International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I4P107
Volume 72 Issue 4, 67-73, April 2024

Original Article

IoT-Enabled Bio-Organic Fertilizer Monitoring for Residual Palm Materials for Sustainable Agriculture

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Received: 28 November 2023 Revised: 15 February 2024 Accepted: 02 March 2024 Published: 24 April 2024

Abstract - *Agriculture has emerged as one of the Internet of Things' (IoT) most notable applications due to its quick and widespread adoption. This study presents several IoT applications in agriculture, focusing on using a sensor system to monitor the quality of bioorganic fertiliser. This system detects changes in temperature, humidity, acidity (pH), electrical conductivity (EC), and the concentrations of nitrogen (N), phosphorus (P), and potassium (K). Then, it sends the data to the cloud platform (ThingSpeak) via MCU ESP32 over Wi-Fi. In the Nong Sue district, 6,083 palm oil plantations generate 9,360 kilos of palm trash per field annually, categorized as a carbon and nitrogen source (C/N). Collaborating with farmers, community businesses, and Rajamangala University of Technology Thanyaburi (RMUTT), this study addresses the challenge of palm waste disposal and its environmental impact, seeking to produce bio-organic fertilizers from this waste using hostile bacteria while reducing soil nitrate levels. To improve the product's quality and quantity, this study integrates an Internet of Things (IoT) sensor system that utilizes intelligent sensors to oversee critical physical and biological factors, ensuring accurate quality monitoring. The paper identifies a research gap in applying IoT technology to quality control in organic fertilizer manufacturing and presents a holistic solution, contributing to sustainable agriculture and improved crop yields. The outcomes of the experiment reveal that this sensor system performs exceptionally well in the precise and reliable detection and monitoring of both physical and biological components through smart devices; this achievement ultimately plays a role in generating Bio-Organic fertilizer products of superior quality.*

Keywords - *Residual palm materials, Harmful microorganisms, Internet of Things, Bio-organic fertilizers.*

1. Introduction

This paper builds upon the previous research, there are about 6,083 fields used for palm oil plantations in the Nong Sue district of Pathum Thani Province, producing an average of 9,360 kilos of palm trash per field annually. This trash is classified as a carbon and nitrogen source (C/N) [2] since it is predominantly made up of dried palm material and includes more than 35% organic matter. Unfortunately, farmers frequently burn this dry palm material as a means of disposal, which is unfavourable to the environment and causes an accumulation of ammonia in two forms: 1) ammonia ion solution (NH4-), which is bad for the growth of other plants, and 2) free ammonia (NH3). Notably, ammonia ion solution is 50 times less hazardous than free ammonia [2]. Farmers, local businesses, and RMUTT have collaborated to produce bio-organic fertilizers using residual palm materials and deploying antagonistic bacteria to address these challenges. The main objective is to lessen nitrate concentrations in the soil, which might minimize the expense of purchasing additional oil palm fertilizers and mitigate nitrate presence, which has been associated with bowel cancer. In order to increase both the amount and quality of products to fulfil Thai organic requirements, RMUTT, in collaboration with community enterprises, has transmitted technology for manufacturing organic fertilizer between 2013 and 2021. They have established sizable producer groups encompassing more than 1,000 farms to address the rising demand for organic fertiliser. Before using bio-enzyme technology powered by hostile microorganisms to produce bio-organic fertilizers from palm waste materials, farmers and community enterprises relied on predictions for completion timetables and the assessment of physical and biological components. This approach, at times, led to Bio-Organic fertilizers not meeting the essential quality standards and possibly lacking essential nutrients, which resulted in reduced crop yields of inferior quality. To address quality issues, smart sensors are being used to identify and track a variety of physical and biological characteristics, including temperature, humidity, electrical conductivity (EC), acidity (pH), and NPK (nitrogen, phosphorus, and potassium), using gadgets such as smartphones and tablets. This research has resulted in the development of an Internet of Things (IoT) sensor system that utilizes smart devices to accurately and consistently measure physical and biological characteristics for monitoring the quality of bio-organic fertilizers.

2. Previous Research

A network of linked physical objects or devices, including appliances, cars, and other items, that are embedded with sensors, software, and connectivity features to exchange critical information among themselves is referred to as the Internet of Things (IoT) in technology [3,4]. Applications for the Internet of Things are widely employed in many different fields, such as manufacturing and industry, home environments, transportation, agriculture, and healthcare, among others [5-10]. IoT plays a critical role in agriculture by enabling continuous monitoring of plant and soil conditions, predictive analysis of production results, and complete tracking of crop development progress [11-14].

For example, as demonstrated in [15], IoT applications provide essential insights into agricultural crop data, allowing exact suggestions for ideal fertilization ratios. Furthermore, as described in [16], sophisticated warning systems use IoT technology to control plant water stress successfully, providing farmers with real-time access to important soil condition data via online interfaces.

Furthermore, as shown in [17], IoT systems use sensors to collect detailed information about vegetable and lime growth, notifying farmers via smart devices and improving decision-making. Furthermore, as illustrated in [18], IoT sensors continuously measure soil humidity levels, providing farmers with real-time data.

Most papers under evaluation have focused on IoT agriculture applications, particularly crop data identification and monitoring. However, there is a significant research gap in the field since no existing study has explicitly incorporated IoT technology to control and improve the quality control procedures related to organic fertilizer manufacturing.

3. Research Methodology

This section overviews traditional methods for controlling and evaluating bio-fertilizer quality. It will then delve into detailed explanations of the conceptual framework, sensor system design, critical functions within the MCU node, smart device user interface, sensor accuracy assessment, and practical implementation within a composting facility.

Fig. 1 The traditional bio-fertilizer production

3.1. The Processes for the Biofertilizers Controlling

Traditional bio-fertilizer production methods combine acidic soil with heavy metals, palm waste, and microbial inoculants [1, 19, 20]. Decomposition typically takes 28 days before the final product is submitted to the Land Development Department. Farmers rely on their experience and informal knowledge to predict humidity levels before adopting the sensor system to monitor biological elements. Unfortunately, even with years of experience, indicating the exact values of NPK remains challenging. Furthermore, when inspected by the Land Development Department, traditional bio-fertilizers frequently fell short of the desired quality. Because of the low quality, the entire procedure must be redone, resulting in a considerable loss of time and effort for the farmer.

3.2. The Design to Install the Sensor into the Composting Plant

5/10 Moo 8, in the Bueng Ba Subdistrict, is the location of the Organic Community Enterprise area. There is a composting facility for making organic fertilizers nearby that the Department of Agriculture built. Palm plantations surround the area. An open building with dimensions of roughly 3 meters in width, 5 meters in depth, and 2 meters in height, this composting facility. Figures 2 and 3 show two oxygen tubes acting as air blowers to aerate and mix the fertilizers below. Due to the relatively massive size of the fertilizer plant. Therefore, the research team intended to install sensors at the five sites where points number 1, 4, and 5 are horizontally aligned in the same plane. Point numbers 1, 2, and 3 are vertically in the same plane represented in Figure 4. Then, take the measured value from the sensor and average it.

3.3. The Creation of a Theoretical Framework

Figure 5 illustrates the conceptual framework comprising sensor nodes and cloud-based data storage through the ThingSpeak platform. The values generated by the sensors are subsequently stored in the cloud, accessible via smart devices from anywhere and at any time. Furthermore, these data will undergo detailed analysis to accurately predict physical and biological variables.

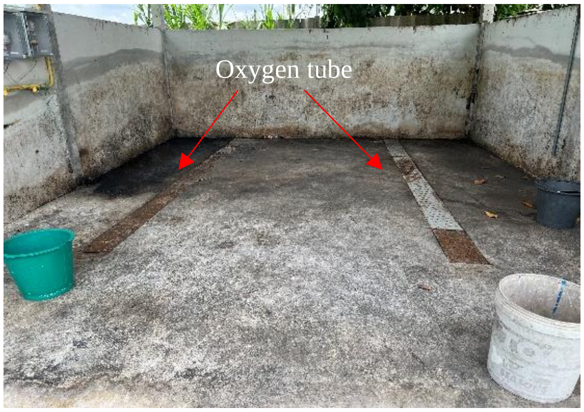


Fig. 2 The environment of the composting plant

Fig. 3 The composting plant with palm waste material

Fig. 4 The five sensor points in the composting plant

3.4. Sensor Node Design and Implementation

The inception of the sensor involved the initial design stage. Figure 6 illustrates the schematic design of the sensor node circuit. In Figure 7(a), a sensor capable of detecting NPK, humidity, temperature, pH, and EC is presented. Figure 7(b) demonstrates the process by which the MCU ESP32 converted and transmitted this data to the cloud (ThingSpeak) via Wi-Fi.

3.5. The Wi-Fi Connection Function

To address the issue of an unstable Wi-Fi signal, we need to implement a Wi-Fi connection function within the MCU ESP32. This function will automatically reestablish the Wi-Fi connection whenever the MCU node loses connectivity, as depicted in Figure 8.

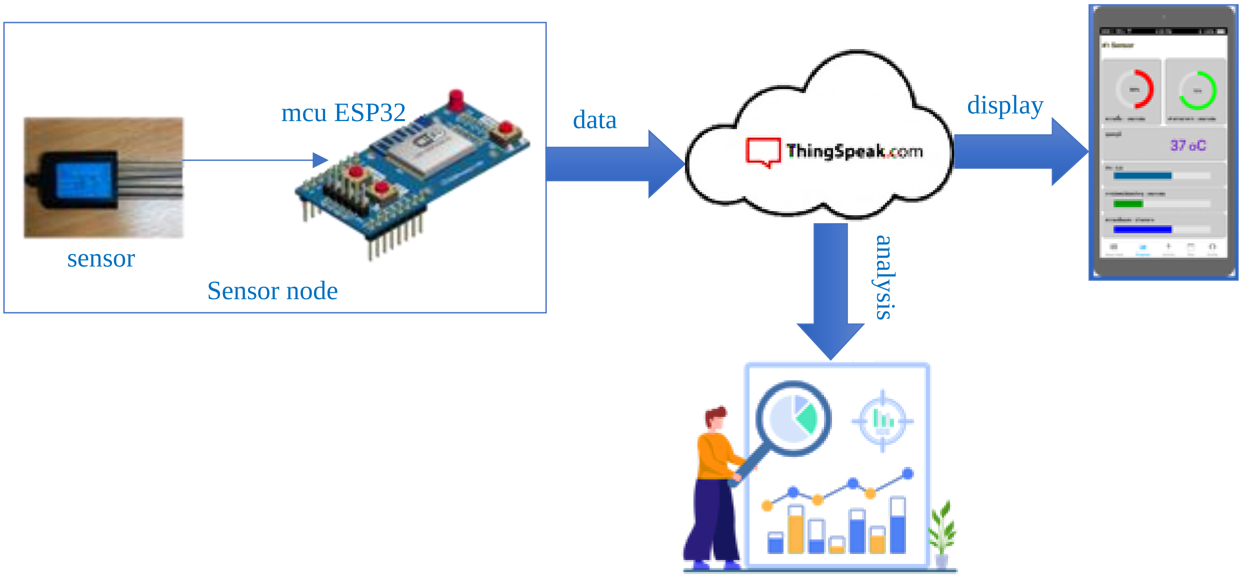


Fig. 5 The conceptual framework

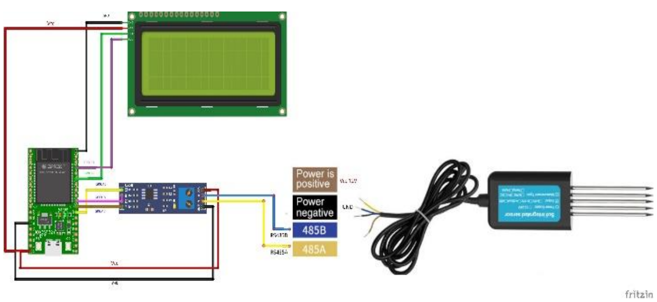
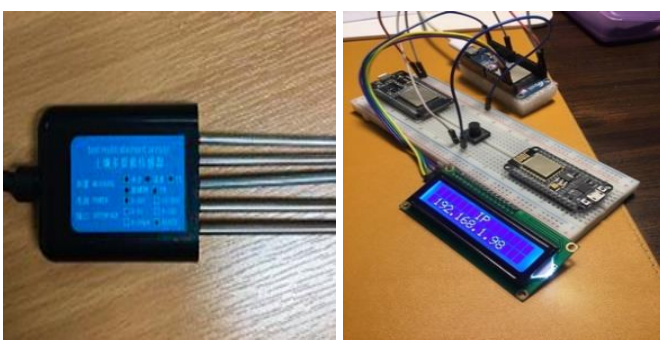


Fig. 6 Sensor node wiring diagram



(a) **(b)**

Fig. 7 Soil sensor (a) and the hardware implementation (b)

```
void loop() {
  unsigned long currentMillis = millis();
  // is configuration portal requested?
  Wifi_Reset_begin();
  if ((WiFi.status() != WL_CONNECTED) && (currentMillis - previousMillis >= interval)) {
    Serial.print(millis());
    Serial.println("Reconnecting to WiFi...");
    WiFi.disconnect();
    WiFi.reconnect();
    Serial.println("IP address: ");
    //ESP.restart();
    Serial.println(WiFi.localIP());
    Serial.println(WiFi.RSSI());

    previousMillis = currentMillis;
  }
```

Fig. 8 The part of Wi-Fi code

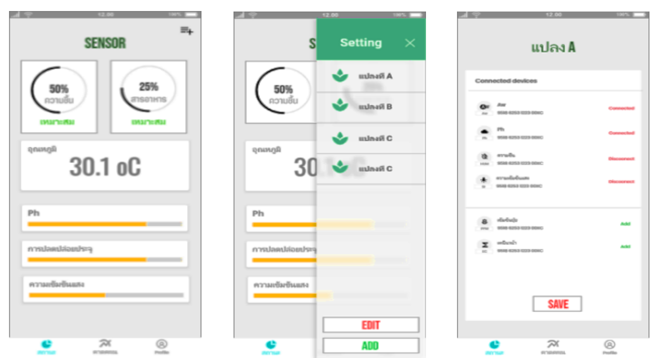


Fig. 9 The UI for smart device

3.6. The Formatting of the Information Presented on Smart Devices

The User Interface (UI) is built on responsive web technology, allowing real-time data visualization and monitoring that is compatible with various devices. This choice simplifies the monitoring of physical and biological variables. To meet the needs of farmers, the data is provided as graphical diagrams and charts, as shown in Figure 9.

3.7. The Sensor Accuracy Evaluation

In a bio-organic fertilizer monitoring system, the accuracy of data recorded by sensors is a crucial parameter. This study assessed accuracy by comparing physical and biological data against standards set by the Department of Land Development.

As reported in the previous study of this work, the sensor observations met all the criteria. Although there is a slight deviation in electrical conductivity from the norm, it falls within a reasonably close range of the standard value and is considered acceptable. As a result, the research team expresses confidence in the precision of the sensor.

4. Results and Discussion

4.1. The Installation of Five Sensor Nodes

Figure 10 depicts the sensor node, seamlessly integrated with an external power source and all pertinent accessories. This holistic assembly has been meticulously designed to function in immediate proximity to real-world conditions, with the added safeguard of a robust metal enclosure akin to those commonly employed in household electrical equipment as consumer units, effectively shielding the weather-sensitive components from environmental influences. All five sensors were installed in the composting plant, as shown in Figure 11. The probe was constructed at a suitable length to minimize signal disruptions, potentially impacting electrical conduction, as shown in Figure 11.

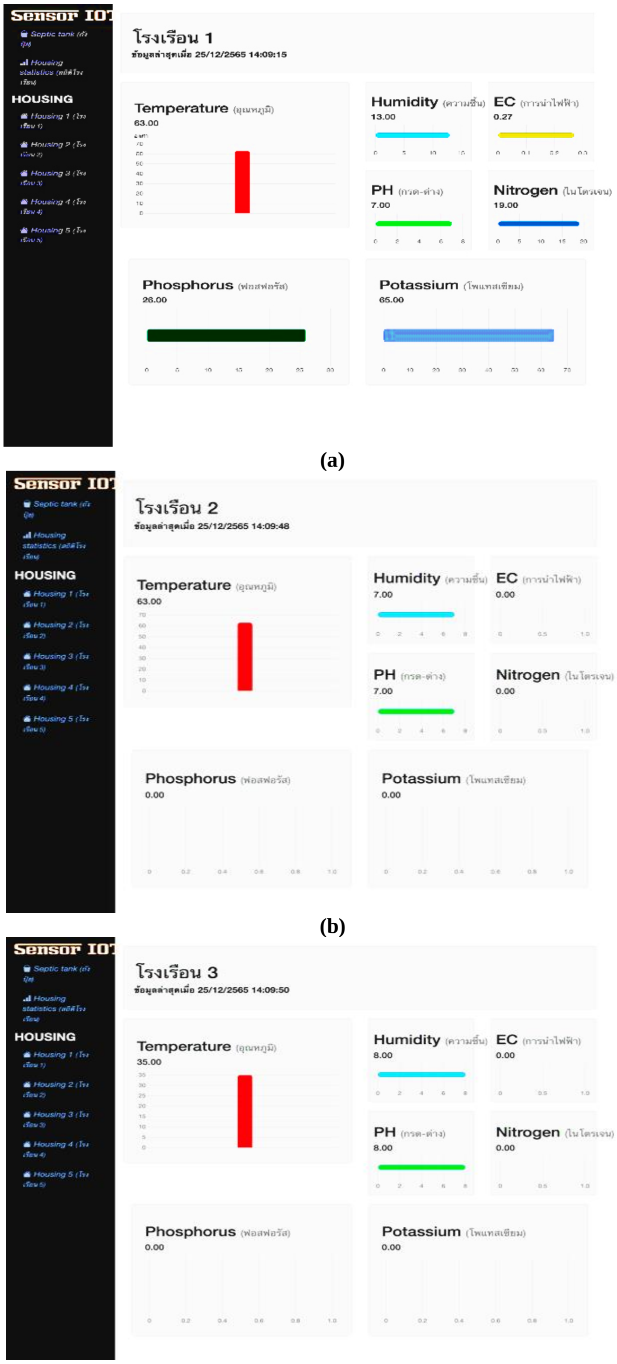
Fig. 10 The sensor node

Fig. 11 The sensor nodes

4.2. The Data Monitoring User Interface

The User Interface (UI) has been designed to be responsive, fitting seamlessly on screens of various mobile devices. The UI is crafted using a combination of color palettes, numerical data visualization, graphs, and status indicators. This enhances user convenience by displaying data in both graphical and alphanumeric formats. Furthermore, as depicted in Figures 12-13 (a-c), users can also access detailed information for each sensor. The graph (Figures 12-13) illustrates temperature varying from 35 to 63 degrees Celsius, humidity ranging from 7% to 13%, electrical conductivity from 0 to 0.27, pH levels between 7 and 8, phosphorus concentrations spanning from 5.2 to 26, potassium levels between 13 and 65, and nitrogen concentrations ranging from 3.8 to 19.

Fig. 12 Monitoring UI for each parameter



(a)

(b)

(c)

Fig. 13 Detailed data for each node

5. Conclusion

A system for controlling and monitoring the Bio-Organic fertilizer excellence, developed from residual palm materials, has been successfully implemented using IoT technology based on the ThingSpeak platform.

Cloud-based data storage facilitates easy access anytime and anywhere via various smart devices. The sensor parameters monitored include NPK, humidity, temperature, pH, and EC. Sensor measurement results are transmitted to the cloud using NodeMCU ESP32.

The collected data is then visualized, forming the basis for comprehensive analysis to ensure the quality of the Bio-Organic fertilizer, considering both physical and biological factors. Creating a prototype sensor system to assess the connection, functionality, data transmission, and measurement of diverse parameters in bioorganic fertilizers is a model for manufacturing sensor units for deployment in bioorganic fertilizer facilities utilizing palm waste.

The measurement accuracy assessment for the sensors yielded an impressive average accuracy rate of 97.77 percent. The system checks the soil nutrient value (N, P, K), pH-alkalinity value, and moisture value. The system can verify and precisely present numerous values by expressing them in graph features and displaying various data for farmers or users to grasp quickly. This application technology may inform farmers immediately about which regions require more watering.

Funding Statement

The National Science, Research and Innovation Fund (NSRF), 2022 (FF code: FRB650070/0168 and Research code: FRB65E0637N.2), Thailand Science Research and Innovation (TSRI), and Rajamangala University of Technology Thanyaburi sponsored and supported this study.

Acknowledgments

The authors want to express our heartfelt appreciation to the Rajamangala University of Thanyaburi for their continuous support and providing of necessary facilities during this research. Their dedication has enabled us to perform this research. The authors are grateful for their important contribution to the project's success.

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