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IoT-based inventory monitoring system for SMEs

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ABSTRACT

Industry 4.0's pervasive digital ideas have completely changed how businesses operate. A lot of big businesses have switched to digital systems. However, due to a lack of funding and digital infrastructure, SME sector digitalization issues still exist. Inventory management is one of the many manual methods that many SMEs still have to rely on, which makes it prone to error. To manage inventories more accurately and effectively, manual systems must be changed. The goal of this project is to improve inventory management efficiency by creating a dependable and affordable automated system. A cloud database is connected to the system to provide quick inventory monitoring on warehouse shelves. Prototyping and statistical testing are used in the study technique to evaluate the system's dependability. Using an Internet of Things-based single-board computer, the research creates an inventory monitoring system. With a daily implementation cost of IDR 642.92, the system is deemed cost-effective based on inventory monitoring results on warehouse shelves. Because the system's performance reached a Cronbach's alpha value greater than 0.8, the inventory management system used in the study is regarded as dependable for application in real-world systems to increase inventory management accuracy.

Keywords: Digital transformation; SMEs; IoT; sensor; inventory monitoring

1. INTRODUCTION

Many different areas are significantly impacted by technological advancements. This transforms how companies operate in the era of Industry 4.0 [1]. This second phase of the industrial revolution is identified by the rise of intelligent technologies including robotics, big data, e-commerce, and e-marketing. The idea of digital transformation, which entails substantial adjustments to job descriptions, work procedures, and product offers as a result of incorporating digital technology into an organization's or business's operational environment, is central to Industry 4.0 [2]. Ninety percent of large businesses now use digital frameworks instead of manual, outdated procedures. In comparison, the majority of Small and Medium Enterprises (SMEs) in the industry still rely on analog use [3]. An essential part of Indonesia's economic structure is played by SMEs. SMEs can increase community welfare and account for a sizeable portion of the nation's financial independence. Because SMEs account for 60.4% of all investments made in the nation, it is imperative to address their position in the economy. But just about 13% of Indonesian SMEs have embraced digitalization because of obstacles like poor infrastructure, exorbitant expenses, and a lack of knowledge about technology [3].

SMEs must manage their inventories well if they want to optimize profits and maintain efficient operations. However, a lot of SMEs rely on antiquated manual methods and require assistance in developing effective inventory management procedures [4]. This method could be more ineffective and prone to mistakes and inaccuracy. making it challenging to maintain inventory properly, track available inventory, and locate missing products [5]. For instance, inconsistencies between inventory data and the actual quantity of goods and mistakes in inventory accumulation at the warehouse. Customer happiness and operational sustainability may be impacted by these inefficiencies.

Technologies and methods that enable automated and cost-effective inventory tracking are desperately needed in response to these issues, as well as in keeping with ongoing technical advancements and digital transformation. Single-board computers (SBCs) are a powerful and reasonably priced computing solution that can completely transform SMEs' inventory management [6]. An SBC is a printed circuit board (PCB) computer that has a CPU, memory, input/output, and additional functionality [6]. Conventional warehouses may be able to leverage digital transformation in this way. The sensors required for warehousing can also be integrated by SBC. SMEs can strengthen their competitive edge against rivals in the digital market by leveraging SBC. The foundation for creating a warehouse management system specifically for SMEs is SBC technology. According to the Internet of Things (IoT) idea, digital devices can transmit and receive data via an internet network without requiring direct communication between computers or people [7].

Technologies like RFID have been investigated for real-time inventory tracking in the context of inventory management to increase the efficacy and efficiency of warehouse management in the manufacturing sector [8]. According to the study, inventory control efficiency can be increased by 69% with RFID-based inventory monitoring. Nevertheless, RFID has drawbacks because of its extremely expensive cost, and the sensor range still needs to be increased [9]. As a result, further research has produced an inventive way to facilitate inventory monitoring: the employment of single-board microcontrollers in conjunction with chatbots and ultrasonic sensors. Prior studies were typically restricted to small-scale inventory detection and calculation, necessitating the integration of systems with broadly accessible databases [10] [11].

This research was done to design an affordable inventory management system that can improve inventory calculations' accuracy to overcome the shortcomings of earlier studies. IoT-based SBC along with a cloud database is used in the design of this system. Real-time synchronization of inventory-related data is possible through the interaction of the cloud database and IoT system. The precision of inventory tracking is improved by this interaction. This strategy builds on the substantial advancement of IoT as a pivotal technology in the Industry 4.0 revolution for more effective automation across a range of industries, including SMEs [4] [12]. Consequently, this technology streamlines inventory management and enhances data analysis.

2. METHODS

The procedures for creating an SBC-based IoT-based inventory management system for SMEs are covered in this section. The methodology used in this study is predicated on an examination of the inventory management requirements of SMEs and the integration of cutting-edge technology to deliver effective and suitable solutions. These actions are anticipated to have a major impact on the body of knowledge and application of inventory management in the context of Industry 4.0, particularly for SMEs that are embracing digitalization.

Design software and hardware

To generate data, we create software for an inventory monitoring system. The use of SBC was taken into consideration when developing the software idea. The program makes it easier to code ultrasonic sensors, load cells, LCDs, and LEDs by utilizing the microcontroller development IDE. An essential component of the SBC, which serves as the primary controller and is thought to be more effective than a computer, is the microcontroller [13]. A microcontroller called Arduino is used in this study. Because of its inexpensive cost, Arduino, an open-source microcontroller, was selected as a microcontroller. It might be a cost-effective way to assist SMEs in using digital technology [14]. **Figure 1** demonstrates the research's workflow.

When ultrasonic sensors are implemented, ultrasonic waves are sent out and their reflection time from an item is measured. This yields information about the object's distance. Information about inventories will be generated from distance data [11]. The use of ultrasonic sensors is constrained, though, as it can only read a stack in the same direction as the sensor [15]. As a result, the data collected by the sensors only occasionally represents the true situation on the shelves if the goods are stacked unevenly. We used load cells to get around this restriction. a mechanically operated scale sensor that applies the pressure principle. A strain gauge is used by this sensor as the detection element [16]. The system can read inventory data according to actual conditions even if a pile is not in the path of the

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ultrasonic sensor since it is equipped with load cells and sensors that provide information on object weight.

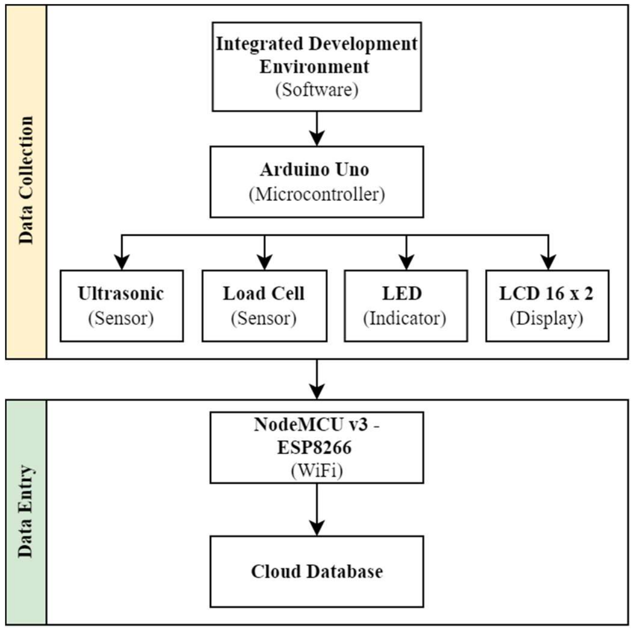


Figure 1. SME warehouse management system workflow

When making decisions in inventory management, the most trustworthy data is given priority when employing load cells and ultrasonic sensors. Consider the following scenario: data from the load cell sensor indicates that the goods' weight has exceeded the maximum limit, yet data from the ultrasonic sensor indicates that there is still open space on the shelf. In that scenario, as item weight data is typically more precise in estimating shelf capacity, the system will give the load cell sensor's data priority. To guarantee the consistency and correctness of the inventory information provided by the system, the final choice will be made on the data judged more credible, even if the data from both sensors are inconsistent.

This device uses LED and LCD to give a visual indication of the current state of shelf availability. The red LED will turn on when the shelf is filled. The yellow LED will turn on in the 80%–60% capacity range, and the green LED will turn on in the 40% capacity range–0%. In the meanwhile, inventory data from load cells, ultrasonic sensors, and inventories will be shown on the LCD. NodeMCU gathers and stores inventory data, which is then analyzed and transferred over the internet (WiFi) to a cloud database. **Figure 2** displays the hardware's architecture.

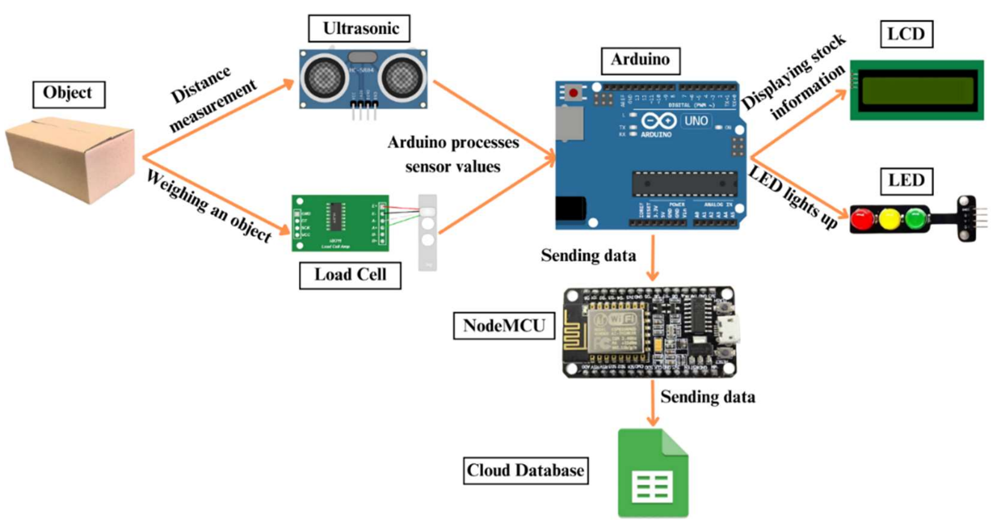


Figure 2. Hardware architecture

Design Prototype

Prototyping is used in this study to evaluate product inventory tracking systems. One method that is frequently used in system development is prototyping, which facilitates system modeling [17]. The prototype construction was selected to give a precise depiction of the shape and design for purposes of research [18]. Industry standards are followed in the selection of materials and the assembly of components. After that, a functional test is run to confirm functionality. The prototype is shown in **Figure 3** arranged on 17 x 9 x 6 cm warehouse shelves. The measurements were chosen using the products that are typically kept on SME shelves.

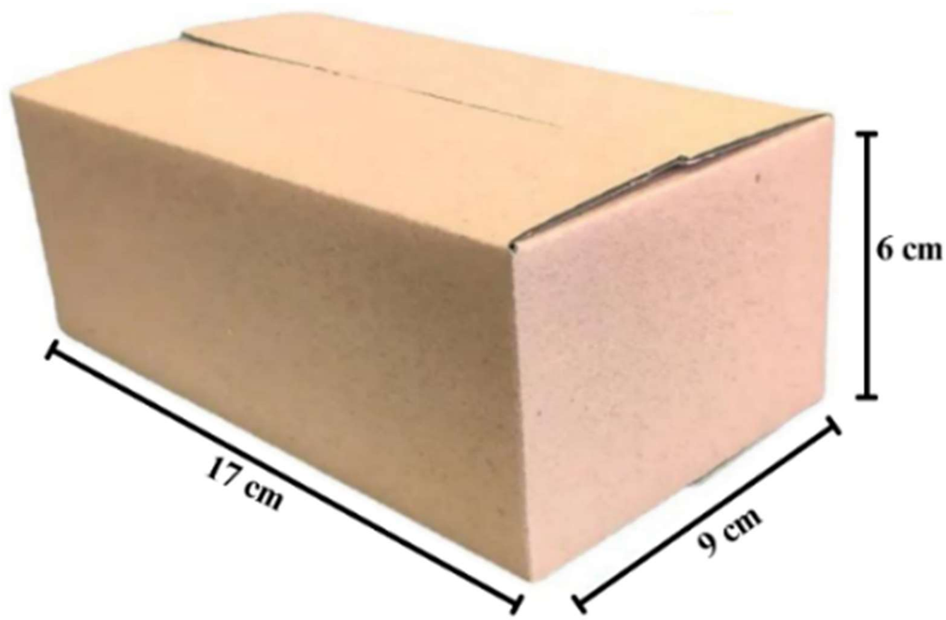


Figure 3. Experimental object

The hardware is organized on 115 x 47 x 41 cm storage shelves, which were selected based on typical SMEs' shelf size. The hardware layout is displayed in **Figure 4.** For every shelf, there are two sets of systems in use. This was due to the assumption that both systems would be sufficient and pertinent to accomplish the goals of the research.

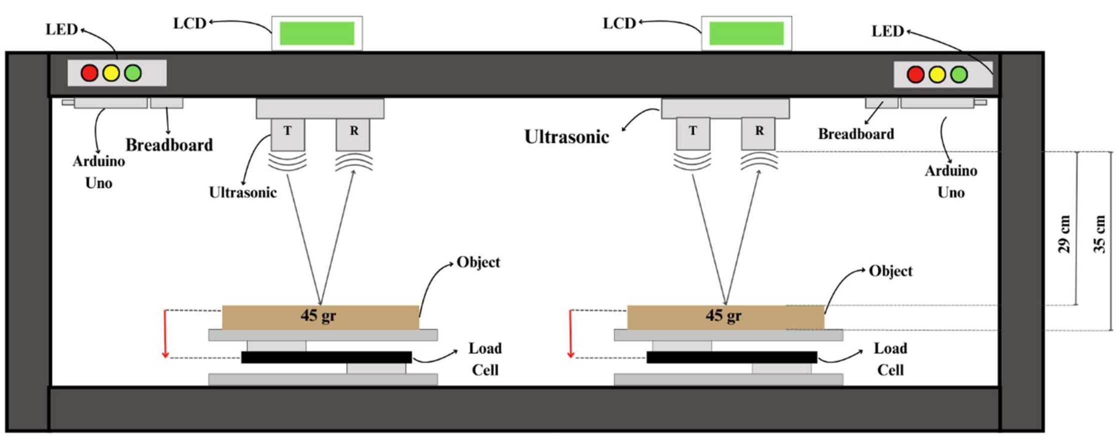


Figure 4. Hardware design on warehouse shelf

Experimental design

To evaluate the capabilities of the Internet of Things-based inventory management system, system testing was done. System performance will be monitored and measured using the data gathered during system testing. The requirements for this prototype's success are:

a) The system needs to turn weight data (gr) from load cells and distance data (cm) from the ultrasonic sensor into inventory data.
b) LCD can display data and inventory statuses read by ultrasonic sensors and load cells.
c) The system must be able to activate LED colors to indicate shelf capacity availability.
d) The system must be able to send data on time, date, inventory, and inventory status in the cloud database.

During system testing, a deviation of roughly 2 cm and 2 grams from the actual dimensions is taken into account. To account for any uncertainties or inaccuracies that may arise during system testing, this tolerance calculation was made. The system architecture is implemented before testing, as shown in Figure 5.

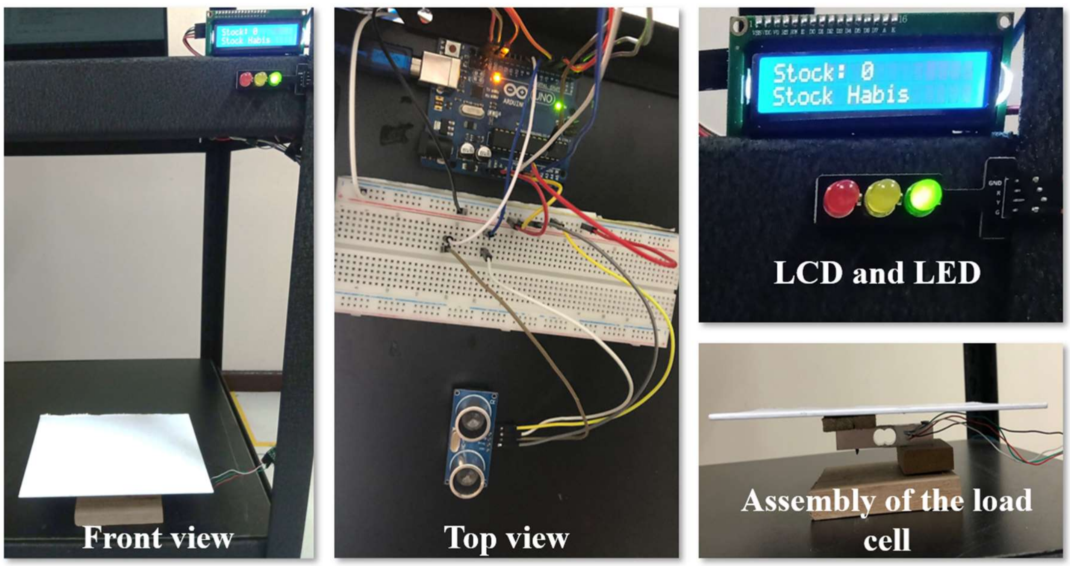


Figure 5. System design warehouse shelf

Data analysis

The procedure used in this study to gather data was placing each product on the shelf one at a time, after which the software IDE showed the weight and distance that the sensor had detected. A reliability test is then used to assess the test results to determine how dependable the measuring device is. When the study yields consistent results over a range of periods, it might be considered reliable [19]. Using SPSS Cronbach's Alpha (Kappa) for reliability testing, the test results were categorized into six groups according to Landis and Koch's recommendations, which are as follows: Kappa value less than zero indicates poor agreement, Kappa 0–0.2 indicates weak agreement, Kappa 0.21–0.4 indicates good agreement, Kappa 0.41–0.6 indicates moderate agreement, Kappa 0.61–0.8 indicates substantial agreement, and Kappa value more than 0.8 indicates complete agreement.

Cost analysis

The process of cost analysis involves figuring out the entire production costs, which include both fixed and variable expenses. The straight-line method is used in this study to calculate the fixed costs associated with equipment depreciation. As in equation (1), capital interest is not taken into account in this computation [20]. The ultimate price (S) in depreciation computations is assumed to be 1% of the equipment price.

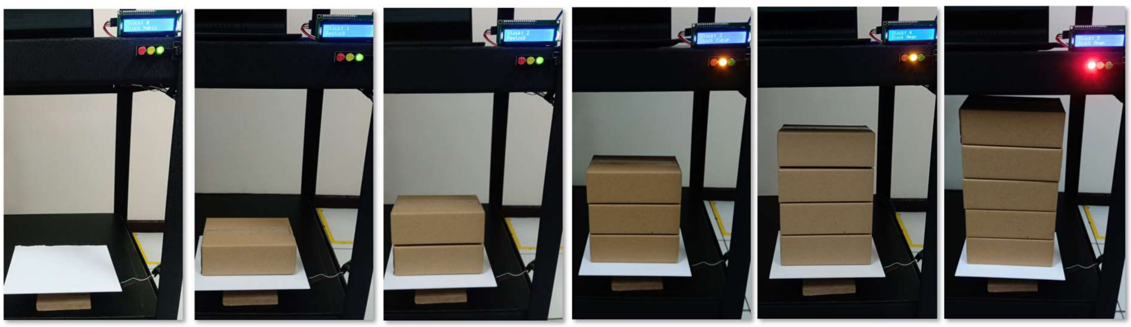
$$D = \frac{(P - S)}{L} \quad (1)$$

With,
D : Annual depreciation costs (IDR/day)
P : Present value (IDR)

S : Saving value (IDR)
L : Estimated economic life (days)

3. RESULTS AND DISCUSSION

Thirty iterations of system testing involved placing and rearranging items one by one on the product's shelf. The system is shown in Figure 6 during testing. It has an LCD that indicates the inventory quantity based on weight and distance measured by load cells and ultrasonic sensors, as well as LED lights that change color based on-shelf availability.



Stock = 0 **Stock = 1** **Stock = 2** **Stock = 3** **Stock = 4** **Stock = 5**

Figure 6. Showing different inventory states

Any inventory data that is recorded and read will be sent to the cloud database via nodeMCU by displaying time, date, inventory, and inventory status as shown in Figure 7.

1	Time	Date	Inventory	Status	1	Time	Date	Inventory	Status
2	17:01:19	02/03/2024	0	Stock Out	20	17:01:37	02/03/2024	3	Adequate Stock
3	17:01:20	02/03/2024	0	Stock Out	21	17:01:38	02/03/2024	4	Adequate Stock
4	17:01:21	02/03/2024	0	Stock Out	22	17:01:39	02/03/2024	4	Adequate Stock
5	17:01:22	02/03/2024	0	Stock Out	23	17:01:40	02/03/2024	4	Adequate Stock
6	17:01:23	02/03/2024	1	Restock	24	17:01:41	02/03/2024	4	Adequate Stock
7	17:01:24	02/03/2024	1	Restock	25	17:01:42	02/03/2024	5	Adequate Stock
8	17:01:25	02/03/2024	1	Restock	26	17:01:43	02/03/2024	5	Adequate Stock
9	17:01:26	02/03/2024	1	Restock	27	17:01:44	02/03/2024	5	Adequate Stock
10	17:01:27	02/03/2024	1	Restock	28	17:01:45	02/03/2024	4	Adequate Stock
11	17:01:28	02/03/2024	1	Restock	29	17:01:46	02/03/2024	4	Adequate Stock
12	17:01:29	02/03/2024	2	Restock	30	17:01:47	02/03/2024	4	Adequate Stock
13	17:01:30	02/03/2024	2	Restock	31	17:01:48	02/03/2024	4	Adequate Stock
14	17:01:31	02/03/2024	2	Restock	32	17:01:49	02/03/2024	3	Adequate Stock
15	17:01:32	02/03/2024	3	Adequate Stock	33	17:01:50	02/03/2024	3	Adequate Stock
16	17:01:33	02/03/2024	3	Adequate Stock	34	17:01:51	02/03/2024	3	Adequate Stock
17	17:01:34	02/03/2024	3	Adequate Stock	35	17:01:52	02/03/2024	3	Adequate Stock
18	17:01:35	02/03/2024	3	Adequate Stock	36	17:01:53	02/03/2024	2	Restock
19	17:01:36	02/03/2024	3	Adequate Stock	37	17:01:54	02/03/2024	2	Restock

Figure 7. Data on cloud database

The system translated load cells' weight and ultrasonic distance data into inventory data based on thirty cycles of system testing. The system successfully transmits data to the cloud database, the LCD can show inventory data and status, and the LED color is active based on the amount of shelf space available. The weight and distance that each sensor read during system testing were gathered. After processing, a line graph is created using the distance and weight measurement data. The ultrasonic sensor reads distance data (in centimeters) as shown in

Figure 8. The test iterations are displayed on the X-axis; each test iteration consists of six distance measurements based on items positioned within the system. The connecting line displays the range of distance values read on the inventory data group, and the Y-axis displays the distance measured by the ultrasonic sensor.

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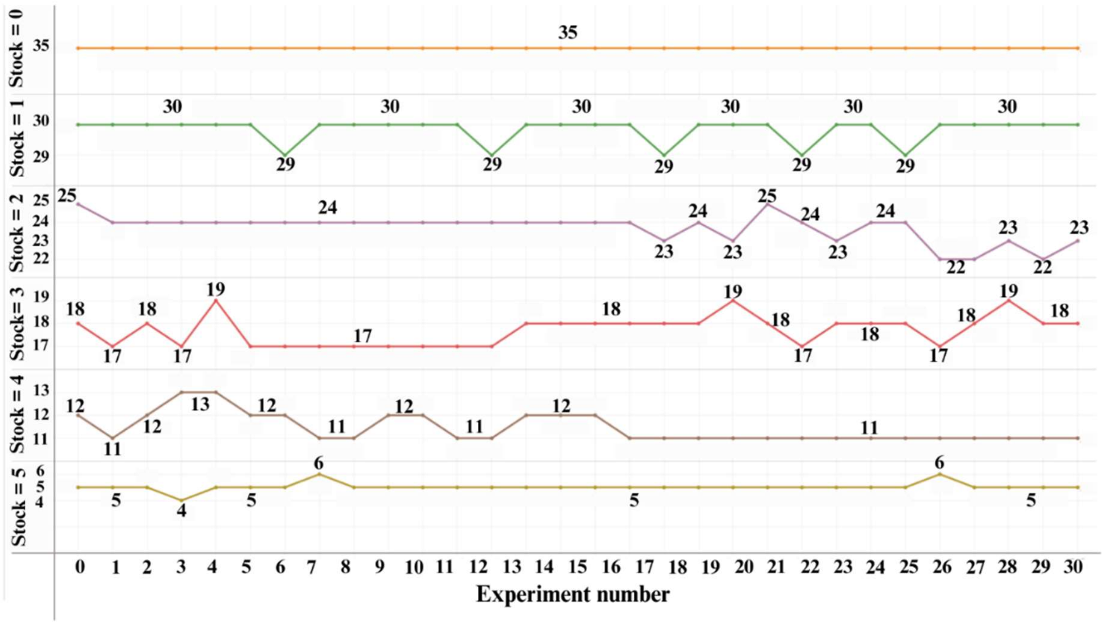

Figure 8. Ultrasonic sensor data

The weight data (gr) obtained from the sensor load cells is shown in **Figure 9.** The test iterations are represented on the X-axis. Each test iteration consists of six weight data (gr) that are based on the objects inserted into the system. The connecting line displays the range of weight values read in the inventory data group, and the Y-axis displays the weight (gr) measured on the sensor load cells.

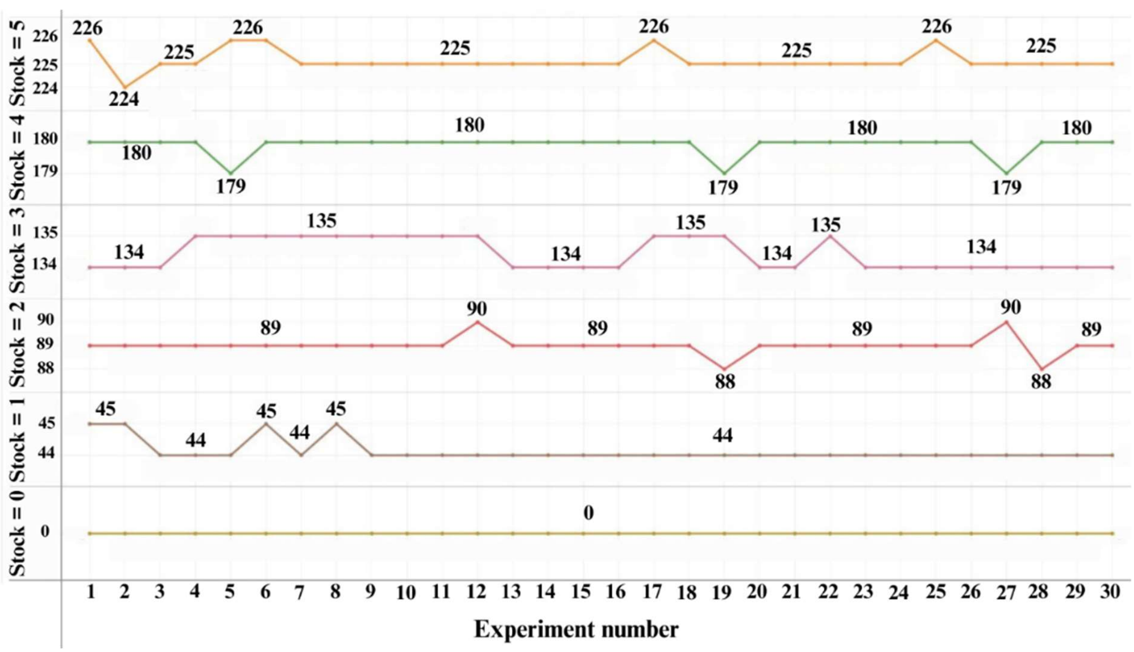

Figure 9. Weight measurement data on load cells

Data analysis

Using the weight and distance information gathered, the average weight and distance are determined for each number of inventories arranged. Next, using a ruler and scales to determine the object's real distance and weight, the average value found by each sensor is compared to the data. **Figure 10** displays a comparison between the actual distance data and the average distance measured by ultrasonics.

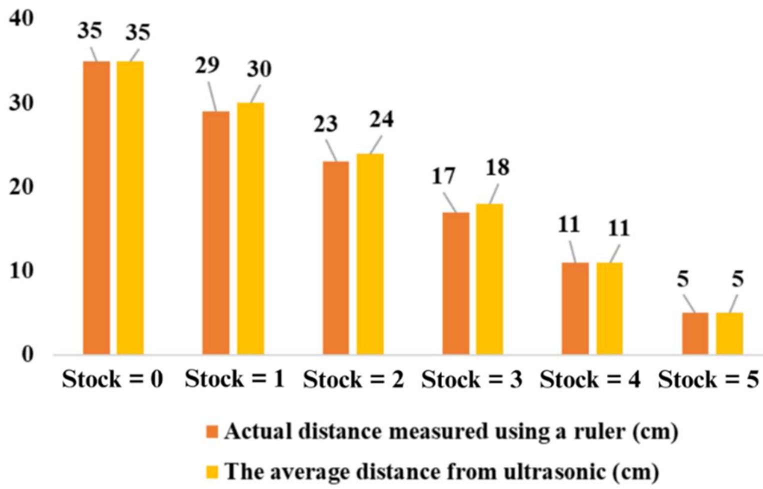

Figure 10. Comparison of object distances using a ruler and ultrasonics

The weight recorded by load cells and the real weight data are contrasted in **Figure 11.** When measuring inventory using amounts one, two, and three, the comparison findings show a discrepancy between the actual measurement results and the data collected from the load cell sensor. However, the average value difference stays within the designated tolerance range.

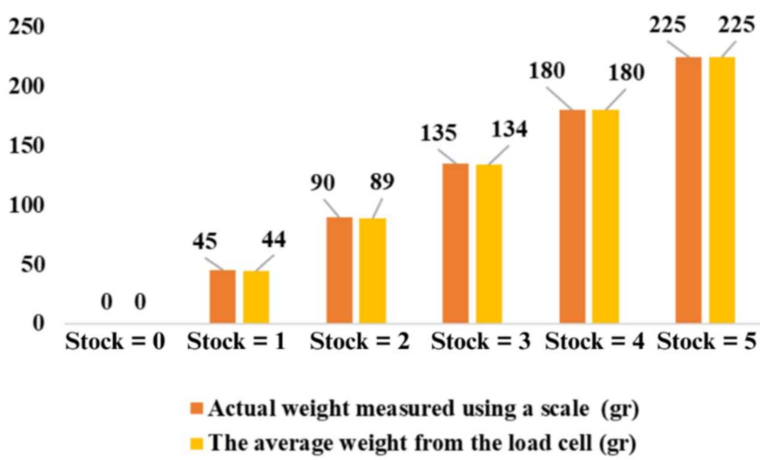

Figure 11. Comparison of the weight of objects using scales and load cells

Reliability test results using analysis of Cronbach's Alpha. Cronbach's alpha results are presented in **Table 1.**

Table 1. Reliability test results

	Sensor	Cronbach's Alpha	N of Items
1	Ultrasonic	.999	2
2	*Load cell*	1.000	2

Based on **Table 1,** the Kappa value on the ultrasonic sensor is 0.999, and the Kappa value on the sensor load cells is 1.000, which means the Kappa value is greater than 0.8. Based on the Kappa value, it can be concluded that the IoT-based inventory management system is reliable and stable.

Cost analysis

Cost analysis is carried out to evaluate the economic aspects of the system being designed. This cost analysis calculation is intended for one set of systems; if more than one set is used, the cost can be multiplied by the number of sets used. **Table 2** shows the total equipment costs and total equipment depreciation. The costs required to procure equipment are IDR 158,900. The equipment is assumed to have a life span of 2 years with a depreciation value of IDR 211.14. The depreciation value calculation is carried out based on equation (1).

Table 2. Total costs and tool depreciation

Item Number	Tool's name	Quantity (units)	Price (IDR)		Life span (Year)	Depreciation (IDR/per day)	
1	Arduino Uno	1	IDR	48.700	2	IDR	66,05
2	Ultrasonic	1	IDR	9.500	2	IDR	12,88
3	Load Cell	1	IDR	35.000	2	IDR	47,47
4	Node MCU	1	IDR	30.500	2	IDR	41,36
5	LCD	1	IDR	25.000	2	IDR	33,90
6	LED	1	IDR	5.200	2	IDR	7,05
7	Jumper Cable	25	IDR	5.000	2	IDR	6,78
	Total tool cost		IDR	158.900			
	Total depreciation (IDR/day)					IDR	215,49

In utilizing an automatic and economical inventory monitoring system, implementation costs can be seen in **Table 3.** The electricity consumption of this system is 66.5 W for 4 hours per day, so it requires 0.220 kWh with electricity costs of IDR 297.44 per day (PLN electricity rate IDR 1,352 per kWh). Equipment maintenance costs are assumed to be IDR 50,000 per year. Therefore, the total cost required daily to use this system is IDR 649.92.

Table 3. The implementation cost of an inventory monitoring system

Number	Cost Type	Cost (IDR/day)	
1	Fixed cost: Tool depreciation	IDR	215,49
2	Variable cost: Electricity	IDR	297,44
	Tool maintenance	IDR	136,99
Total cost (Rp/day)		IDR	649,92

Discussion

The system was shown to be able to function by the established success criteria after thirty iterations. The simplicity of system integration with a cloud database comes with the ability to record and retrieve data even if an object's position remains unchanged. Additionally, there is no discernible variation in the comparison results between the sensor-generated data and the real data, suggesting a high degree of agreement between the two data sets. The Kappa score for both sensors is > 0.8 in the Cronbach's alpha reliability test, confirming sensor consistency in measurements. However, because numerous sensors must be positioned on the shelf, the limited distance that ultrasonic sensors can detect on a single stack presents a problem for little goods.

The equipment cost of IDR 158,900 and the daily implementation cost of IDR 649.92 are taken into account when designing the system's economic aspect. The cost of the system is relatively inexpensive when compared to the potential daily income of basic food wholesale SMEs, which is between IDR 15,000,000 and 20,000,000. This approach is far more cost-effective than an RFID system because putting RFID technology into practice necessitates significant expenditures in fixed and variable costs, including hardware, software, and employee training [21]. As a result, compared to comparable technologies, this system can be considered a more affordable choice for inventory tracking. In addition to being cost-effective, this system offers advantages for inventory control that boost productivity.

4. CONCLUSION

Using a single kind of identical object, a WMS model for IoT-based SME inventory management has been successfully established. The created system is thought to be cost-effective. The system will cost IDR 649.92 every day to implement, and IDR 158,900 worth of tools are required. When compared to the daily revenue of basic food wholesale SMEs, which ranges from IDR 15,000,000 to 20,000,000, the necessary expenses are rather minimal. According to system testing, the system efficiently keeps track of the inventory on the shelves and saves it in a cloud database. Additionally, this system can send out alerts regarding shelf availability, which will improve inventory management and efficiency. The findings of a reliability test that examined the correctness of the sensor data and revealed a Kappa value > 0.8 further contributed to the success of this study. Therefore, it can be said that this system offers a dependable, integrated, and affordable way for small- to medium-sized warehouses to manage their inventory. Because it will take multiple ultrasonic sensors to detect little things on shelves, using ultrasonic sensors has limits. SMEs that handle goods on a big scale, such as wholesale SMEs, are better suited to employ this technique because cardboard is typically used as the primary packing material. To increase the effectiveness of sensor use, it is advised that more suitable sensor solutions for small items be discovered for future research.

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