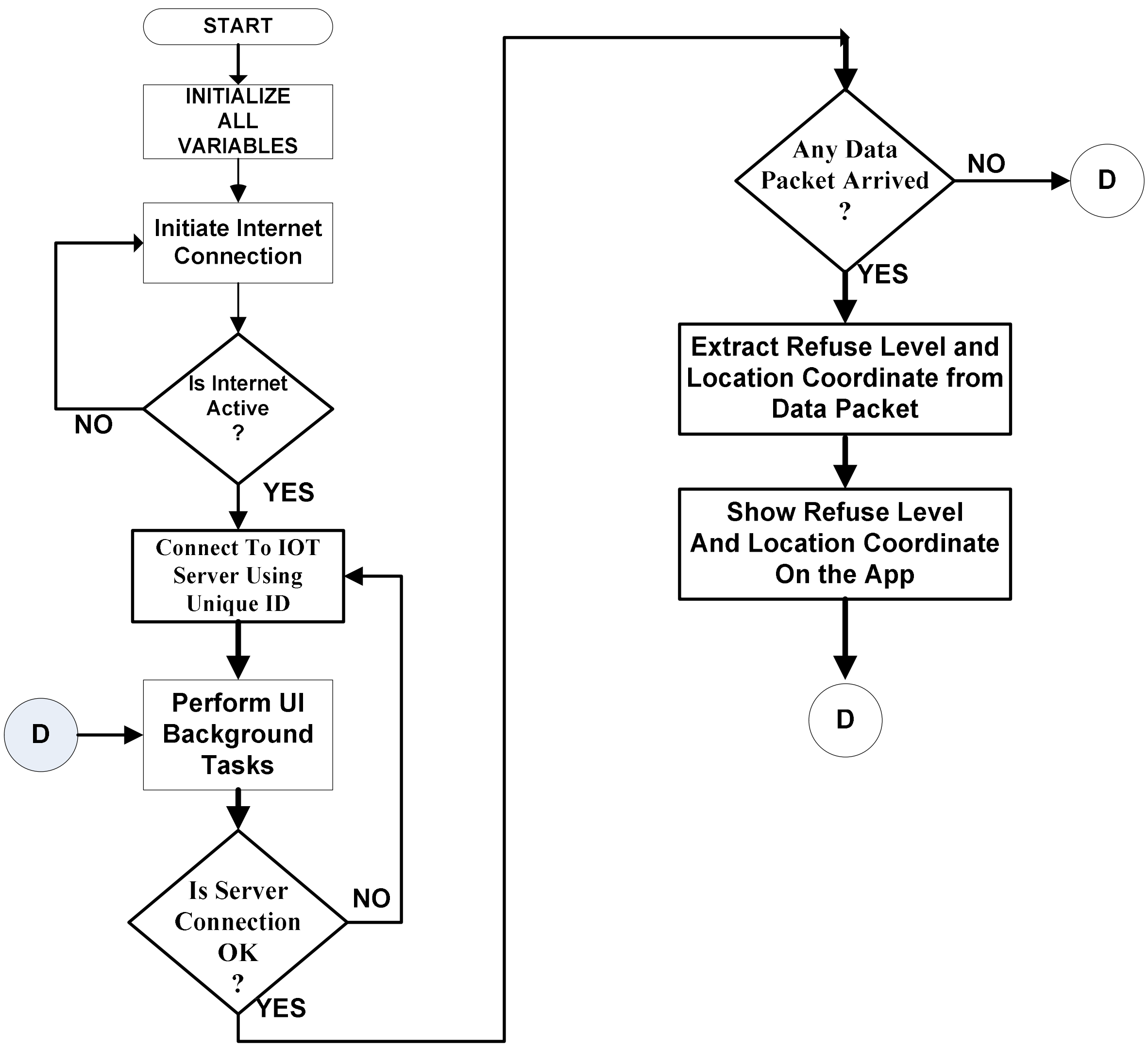

Figure 9: Flowchart for the Mobile App

4. RESULTS AND DISCUSSION

Pictures of circuit board and complete Smart bin for the proposed waste management system are shown in Figure 10 to Figure 12. The bin is made up of polished wooden material with dimension of 80cm (height) by 35cm (breadth) by 34 cm (width).

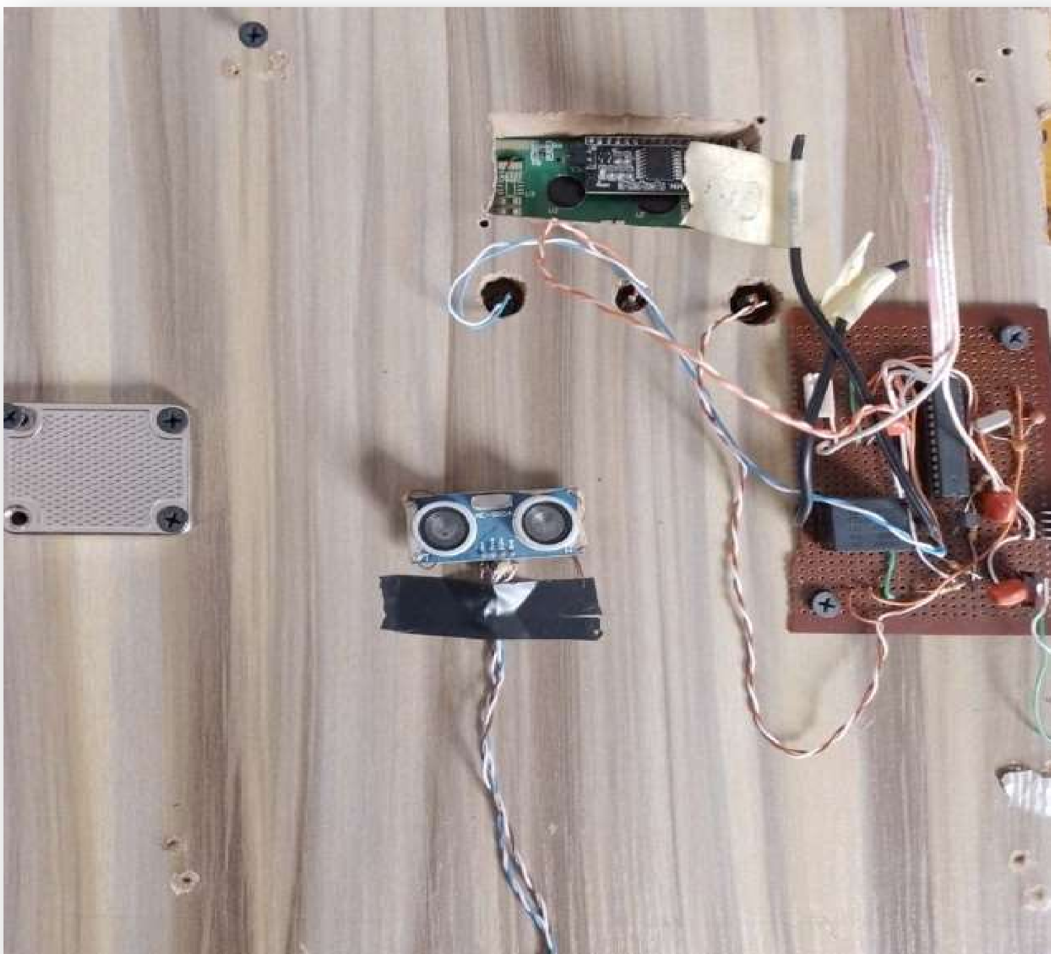

Figure 10: Circuit Board of the developed Smart Refuse Bin

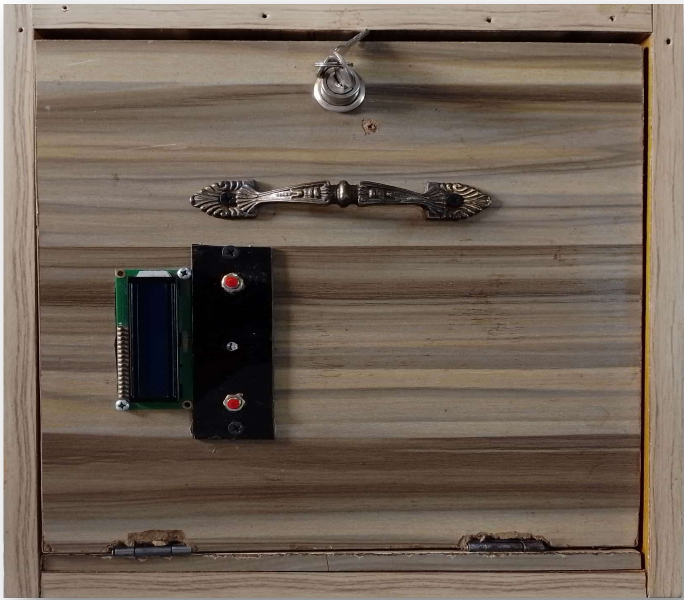

Figure 11: Aerial View of the Smart Bin

Figure 12: Side View of the Smart Bin

4.1 Refuse Monitoring Using Web App

MQTT Lens is used to view the data sent to the IoT server by the smart bin. MQTT Lens is an add-on for the chrome browser that allows one to publish messages to an MQTT broker, subscribe to MQTT topics, and receive messages using the chrome web browser. Hivemq is used as the MQTT broker for the smart bin; connected at port 1883. The web interface shown in Figure 13 is the screenshot of the web app while creating a communication link to the server for the purpose of monitoring the data sent from the smart bin.

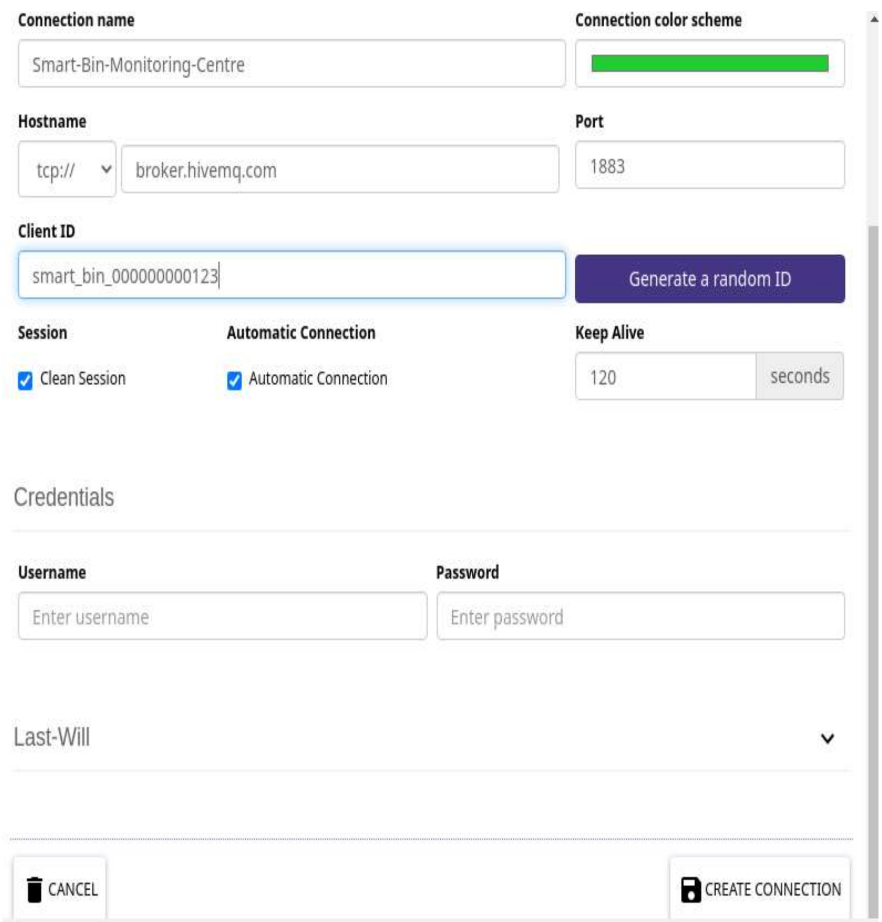

Figure 13: MQTTLens web interface during Connection to IoT server

Subscription is made to MQTT topic, *refuse_bin_level* after a successful connection to the server. The data sent by the Smart bin can be observed under the topic in Figure 14 and Figure 15 below. In Figure 14, the Waste level can be observed to be 0 %. This implies there is no refuse in the bin. In Figure 15, the refuse level is reported to be 95%. This observation was made when the bin was almost filled to the brim. As shown in the web app screenshots, the batteries

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as well as the geographical coordinates of the bin are also sent with the refuse level. This information is very helpful in determining the location of the bin for the purpose of evacuation.
Though a 10W solar panel is connected to the battery via a charge controller, however dust coverage on the panel, as well as faults on the battery charging unit may be unnoticed if real-time information is not provided about the battery status. Thus, the information about the battery terminal voltage is very important in preventing the system failure.

Figure 14: Smart Bin Data Packet when Bin is Empty

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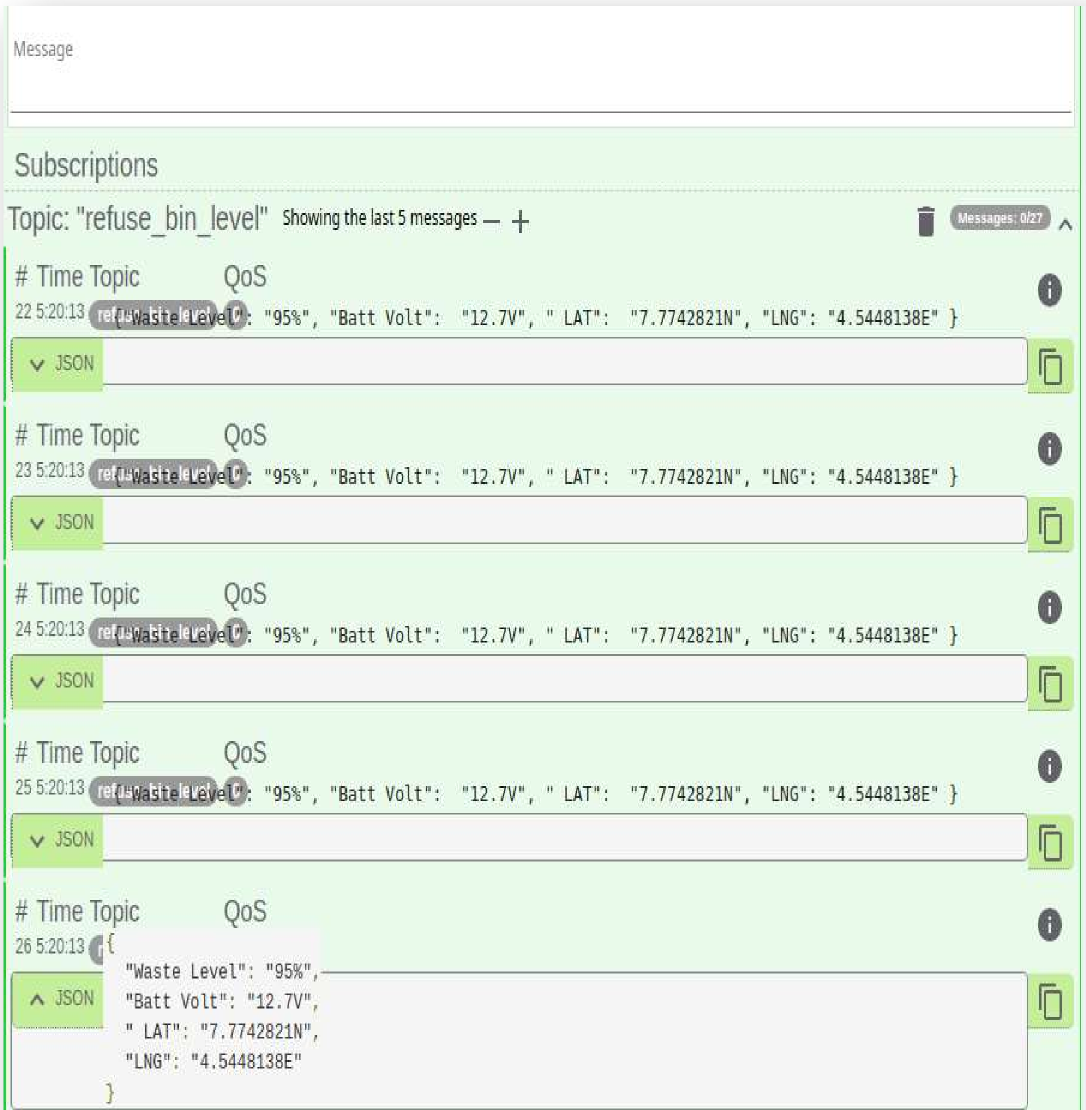

Figure 15: Smart Bin Data Packet when Bin is filled to the brim.

3.2 Mobile App Interface

The mobile app for remote monitoring of refuse is developed with Java Programming Language in Android Studio IDE. The user interfaces of the mobile app are shown in Figure 16 to Figure 19.

Fig 16: User Log-in Interface for Monitoring App

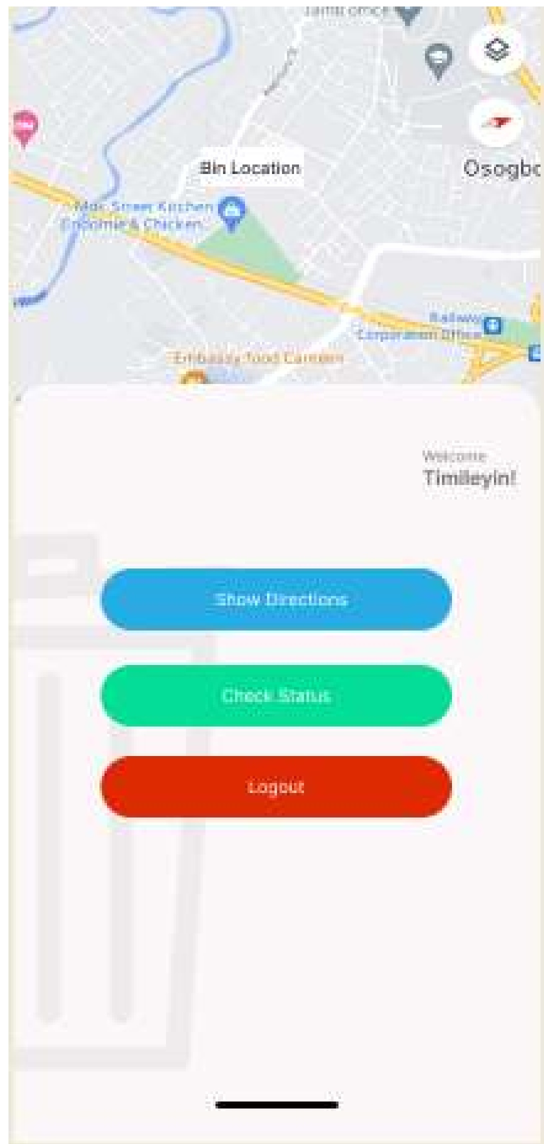

Fig 17: Location Interface for Selected Smart Bin

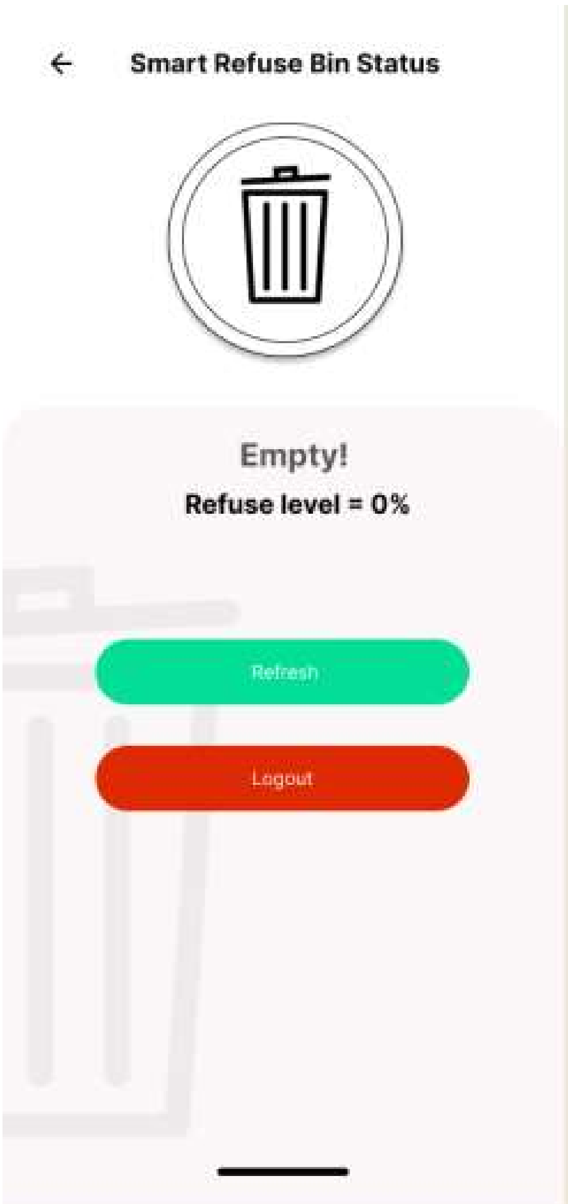

Figure 18: Mobile Monitoring App Level Interface Interface when the bin is empty

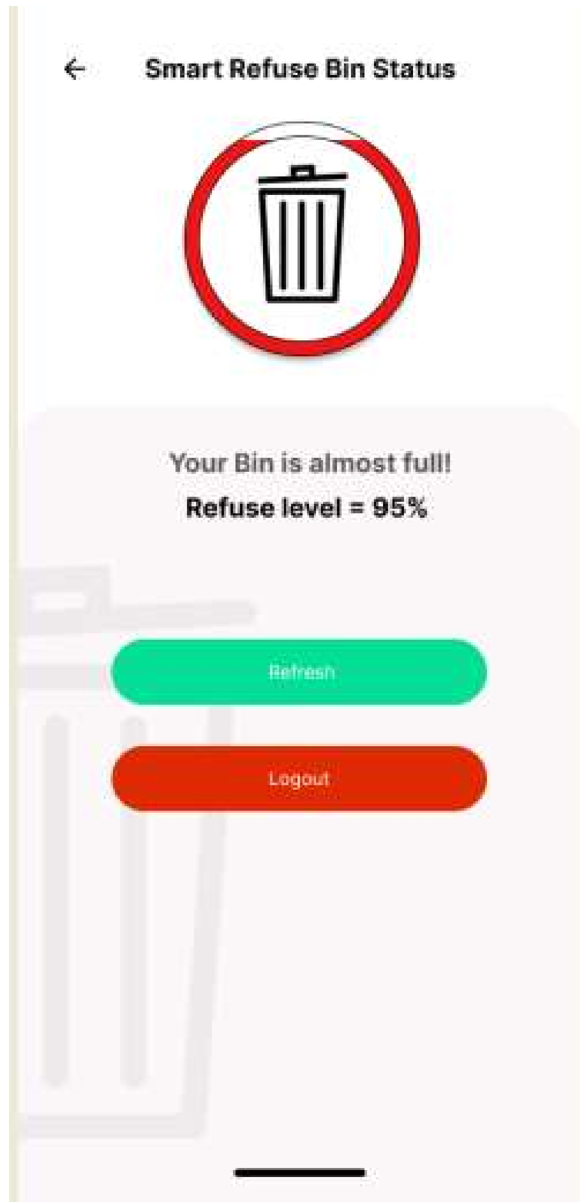

Figure 19: Mobile Monitoring App Level when the bin is filled up

5. CONCLUSION

This study has re-emphasized the need for efficient waste management systems in our communities in order to prevent disease and wastage of resources. Survey of existing solutions that leverage on IoT technologies is carried out. A simple low-cost smart waste management system that uses ultrasonic sensor to determine the level of refuse in bins is proposed. The refuse level can be monitored remotely via any web app that supports MQTT protocol. A dedicated android mobile app is also developed for the purpose of seamless refuse level and location monitoring. The system can be used by municipal authority to monitor and analyze waste generation and collection in near real-time. The system is also useful for truck drivers to optimize routes for refuse collection. The system - if adopted in monitoring of solid waste in urban- will assist the municipal authorities in saving cost and aid in government efforts to protect the environment. It could also assist private organization to minimize cost of fuelling operational vehicles by optimizing the vehicles capacity and routes. Most importantly, it would provide environment friendly waste management practices.

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Emotion Recognition and Prediction Using Machine Learning

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ABSTRACT

Sports is an activity requiring skill or physical prowess and often of a competitive nature. It is also an area which requires a lot of data analysis nowadays as Cintia and co. agreed in 2015. Analysis in sports is now used to judge sports performance using various scientific methods and techniques from different areas such as statistics, data mining, data analysis, e.t.c. The ability to recognize facial expressions of emotion is vital for effective social interaction. Facial expressions show a lot of emotions being felt by an individual and being able to recognize these expressions would help us to know how certain individuals feel and subsequently know how they interact with others. According to emotions theorist Izard (2002), the inability to recognize nonverbal forms of emotional expression can negatively affect intra-and interpersonal behaviour and may serve as a risk factor for poor adjustment and future adverse outcomes. This paper examined emotion recognition and prediction of outcomes in sports using machine

Keywords: Emotion, Emotion Recognition, Emotion Prediction, Machine Learning, Facial Expression, Facial Expression Recognition (FER).

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1. INTRODUCTION

As we now have intelligent machines, the need to be able to recognize emotions is also rising on par. In the area of theoretical science to engineering, emotion recognition has drawn extra concentration. Emotion has a great impact on decision-making and interpersonal communication and there are a lot of difficulties in being able to detect emotions. Because the number of basic emotion labels is arguable till now (Ortony, 2004) and the same emotion can be defined in different ways depending on the situation. Another problem is that the emotion of a particular class may carry the component of other classes.

Emotions speak volumes about the state of mind of individuals. Different individuals express varying degrees of emotions in similar circumstances. And the ability to accurately determine or predict these various emotions place a significant role in being able to advise, motivate or mollify any of such individuals. Emotion Prediction is becoming an active area of study. Ordinarily, based on personality attributes or types, most persons hardly express their emotions openly or formally.