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IoT-based Recording of Waste Types and Weights in Waste Processing System

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Abstract

Effective waste management requires the separation of waste types into categories such as organic, non-organic, and recyclable. This is necessary because not all types of waste can be processed. Therefore, accurate recording of waste types and weights is crucial in waste processing. A common issue today is that waste data is still recorded manually, leading to a lack of accuracy in the records. This research aims to develop an IoT-based waste type recording tool that can accurately record the weight and type of waste by retrieving values from a scale and transmitting the data in real-time to a waste processing system. The device development method used is the prototype model. This research successfully connected to and retrieved values directly from the Sayaki T-18 digital scale, ensuring that the weight values sent to the system are more accurate. During the testing of the developed IoT device, it accurately recorded and transmitted the quantity and type of waste as specified by the user, and the data stored in the system matched the test data accurately.

Keywords: Waste; IoT; Digital Scale; ESP32; PIN; Prototyping.

1. Introduction

Waste is defined as leftover materials no longer in use, discarded from industrial or household production processes (Afuan, Nofiyati, & Umayah, 2021). It can also be described as the byproducts of human activities, comprising both organic and inorganic matter, which require proper management to maintain environmental cleanliness and sustainability. According to Indonesian Law No. 18 of 2008, waste is the solid residue of daily human activities or natural processes (Undang-Undang Republik Indonesia Nomor 18 Tahun 2008 tentang Pengelolaan Sampah, 2008).

Inadequate waste management leads to environmental issues such as flooding, disease outbreaks, reduced sanitation, depletion of soil nutrients, and contributes to global warming (Tamyiz, Hamidah, Widiyanti, & Rahmayanti, 2020). These problems are worsened by limited public awareness and government capacity, as seen in the daily buildup of waste (Gobai, Surya, & Syafri, 2021). With rising populations and advancing technology, effective waste management becomes increasingly important.

Several regions in Indonesia have adopted the 3R (reduce, reuse, recycle) approach to manage waste (Junaidi & Utama, 2023). Proper sorting is key to this strategy, as it identifies waste types suitable for the 3R program (Juliandi, 2023). However, manual data recording often raises concerns over accuracy, and data loss is possible if records are misplaced. To address these challenges, this research utilizes an IoT (Internet of Things)-based system to automatically collect and record waste data from digital scales, sending it directly to an application. Recent advancements in robotics and microcontroller technology offer accurate solutions, optimizing the entire waste management process (Sohor, Mardeni, Irawan, & Sugiati, 2020).

The Internet of Things (IoT) enables physical devices to connect to the internet, facilitating automatic communication and data sharing without direct human involvement (Wilianto & Kurniawan, 2018). This evolution extends the internet's reach beyond computers and smartphones to everyday objects across domains such as smart homes, healthcare, and urban environments (Yudhanto & Azis, 2019). Despite its advantages, IoT presents new challenges, particularly around privacy and data security, given the growing number of interconnected devices (Munawar, Suparman, Rahardja, Umanailo, & Hasugian, 2023). In this study, IoT is used to transmit weight data from digital scales to a system, secured with a Personal Identification Number (PIN).

A Personal Identification Number (PIN) is a commonly used security mechanism for authenticating user access to systems or devices, usually consisting of four to six digits (Akomolafe & Afeni, 2014). Users are advised to create strong, unpredictable PINs to prevent unauthorized access, avoiding personal information or simple sequences (Ludvigsson, Otterblad-Olausson, Pettersson, & Ekbom, 2009; Vaithyasubramanian, 2020).

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The IoT-based waste recording system developed in this study aims to enhance waste management efficiency by integrating digital scales, microcontrollers, and authentication mechanisms. Waste officers use Sayaki T-18 digital scales to weigh waste, with the ESP32 microcontroller capturing weight data via RS232 serial communication. Officers select waste types through a keypad and verify their input using a PIN, after which the system transmits the data to an integrated application via API.

2. Literature Review

2.1 Internet of Things

The Internet of Things (IoT) describes a networked ecosystem where physical objects are embedded with connectivity and computing capabilities, enabling them to autonomously gather, process, and exchange data via the internet. This paradigm bridges the digital and physical worlds, facilitating real-time monitoring, automation, and enhanced decision-making in sectors like smart homes, healthcare, and environmental management (Hossain, Fotouhi, & Hasan, 2015; Xu, He, & Li, 2014).

Recent advancements in wireless sensor networks, miniaturized hardware, and cloud computing have accelerated IoT adoption (Hossain et al., 2015). In waste management, IoT-based systems allow automatic monitoring of waste bin levels and weights, optimizing collection routes and reducing costs (Nur Pasha, Supriyadi, & Hanifatunnisa, 2022). Nevertheless, IoT systems also introduce complexities related to interoperability, scalability, and security (Xu et al., 2014).

2.2 Data Security and PIN

Security remains a major concern in IoT deployments, especially in open and resource-constrained environments. IoT devices are susceptible to various threats, including unauthorized access, eavesdropping, device spoofing, and denial-of-service attacks (Ahanger & Aljumah, 2019). Authentication, such as using a PIN, is a fundamental measure to restrict access and verify user identity. However, simple PINs can be vulnerable to brute-force, social engineering, or observation-based attacks.

Aljumah highlights the importance of combining PIN authentication with encryption, multi-factor authentication, secure key management, and ongoing monitoring to secure IoT systems (Ahanger & Aljumah, 2019). Sicari, Rizzardi, Grieco, and Coen-Porisini (2015) further advocate for lightweight cryptographic methods and adaptive access control suited to constrained devices and dynamic networks. In sum, a layered and context-aware security approach is essential to protect IoT data and services.

2.3 Related Studies

Research has explored diverse IoT implementations for monitoring and automation. For instance, Nur Pasha et al. (2022) developed an IoT-based household waste monitoring system that measures waste weight and volume in real time, issuing alerts when bins approach capacity to avoid overflows. Martins (2023) introduced an IoT-based smart lighting control integrating NodeMCU and light sensors, allowing remote and automatic brightness adjustments via a mobile app, yielding both convenience and energy efficiency.

Moreover, Hossain et al. (2015) reviewed IoT security challenges and recommended a blend of traditional access control (such as PINs), lightweight encryption, and emerging solutions like blockchain-based authentication for robust IoT infrastructures. Collectively, these studies emphasize the need for strong authentication and advanced security to ensure the reliability and safety of IoT systems.

3. Method

This research adopts the prototype model as the development approach. Within the Software Development Life Cycle (SDLC), the prototype model is an iterative process involving repeated cycles of designing, building, testing, and refining a working model of the system (Fowler, 2004; Pressman, 2009). The process starts with initial requirements, which may be incomplete, followed by rapid development of a prototype to showcase core functionalities. Users provide feedback, and the system is refined through further iterations until it meets expectations. The overall prototype paradigm is illustrated in Figure 1.

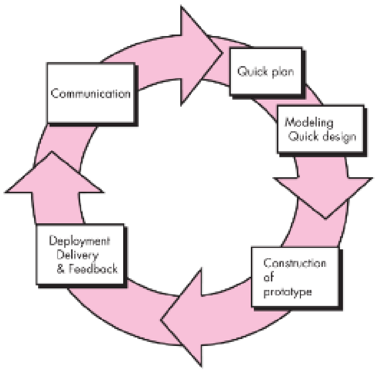

Fig. 1. The Prototype Model Paradigm.

3.1. Communication

In this phase, the research team conducted interviews with stakeholders, specifically residential waste managers, to understand end-user requirements. This ensures that the device design addresses practical needs encountered in the field. The results of these interviews informed the next development steps.

3.2. Quick Plan and Design

Based on the interview findings, a quick planning and initial design phase was carried out, allowing the creation of a preliminary device model, as depicted in Figure 2. This initial model provided the foundation for the construction and further refinement stages.

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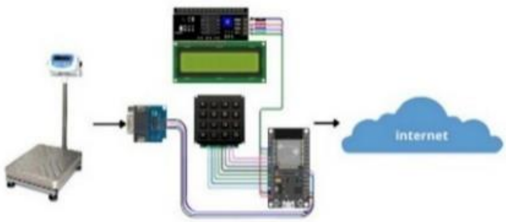

Fig. 2. The Initial Design of an IoT Device.

3.3. Construction of Prototype

The device was then constructed and programmed according to the specified requirements. Adjustments were made based on real field conditions and operational needs, ensuring that the device could effectively address the problems identified during interviews.

3.4. Deployment

During this stage, the prototype was installed and configured in a real-world environment and handed over to the intended users. The deployment process included operational setup, user documentation, and system support. User feedback was gathered to assess the system's functionality, usability, and alignment with user expectations. This input was critical for refining the system in subsequent iterations to produce a user-friendly final product.

4. Result and Discussion

The developed IoT-based recording device was successfully able to transmit weight data from a digital scale and log the type of waste into an integrated web system. However, the device still requires manual input by the operator for weighing, waste type selection, and PIN entry as a security step. The device displays the waste's weight (taken directly from the scale), then prompts the user to select the waste type and enter the PIN before sending data to the server for storage.

4.1. Device Implementation and Program Code

The hardware setup consisted of an ESP32 microcontroller, RS232 to TTL converter, 4x4 keypad matrix, and a 16x2 mini-LCD. All modules were connected according to the wiring diagram shown in Figure 3, with the ESP32 serving as the central controller. The assigned pins are critical, as the program code references only the pins specified for each device. The connection between the RS232 and ESP32 pins is detailed in Table 1.


Fig. 3. Wiring IoT Connection Device.

Table 1. Pin Format from RS232 Pin to ESP32 Pin.

RS232 Pin	ESP32 Pin
VCC	3V3
RX	TX2
TX	RX2
GND	GND

The C program code, as shown in Figure 4, enables the ESP32 to read data from the RS232 module. For example, line 1 imports the SoftwareSerial library to enable serial communication, line 3 sets up the GPIO variables, and lines 10-32 define the function for reading weight data with appropriate conditions and loops. If no data is read, the function returns an empty value.

```
1  #include <SoftwareSerial.h>
2
3  SoftwareSerial timbangan(4, 2);
4
5  const int BUFFER_SIZE = 9;
6  char buf[BUFFER_SIZE];
7  int bufIndex = 0;
8  bool isReading = false;
9
10 String readWeight() {
11   while (timbangan.available()) {
12     char c = timbangan.read();
13     delay(1);
14
15     if (c == '=') {
16       isReading = true;
17       bufIndex = 0;
18     }
19
20     if (isReading && bufIndex < BUFFER_SIZE - 1) {
21       buf[bufIndex++] = c;
22     }
23
24     if (c == '\n' || bufIndex >= BUFFER_SIZE - 1) {
25       buf[bufIndex] = '\0';
26       isReading = false;
27       removeInvalidCharacters(buf, bufIndex);
28       return String(buf);
29     }
30   }
31   return "";
32 }
```

Fig. 4. Example Program Code in the C Language.

4.2. Application Interface for Data Storage Results

All measurement data is stored in a database and displayed via an integrated system interface, accessible in both mobile and web versions. An example of the website interface is presented in Figure 5, which demonstrates how recorded data can be accessed and monitored by users.

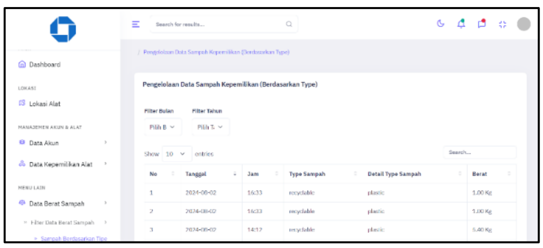
Fig. 5. Example Interface of a Website-based Integrated System.

3.3. Device Testing

Device testing was performed using BlackBox Testing methods, evaluating all developed functions in various scenarios. The results showed a 99% success rate in transmitting and retrieving data. The 1% error rate was due to the scale sometimes requiring more time to obtain precise weight readings, leading to minor discrepancies. However, such incidents were rare.

5. Conclusion

The IoT-based device developed in this study effectively integrates several modules—ESP32, RS232 to TTL converter, keypad matrix, and LCD—to record and transmit weight data from a digital scale to a web-based system. Functional testing using BlackBox Testing demonstrated a high degree of accuracy, with 99% of data sent and received correctly. Although minor delays in weight readings were noted, they did not significantly impact the overall system performance. The solution has been deployed in both web and mobile versions, offering a reliable and integrated data interface for waste management operations.

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