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Development of Warehouse Management System to Manage Warehouse Operations

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Abstract*— The Warehouse Management System (WMS) is software designed to assist in managing and monitoring warehouse processes. The purpose of this research is to improve warehouse operational management by developing a WMS using the Extreme Programming method and implementing a monitoring system to display real-time temperature and humidity measurements. The research addresses issues observed in the warehouse operations of PT. Shippindo Teknologi Logistik (Shipper), a warehouse rental services company. The problems identified in Shipper's warehouse operations largely stem from human errors. Hence, this research aims to provide a viable solution to reduce human errors by implementing various management processes, including inbound and outbound management and tracking, as well as visualizing product placement within the racks using rack maps. Additionally, the integration of a temperature and humidity monitoring system in the warehouse helps monitor the warehouse's condition in real-time. Testing using the black-box method for WMS in this research was successful, demonstrating that the system can execute all functions and display temperature and humidity data as per the designed specifications (inbound, mapping, storage, temperature and humidity monitoring, outbound). The average error in temperature and humidity measurements is relatively low, with 0.9% for temperature and 1.3% for humidity. However, further development is still required to enhance the system for better performance. This includes creating a more robust model for product detection labeling on the storage page to improve label accuracy and developing control systems for advanced temperature and humidity monitoring.

***Keywords*— Warehouse Management System (WMS); Extreme Programming; Monitoring; realtime; blackbox.**

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I. INTRODUCTION

Companies in Indonesia have started implementing various technologies within them as support and complements to their needs, such as inventory management, which can influence the effectiveness of a company's operational activities [1], [2], [3], [4], [5], [6]. Technologically integrated systems should ideally be maximally utilized to help complete tasks, especially as Indonesia experiences increased growth in digital economy and digital competitiveness [7], [8], [9], [10], [11]. PT. Shippindo Teknologi Logistik, also known as Shipper, is one of the companies offering warehouse rental services for storing ready-to-distribute production items. certainly need technology to support their operational activities. Based on the real case provided by Shipper, Excess manpower and time are still required. One of the issues identified is in the process of recording items (inbound, storage, and outbound), which

often occurs due to manual input, resulting in longer processing times and occasional input errors. Furthermore, in the putaway process, manual mapping of stored items is performed by searching for available racks, leading to items piling up at the putaway door, increasing the risk of losses. Lastly, to maintain the quality of goods in the warehouse storage area, monitoring of temperature and humidity is still carried out directly and periodically [12], [13], [14], [15], [16]. These problems give rise to issues that can affect customer satisfaction. Based on the description of the existing problems, Shipper's warehouse has lagged behind in technological advancements over time, resulting in the inability to fully address the existing problems and even causing a decline in success. Therefore, there is a need for an update, including system improvements outlined in the research titled "Warehouse Management System for Managing Warehouse Operations". The objective of this research is to assist in warehouse operational management by developing a Warehouse Management System (WMS) using the Extreme Programming method and implementing a temperature and humidity monitoring system based on the Internet of Things (IoT) integrated into the WMS. This monitoring system is built to assist warehouse's staff to monitoring warehouse temperature and humidity in real-time through the WMS, which can be accessed anytime and anywhere [17], [18], [19]. Temperature and humidity are important factors that can affect the quality of items, The method used to test the WMS is BlackBox Testing by executing system functions, and the results showed that the system successfully received responses for every request sent. While the monitoring system was tested in 2 ways: accuracy testing with 10 measured data samples compared to the HTC-1, resulting in low average error values of 0.9% for temperature and 1.3% for humidity. The second test is to measure the maximum distance of the monitoring tool in reaching WiFi, the result is that the tool can only retrieve data if the distance from the tool to WiFi is a maximum of 66 meters.

II. MATERIALS AND METHOD

Based on several studies on Warehouse Management Systems and Monitoring Systems, there have been previous studies that share similarities with this research. The first one is a research conducted by Fauziah et al. in 2017 with the title *System* Pada PT. Feedmill Indonesia”, Where the issue addressed concerns the large number of items that need to be entered, while the data entry process is done manually, the proposed solution is the design and development of a warehouse management system to support employees in completing warehouse tasks with a waterfall development method [20], [21], [22], [23], [24]. The second similar study to this research is a study conducted by Prasetyo et al. in 2020 with the title “Sistem Pemantauan Suhu dan Kelembaban Ruangan Secara *Real-Time* Berbasis *Web Server*”, This study discusses a solution to address the issue of real-time temperature and humidity monitoring, leading to the development of a monitoring system using DHT11 and ESP8266 [25],[26], [27], [28], [29]. Both of those studies share similarities with this research because they all aim to provide solutions to warehouse-related issues. However, the warehouse problems addressed in the previous studies only covered manual data entry processes and the development of temperature and humidity monitoring devices using DHT11 and ESP8266. This provides an opportunity for the solutions implemented in this research, which involves developing a Warehouse Management System (WMS) using the Extreme Programming method to assist in warehouse operational management, visualizing item mapping on shelves using maps to address manual item mapping. Lastly, an Internet of Things (IoT)-based temperature and humidity monitoring system is developed using DHT22 and ESP32, which is integrated into the WMS, to assist the staff in monitoring warehouse temperature and humidity in real-time, accessible anytime and anywhere. The stages carried out during the research consist of various activities as outlined in Figure 1.

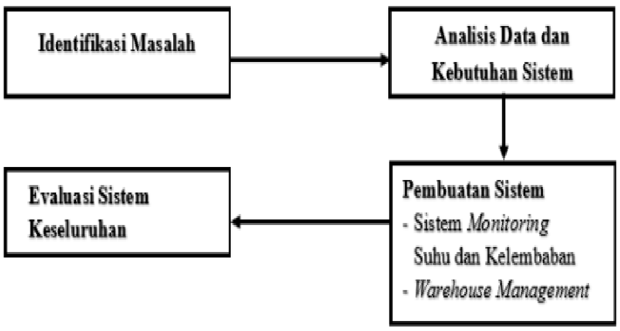

Fig 1. The Steps of Research

Is the stage conducted in this research, starting with the identification process to discover the research theme, data analysis, and system requirements for analysis and processing, including collecting system requirements such as hardware and software. Once all requirements are met, system development can begin, which is divided into two parts: build a temperature and humidity monitoring system with the steps as shown in Figure 2.

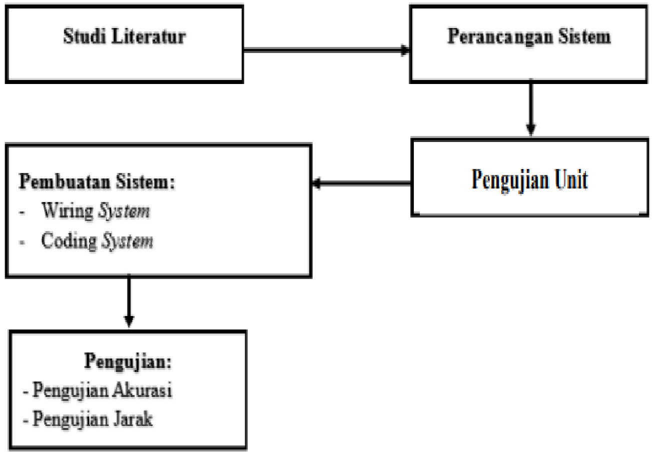

Fig. 2. Steps of Monitoring System Development

While for the development of the warehouse management system, it was develop using the Extreme Programming method with the staeps as shown in Figure 3.

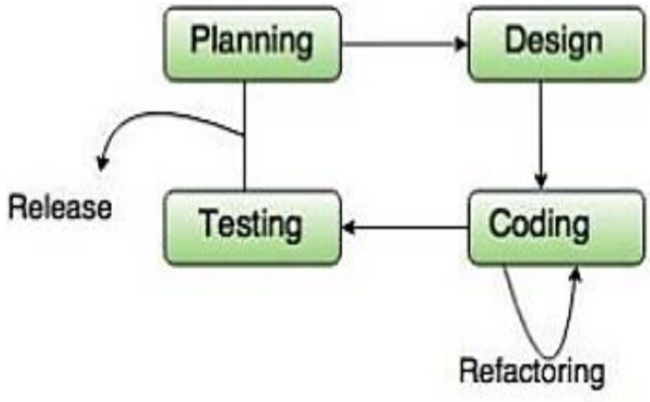

Fig. 3. Steps of WMS Development

The planning process to understand the system's requirements by comprehending the context of the identified issues, design to depict system outputs using Unified Modeling Language, coding to implement the design into the source code, and testing to evaluate the system's performance. The final steps of the research is evaluation, which involves analyzing the overall success of the system development.

III. RESULT AND DISCUSSION

A. *Problem Identification*

This research starts with problem identification, which aims to choose the Warehouse Management System theme, then examine the cause-and-effect that occurs, resulting in several identified problems.

TABLE I
PROBLEM IDENTIFICATION

No	*Research Problem* (*RP*)
1	The high number of logistics companies experiencing failures in managing warehouse systems
2	Insufficient implementation of technology to support warehouse operations.
3	Inaccurate recording of itemss in the warehouse.

TABLE I (CONTINUED ON PAGE 1)
PROBLEM IDENTIFICATION

No	*Research Problem* (*RP*)
4	Lack of human resources to optimize warehouse management systems.
5	The quality of the system that can affect the success of warehouse operations.

So that after identifying the problem, it can be continued with the formulation of the problem to the objectives that will be carried out in this study.

B. *Data Analysis and Requirements*

The information is obtained from supporting data and theories, so several methods are needed, including the following:

1) Interview

To generate data that can be used as references for the development process, such as excessive use of manpower and time, mapping of storage shelves, identifying suboptimal shelves, and challenges in maintaining warehouse conditions.

2) Literature Review

This steps is carried out by reviewing 26 journals from the last five years related to the theme or topic under investigation. For example, the Warehouse Management System, which is widely used to enhance warehousing processes, has room for improvement as most previous studies have certain limitations over time. Therefore, a potential solution to address existing issues is to facilitate customers in inputting items data to reduce excess human resources in warehouse operations. Additionally, visualizing the mapping of items on racks through a rack map and implementing a temperature and humidity monitoring system to assist Shipper in monitoring warehouse temperature and humidity conditions, which can be accessed simultaneously within the Warehouse Management System.

The requirements in this research are divided into two different but interrelated parts. The first is software requirements, such as Arduino IDE 1.8.19, Visual Studio Code 1.61.2, Antares, Postman, and Google Chrome Web Browser. Meanwhile, hardware requirements are listed in Table 2.

TABLE II
HARDWARE REQUIREMENTS

Type	Spesifications
Laptop	*Intel® Core™* i5-3210M CPU @2.50GHz, RAM 4 GB
Smartphone	*Realme* 9.0 (Pie), *Qualcomm®*
Mouse	ROBOT *Wireless*
Printer	HP *Ink Tank* 115
Mikrokontroler	NodeMCU ESP32
Temperature and humidity sensors	DHT22
USB cable	Mikro
Jumper cable	*Female to Male*
LCD Display	Type 16 x 2
BreadBoard	170 nodes
Toolbox	Size X6 (11,5 x 18,5 x 6,5)

C. *System Development*

The first system development is the temperature and humidity monitoring system as follows:

1) Literature Reviews

Collect information and references relevant to the research topic taken, including: information about temperature and humidity monitoring systems focused on ESP32 and DHT22, understanding how to install components to develop a temperature and humidity monitoring system.

2) System Design

Create a block diagram, wiring diagram, and system architecture.

- Block Diagram

  This diagram is used to map the workflow process.

Fig. 4. Block Diagram

In the input section, there is a DHT22 to collect room temperature and humidity data. The ESP32 microcontroller serves as the data processing unit, with the expected output being temperature and humidity data to be sent to the Antares cloud.

- Wiring Diagram

  This design illustrates the relationship between components connected with jumper cables.

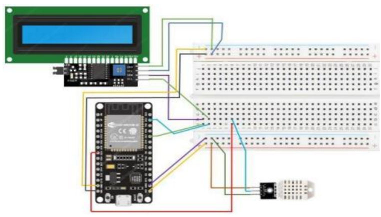

Fig. 5. Wiring Diagram

is a wiring diagram to depict the connection of the DHT22 sensor and LCD to the ESP32 microcontroller using a breadboard to ensure they are interconnected.

- System Architecture

  To depict the components more specifically and in a structured manner.

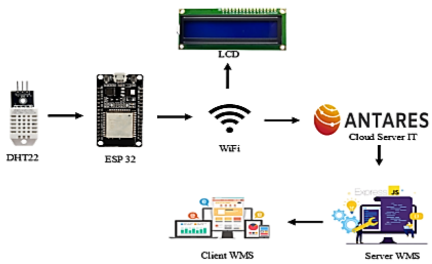

Fig. 6. System Architecture

First, the DHT22 sensor, which measures temperature and humidity, is connected to the ESP32 microcontroller. The ESP32 microcontroller as the brain, is connected to WiFi to transmit data over the internet without human interaction, so the results can be displayed on the LCD screen and the Antares cloud server. Antares is used as a server to store the successfully measured temperature and humidity data. The WMS server is used as a bridge to retrieve data stored in Antares, and the WMS client is used to display real-time data.

3) Unit Testing

It is performed to determine whether the ESP32, DHT22, and LCD can run and be used or not.

- ESP32 Testing

  is performed by wiring the ESP32 through a USB cable to the laptop's USB port for programming.

Fig. 7. Wiring ESP32

After connecting the ESP32 as shown in Figure 7, proceed to run the program as shown in Figure 8.

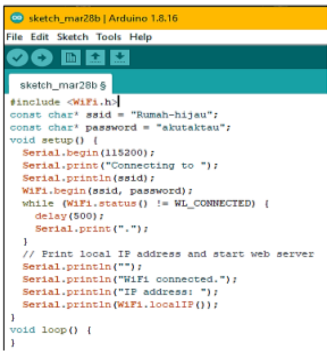

Fig. 8. ESP32 Testing Program

After running the code, it will produce an output as shown in Figure 9.

Fig. 9. Outpu*t* Pengujian ESP32

The output generated displays information about the successful connection of ESP32 to the "Rumah-hijau" WiFi network, indicated by the appearance of the output set in the program in the form of the sentence "WiFi connected," along with the IP Address 192.168.43.32.

- DHT22 Testing

  DHT22 testing is conducted by connecting DHT22 to ESP32.

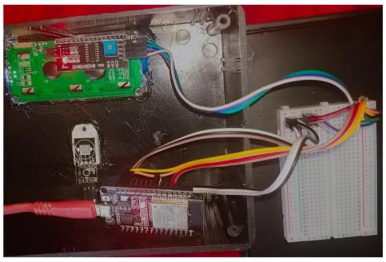

Fig. 10. Wiring DHT22

Wiring of DHT22 is done using Female to Male jumper cables to connect the DHT22 sensor, ESP32, and LCD to the BreadBoard. After the wiring process, coding is performed and executed. After the code execution is completed, the temperature and humidity data will appear on the COM monitor as shown in Figure 11.

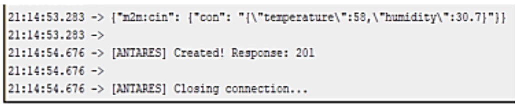

Fig. 11. Output COM

Meanwhile, the output displayed on the LCD as shown in Figure 12.

Fig. 11. Output *LCD*

- LCD Testing

  is conducted by connecting the LCD and BreadBoard using female-to-male jumper cables and then performing the coding.

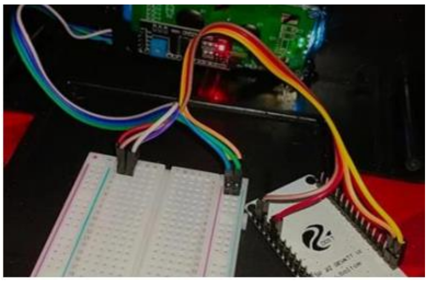

Fig. 12. LCD Testing

The output generated from the LCD testing can be seen in Figure 14.

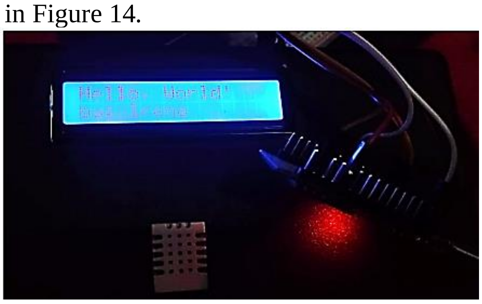

Fig. 13. Output LCD Testing

4) System Development

is the implementation of the designed system, where the implementation is divided into two parts, namely the wiring system and coding using Arduino IDE. First is wiring process using the I2C (Inter-Integrated Circuit) module, by connecting pin D21 to SDA, pin D22 to SCL, pin GND to GND, and finally pin VIN to VCG. As for the wiring of the DHT22 sensor with the ESP32 Microcontroller, connect pin VCC to 3.3V for power supply, pin GND to GND for ground connection, and pin OUT to D25 to receive the output value from the DHT22 sensor.

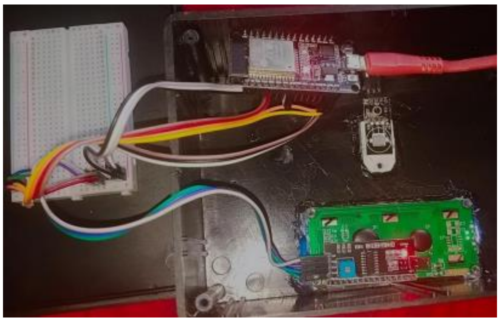

Fig. 14. Wiring Monitoring System

Next is the coding as shown in Figure 16.

```
//untuk pembacaan data suhu & kelembaban
void loop() {
  float hum = dht.readHumidity();
  float temp = dht.readTemperature();
   if (isnan(hum) || isnan(temp)) {
      Serial.println("Gagal!");
      delay(3000);
      return;}
//untuk menampilkan ke lcd
lcd.setCursor(0,0);
lcd.println("T:" + (String)temp);
lcd.setCursor(8,0);
lcd.println("H:" + (String)hum);
lcd.println("H:" + (String)hum);
antares.add("temperature", temp);
// untuk mengirimkan ke antares
antares.add("humidity", hum);
antares.send(projectName, deviceName);
delay(10000);}
```

Fig. 15. Monitoring System Coding

The coding consists of defining variables to store temperature and humidity data. Then, configuring the output to be displayed on the LCD and sent to the Antares cloud.

5) System Testing

is conducted to ensure that the system that has been developed can function and display results as expected. The first test involves displaying temperature and humidity data on the COM monitor, as shown in Figure 17.

```
{"m2m:cin": {"con": "{\"temperature\":27.1,\"humidity\":87.4}"}}

[ANTARES] Created! Response: 201

[ANTARES] Closing connection...

Autoscroll   Show timestamp
```

Fig. 16. Output Monitoring System (COM)

Figure 17 displays data retrieved from the DHT22 measurement, which consists of temperature (27.1) and humidity (87.4) values, similar with Antares in Figure 18.

Data

```
{
  "temperature": 27.1,
  "humidity": 87.4
}
```

Fig. 17. Output Monitoring System (Antares)

Similarly, the output displayed on the LCD can be seen in Figure 19.

Figure 18. Output Monitoring System (LCD)

The System Monitoring test successfully displayed the data sent to Antares and shown on the LCD. However, to ensure the accuracy of the data measured using the DHT22 sensor, the next test was conducted by reading the data under normal, hot, and cold conditions using a comparative device, the HTC-1 Thermometer Hygrometer.

TABLE III
ACCURACY TESTING OF THE MONITORING SYSTEM

Condition	**No.**	**Delay (s)**	**DHT22**		**HTC-1**		**Error (T)**	**Error (H)**
			T (°C)	**H (%)**	**T (°C)**	**H (%)**		
Cold (Freezer)	1	18	13.7	99,9	13,7	99,0	0	0,9
	2	18	13,4	99,9	13,3	99,0	0,7	0,9
	3	59	13,4	99,9	13,2	99,0	1,5	0,9
	4	18	14,2	99,9	14,7	99,0	3,5	0,9
	5	18	14,1	99,9	14,3	99,0	1,4	0,9
	6	18	14,0	99,9	13,9	99,0	0,7	0,9
	7	19	13,8	99,9	13,5	99,0	2,2	0,9
	8	18	13,7	99,9	13,5	99,0	1,5	0,9
	9	24	13,7	99,9	13,4	99,0	0,2	0,9
	10	24	13,6	99,9	13,4	99,0	1,5	0,9
Mean Error							**1,3**	**0,9**
Condition	**No.**	**Delay (s)**	**DHT22**		**HTC-1**		**Error (T)**	**Error (H)**
			T (°C)	**H (%)**	**T (°C)**	**H (%)**		
Normal (Room)	1	18	28,2	92,4	28,2	88,0	0	0,5
	2	17	28,1	91,9	28,0	92,0	0,4	0,1
	3	18	28,2	93,1	28,1	92,0	0,3	1,2
	4	18	28,3	92,5	28,5	92,0	0,7	0,5
	5	17	28,3	91,7	28,9	91,0	0,2	0,8
	6	19	28,3	92,0	28,4	91,0	0,7	1,1
	7	17	28,2	91,4	28,3	90,0	0,3	1,5
	8	19	28,3	91,4	28,2	90,0	0,1	1,6
	9	17	28,2	91,4	28,1	89,0	0,4	2,6
	10	36	28,2	91,2	28,0	89,0	0,7	2,4

Condition	No.	Delay (s)	DHT22 T (°C)	DHT22 H (%)	HTC-1 T (°C)	HTC-1 H (%)	Error (T)	Error (H)
Mean Error							**0,4**	**1,2**
Panas (Lilin)	1	12	29,5	89,1	29,7	85,0	0,7	4,6
	2	19	29,6	88,7	29,9	88,0	0,1	0,8
	3	18	29,9	88,2	30,1	88,0	0,7	0,2
	4	19	29,9	87,9	30,1	88,0	0,7	0,1
	5	20	30,0	87,5	30,3	88,0	1,0	0,9
	6	18	30,2	87,2	30,3	88,0	0,3	0,9
	7	19	30,4	87,3	30,4	88,0	0,3	0,8
	8	18	29,3	95,4	30,5	89,3	4,0	6,4
	9	18	30,9	90,1	30,8	90,3	0,3	0,2
	10	19	30,9	88,0	31,1	90,0	2,5	2,2
Mean Error							**1,1**	**1,7**

The error results listed in Table 3 are calculated using the error formula [30].

$$\%\text{Error} = \left|\frac{x_1 - x}{x}\right| x\ 100\%$$

Explanation:
x = Actual instrument reading (true value).
x_1= Measured value (value from the prototype).
To calculate the mean error, use the formula (Sumber: https://www.rumusstatistik.com/):

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Explanation:
$\underline{x}$ = Mean values.
x_i = Sample value.
n = Number of Sample.

Based on the testing in Table 3, the overall mean error obtained is relatively low, around 0.9% for temperature and 1.3% for humidity. The final test is conducted to determine the maximum distance of the temperature and humidity measuring system from the WiFi connection.

TABLE IV
DISTANCE TESTING OF THE MONITORING SYSTEM

Jarak	Waktu	Delay (s)	DHT22 T (°C)	DHT22 H (%)	Status
0 – 5	24/02/2023 13:17:34	10	30,9	90,1	Berhasil
5 – 10	24/02/2023 13:19:45	20	30,5	81,3	Berhasil
10 – 15	24/02/2023 13:22:21	18	30,1	83,8	Berhasil
15 – 20	24/02/2023 13:24:25	55	29,9	82,2	Berhasil
20 – 25	24/02/2023 13:25:07	18	29,9	83,2	Berhasil
25 – 30	24/02/2023 13:26:30	19	29,8	85,7	Berhasil
30 – 35	24/02/2023 13:28:21	19	29,7	86,7	Berhasil
35 – 40	2023/02/24 15:43:54	24	27,9	83,7	Berhasil
40 – 45	24/02/2023 15:49:40	27	28,1	87,3	Berhasil
45 – 50	24/02/2023 15:52:28	24	28,3	89,8	Berhasil
50 – 55	24/02/2023 15:53:03	65	28,3	94,2	Berhasil
55 – 60	24/02/2023 15:57:15	92	28,6	89,7	Berhasil
60 – 65	24/02/2023 15:58:11	18	28,6	84,3	Berhasil
65 – 66	24/02/2023 15:59:43	18	28,5	85,4	Berhasil
66 – 70	-	-	-	-	Gagal

Based on the distance testing, the system can only reach WiFi up to a distance of 66 meters.

The second system development is Warehouse Management System as the core system to manage the warehouse.

1) *Planning*

To understand the information obtained through interviews and literature studies, this information is used to create user stories that will describe the system's output features.

TABLE V
SYSTEM FUNCTIONAL REQUIREMENTS

No	Feature	Explanation
1	Login Page	To validate user access rights, this function is essential to gain access to database modifications..
2	Home Page	For the first page after the login process.
3	Halaman *Scanner*	To manage items in the warehouse, it contains several buttons for managing the items in and out processes.
4	Warehouse Page	For warehouse mapping, it includes various types of racks, descriptions of items on the racks, and temperature and humidity monitoring.
5	Items Page	To manage the list of incoming and outgoing goods.
6	Validation Page	To perform a check on incoming goods against the input data.
7	Profile Page	For account information and the logout feature from the system.
8	Registration Page	To register a customer account in order to access all features in the customer system.
9	Storage Page	To manage items that will be stored, including filling, modifying, and printing QR-Codes.
10	Pickup Page	To send out items from the warehouse.

2) Design

This steps consists of designing the system using Unified Modeling Language (UML), which is used to provide an overview of the Warehouse Management System. The first design is the use case diagram for customers and administrators, which is used to display interactions between the system through use cases with actors (customers and administrators). This design shown in Figure 20.

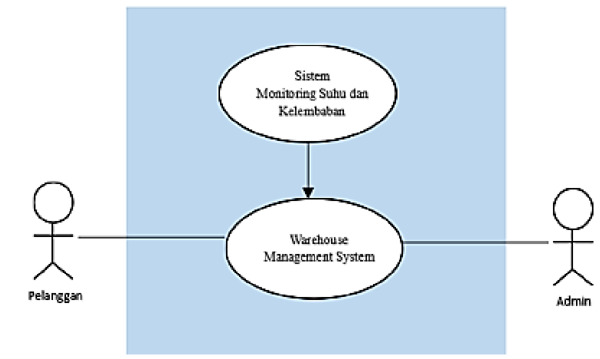

Fig 19. Use Case Diagram

This diagram depicts the relationship between WMS use cases and the Monitoring System with actors. Next is the design of the class diagram as shown in Figure 21.

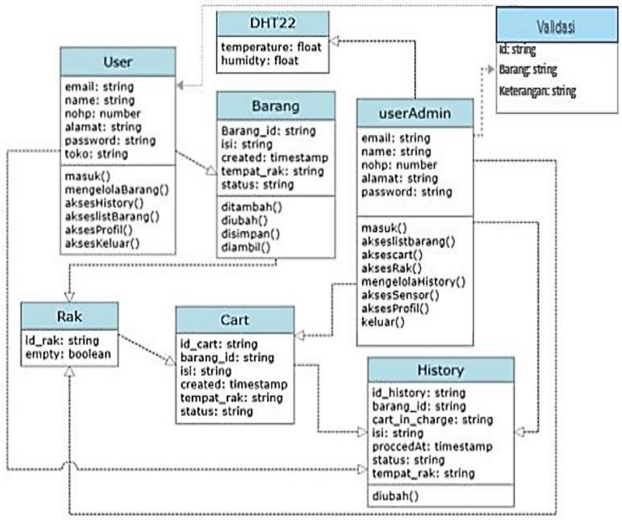

Fig. 20. Class Diagram

is used to illustrate the classes used in the development of the Warehouse Management System, where the depicted classes consist of 8 classes, each of which has attributes and functions or operations. The classes include user, DHT22, validation, item, history, userAdmin, cart, and rack.

After design using Unified Modeling Language, the next step is interface design. Here is one of the interface designs created to provide an overview of the warehouse page.

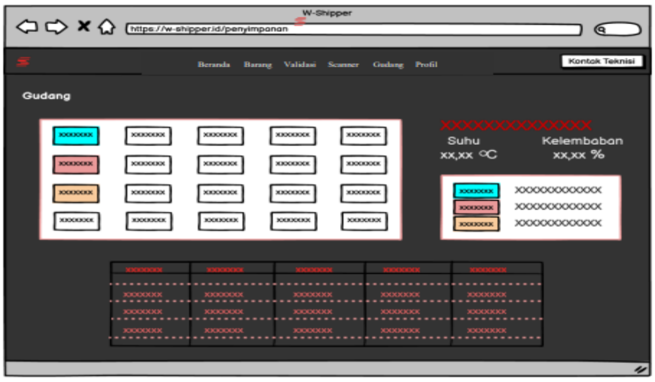

Fig. 21. User Interface

User interface design for the warehouse page in the admin system. It contains a shelf map with shelf color descriptions, room conditions based on temperature and humidity, and a table of data for items in the shelves.

3) Coding

Is part of implement the system design using code. The programming languages used are JavaScript and JavaScript React. Figure 23 is a snippet of code used to create a shelf map on the warehouse page.

```
fetch(`${process.env.REACT_APP_API_ENDPOINT}/produc
t?id_cart=cart-1`, requestOptions)
 .then((response) => response.json())
 .then((result) => {
 if (result.status === 200){let cssList="w-full";
 let dataList = result.body.data.map((val, key) =>
 {cssList += ` ${val.status}-${val.tempat_rak}`;
   return (<tr key={key} className="border-b
 border-gray-400"><td className="p-4 text-sm
 sm:text-lg text-neutral-400">{val.tempat_rak}</td>
 <td className="p-4 text-sm sm:text-lg text-
 neutral-400">{val.barang_id}</td><td className="p-
 4 text-sm sm:text-lg text-neutral-
 400">{val.isi}</td></tr>
 );
```

Fig. 22. Snippet of warehouse page code

This code for sending requests to the server to display rack status and codes, which will be visualized on the rack map. You can view the output in Figure 24.

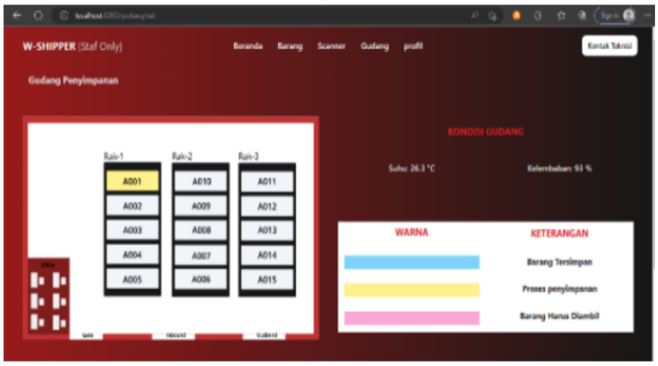

Fig. 23. Output Warehouse Page

4) Testing

This steps is carried out to identify errors or shortcomings and to assess the system's compliance with the design. The testing method used is black-box testing:

TABLE VI
BLACKBOX TESTING

No	Test Items	Scenario	Result
1	[P] Register	Registering an account	successful
2	[P] Log in	Data validation	successful
3	[P] Storage of items	Adding product data	successful
4	[P] Status	Tracking item data in the warehouse	successful
5	[P] Pickup	Requesting item pickup	successful
6	[P] Profile & Log out	Displaying account information and logging out of the system	successful
7	[A] Log in	Data Validation	successful
8	[A] Items	Displaying incoming and outgoing item data	successful
9	[A] Validation	Validating new item data	successful
10	[A] *Scanner*	Scanning QR-Code and selecting an action	successful
11	[A] Warehouse	Displaying a list of items in the shelves and room temperature-humidity	successful
12	[A] Profile & Log out	Displaying account information and logging out of the system	successful

Based on the results of the blackbox testing conducted, it can be concluded that each process flow within the WMS is in line with the design, and functionally, it can be used according to the intended flow. Therefore, it can be considered a good solution for the previously mentioned issues.

D. *Overall System Evaluation*

The test results indicate that the features in the Warehouse Management System can function as designed, generating responses to each request. Meanwhile, the integrated monitoring system in the WMS successfully displays real-time temperature and humidity values from the DHT22 sensor. This allows monitors to quickly address temperature and humidity changes.

The temperature and humidity monitoring system testing was also successful, shown relatively low error values of less than 5%. This testing involved taking 10 data samples and comparing them with a thermometer hygrometer HTC-1. The results showed an overall mean error of 0.9% for temperature and 1.3% for humidity. Additionally, the testing of the system's connectivity range to WiFi revealed a range of 66 meters.

However, there are still some limitations in detecting the types of items to be stored, particularly in labeling. This attribute use COCoSSD model, which categorizes items based on data from the COCO dataset, but potentially result in inaccurate categorization.

IV. CONCLUSION

This research has the potential to improve warehouse operational management with features provided by the Warehouse Management System (WMS). These features include item registration by customers, validation of incoming item data, and automated rack mapping to reduce input errors leading to discrepancies. The system assists administrators in efficiently mapping items within racks, saving time and labor in warehouse management processes, and reducing the risk of lost items during periods of high inventory density. Blackbox testing has shown that the WMS features perform well, although there are limitations in item type detection. Additionally, the integration of a room temperature and humidity monitoring system into the WMS provides real-time data, ensuring that the warehouse conditions meet established standards.

In Addition, the measurement tool created for monitoring room temperature and humidity using the DHT22 sensor and ESP32 microcontroller demonstrates a high level of accuracy, as indicated by the low mean errors (0.9% for temperature and 1.3% for humidity) and a maximum monitoring range of 66 meters to WiFi. However, the system in this research still has limitations and requires further development for improvement. Two recommended areas for development that could have a significant impact on the system are implementing more advanced modeling for the item detection labeling process on the storage page to improve label accuracy and further develop the control system as a next step in automating temperature and humidity monitoring.

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