IoT-Based RFID System for Automated Inventory Management at Depo Train Surabaya Pasar Turi

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Abstract – The development of technology in the field of IOT can help human work, especially in the process of data collection of goods. The manual process of data collection of goods often experiences problems such as human error, insecure data, and low efficiency levels. To overcome this, this research designs an IoT-based goods data collection automation system using RFID. This system consists of ESP32 microcontroller as the control center, RFID for item identification, Google Spreadsheet for real-time data storage, and Telegram as an automatic notification. Equipped with keypad for NIPP input, buzzer as audio indicator, and LCD for information display. The test results showed 100% accuracy of item data collection through a trial of 15 items, with an average Google Spreadsheet data update time of 3.01 seconds and Telegram notifications successfully sent in an average time of 3.08 seconds. This system is expected to improve accuracy, efficiency, and security in data collection of goods, thus supporting the operation of PT KAI facilities warehouse more effectively.

Keywords: IoT, ESP32, RFID RC-522, Sticker Label RFID, Telegram, Google Spreadsheet

I. INTRODUCTION

Along with technological advances, the use of the Internet of Things (IoT) is increasingly widespread to support human work efficiency through systems that can be controlled and monitored remotely. IoT is an integrated system between sensors, software, and internet networks that allows real-time monitoring and data collection as well as automatic interaction between devices.

According to Rushton, Croucher, and Baker, warehouses are an important part of the supply chain as they serve to store and manage inventory [1]. However, the manual system that is still widely used often causes problems, such as data inconsistencies, human error, damage or loss of records, slow data retrieval, and difficulty in monitoring stock in real time. These problems are often encountered in KAI warehouses, especially during the stock opname process.

To overcome these problems, Radio Frequency Identification (RFID) technology can be the solution. RFID is able to detect objects without physical contact through radio waves. This system consists of transponders (tags) and interrogators (readers) that work automatically in reading and transmitting data [2]. RFID technology has been successfully applied in various fields, such as smart shopping systems, access management, attendance systems, and warehouse management. Several studies have been conducted by utilizing RFID technology in certain fields such as shopping centers (e-shop)[3][4], space access[5][6], warehousing systems [7] [8], and attendance[9][10][11][12][13].

This research designs an automation system for data collection and monitoring of goods based on IoT using an ESP32 microcontroller. The system is equipped with an RFID sensor to read item tags, keypad as NIPP input and mode selection (goods in/out), buzzer as an audio indicator, and LCD to display real-time process information. The reading data will be automatically recorded to Google Spreadsheet and sent as a notification via Telegram. This design is expected to increase the accuracy and efficiency of data collection of goods in the KAI warehouse and facilitate officers in connecting the movement of goods practically and reliably.

II. METHODS

Research Stages

In this research, the system design method is used, which was chosen because it is considered the most appropriate to produce a tool that is able to build an automatic data collection system in the warehouse. This system utilizes RFID sensors and ESP32 microcontroller-based keypads as the main components in the process of identification and input of goods data. To support efficiency and accuracy, this system applies Internet of Things (IoT) technology that allows RFID reading data to be sent and stored automatically into a Google Spreadsheet that functions as an online database. In addition, the system is also equipped with a real-time notification feature through the Telegram application, which provides information regarding the identity of users who carry out activities to pick up or store goods in the warehouse. The application of this design method allows researchers to customize the design and function of the system to the specific needs of the warehouse, so as to increase the effectiveness of monitoring, transparency of management, and control of stock of goods in a comprehensive and integrated manner.

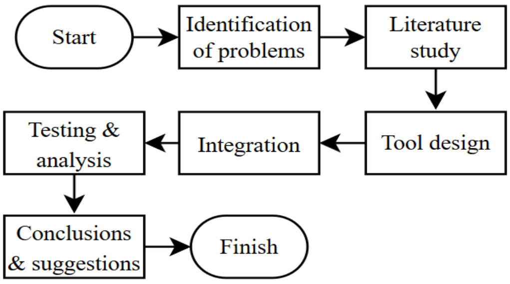


Figure 1. Research Flowchart

In figure 1, a flowchart showing the stages of research from start to finish, starting from problem identification to the preparation of conclusions and suggestions. This research is required in accordance with the stages of the diagram below in order to run systematically and structured. This research was carried out in the even semester of the 2024/2025 academic year. Meanwhile, the collection of reference research materials was carried out in the odd semester of the 2024/2025 academic year. This research was carried out in Building A8, 4th floor of the Control System Lab, the place was chosen because it has complete facilities to support the design and manufacture of research tool systems.

Hardware Design System

In Figure 2, the design of this IoT-based goods data recording system, the selection of the main components is done by considering aspects of performance, reliability, and ease of integration. The ESP32 microcontroller was chosen because it has Wi-Fi and Bluetooth connectivity, a powerful dual-core processor, and many GPIO pins that support various functions. RFID sensors are used for fast and accurate identification of goods, with a working voltage that is directly compatible with the ESP32. Items are labeled using RFID stickers that have unique IDs and high durability. For display, a 16x2 I2C LCD is used because it is easy to read and directly integrated with ESP32. The 4x4 keypad functions as NIPP input and mode selection, and is compatible with the ESP32 working voltage. As an indicator, a buzzer is added to provide sound feedback on the success of the RFID reading process. In terms of software, Telegram is used to send real-time notifications to warehouse staff, while Google Sheets acts as a cloud-based automatic data recording medium that is easily accessible, free, and integrated through App Script. This combination of components is designed so that the system works optimally in supporting the efficiency and accuracy of recording data on goods in the KAI facility warehouse.

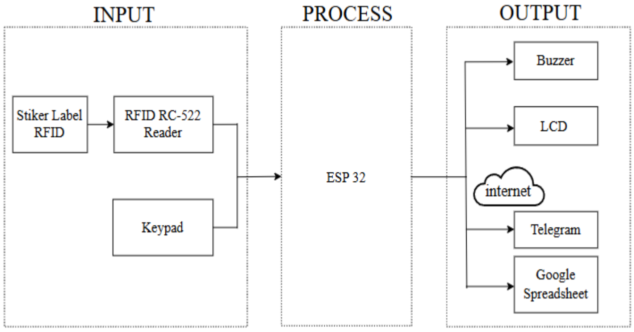


Figure 2. System block diagram

In this step, the hardware and software designs that have been designed will be implemented into an integrated operational system. This integration process aims to make all components of both hardware and software work synchronously and optimally. This process includes hardware installation, software setup, internet network connection configuration, integration between other components such as ESP32 as a microcontroller, RFID sensor, 4x4 keypad, I2C LCD, buzzer module and other platforms such as Google Sheets, Google App Script and Telegram. The following is a circuit design drawing of the hardware system design.

Table 1. Pin configuration in hardware wiring

Keypad 4x4	ESP32
Pin 1	GPIO13
Pin 2	GPIO12
Pin 3	GPIO14
Pin 4	GPIO27
Pin 5	GPIO26
Pin 6	GPIO25
Pin 7	GPIO33
Pin 8	GPIO32
LCD I2C	ESP32
GND	GND
VCC	5V
SDA	GPIO21
SCL	GPIO22
RFID RC-522	ESP32
VCC	3.3V
RST	GPIO15
GND	GND
MISO	GPIO19
MOSI	GPIO23
SCK	GPIO18
SDA	GPIO4
Buzzer	ESP32
GND	GND
IN	GPIO17

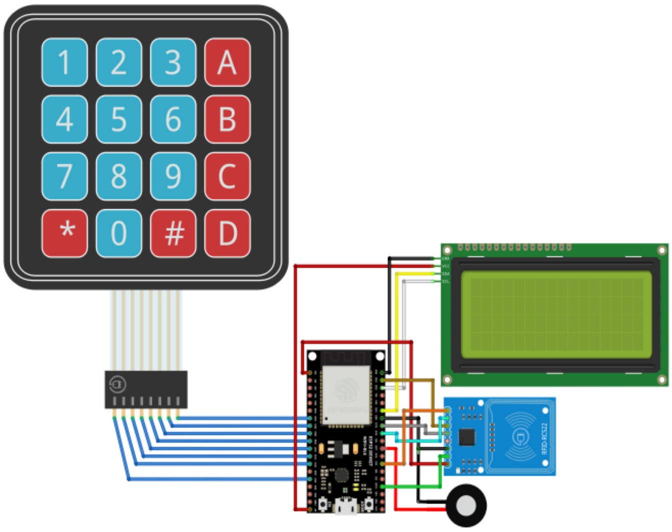


Figure 3. Flowchart designing software

The hardware system in figure 3, there are several pins used to connect each component. Several pin configurations in the hardware wiring system are listed in table 1.

Software Design System

In figure 4, Flowchart of the system software, starting with connecting the internet network, if the system is connected to the internet, then do the initial registration to enter NIPP data, employee name, item name, item ID and warehouse employee phone number in the system code. If the data has been registered then the user enters the code for the Employee Identification Number (NIPP) through the keypad, the system will verify. If the NIPP is not registered, the user must repeat entering the NIPP until the data is correct. If the NIPP is registered, then select the method between outgoing goods or incoming goods. Next, the user brings the tool to bring the RFID Reader closer to the RFID label sticker on the warehouse shelf goods board to read the identity of the goods. If the tag is successfully read, the buzzer will light up with a short tone as an indicator of success. After the tag is read, the system will automatically store data on goods such as information on the date and time of goods out / in, the name of the warehouse employee, the name of the item on the Google Spreadsheet. In addition, the system will also send a notification to the Telegram application containing information on the date, time, mode of goods out/in, employee name, item name. This process ensures that data collection is fast, accurate, and can be monitored directly from a distance.

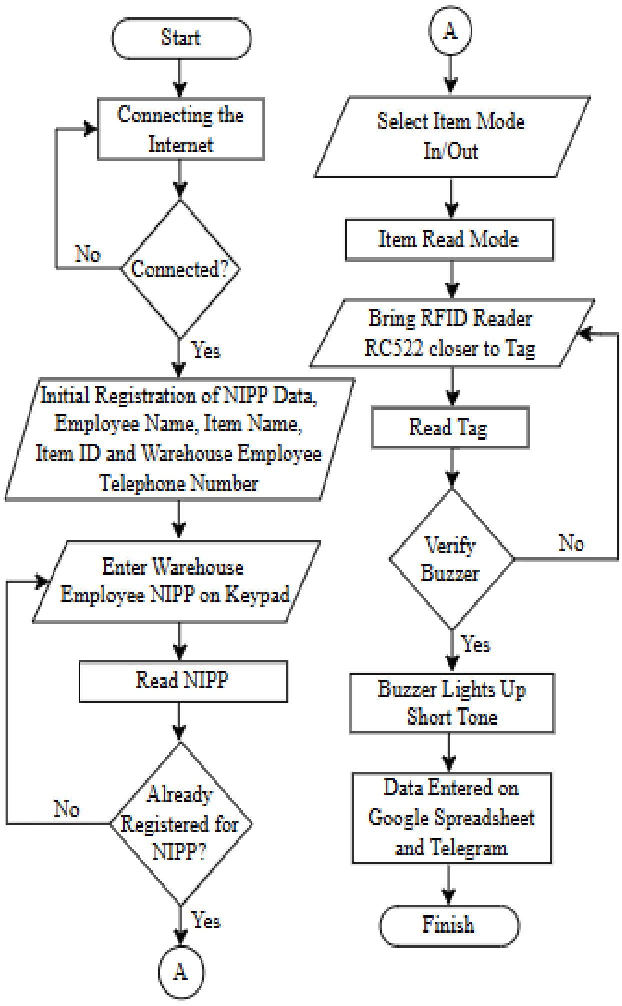


Figure 4. Flowchart designing software

III. RESULT AND DISCUSSION

Figure 5. Data collection automation system

RFID Testing

Table 2. RFID label sticker duration testing

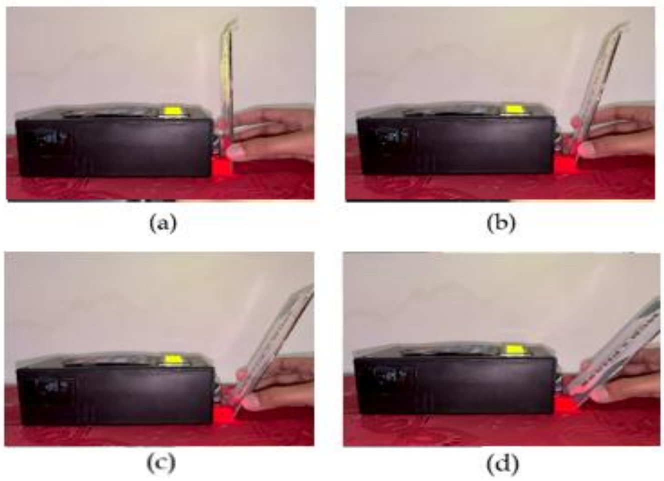
Testing No.	Sticker Label RFID	Status	Reading Time (s)
1	Stiker label 1	read	0.99
2	Stiker label 2	read	0.98
....	....	....	....
....	....	....	....
20	Stiker label 6	read	0.76
21	Stiker label 7	read	1.18
Average			**0.84**

Based on the table 2, the results of the RFID label sticker reading test at a distance of 0 cm show the fastest duration of 0.41 seconds and the longest duration of 1.99 seconds. This variation in reading time is caused by the system's internal identification process of the ID on the RFID label. The average reading time is 0.84 seconds which is included in the good category. As a comparison, the results of previous research show an average reading of 1.90 seconds [14] so these results indicate an improvement in performance. This difference may be influenced by environmental conditions, test methods, and the type of device used. To evaluate the consistency of label sticker reading in the system, a standard deviation calculation was performed.The result obtained is a value of 0.34 seconds which indicates that the average deviation of the reading time from the average value is quite small so that the system can be said to be stable.Based on the table 2, the results of the RFID label sticker reading test at a distance of 0 cm show the fastest duration of 0.41 seconds and the longest duration of 1.99 seconds. The smaller the standard deviation value, the more uniform the test results. [15]. The reading success rate in this test reached 100%, indicating that the system was able to read all RFID labels perfectly at that distance in table 3.

In Figure 6, the test results on the position of the RFID label sticker show that the average reading time increases as the angle of inclination of the label towards the reader increases. In position (0°) the lowest reading time was recorded at 0.35 seconds and the highest was 0.50 seconds. While in the 45° tilt position the reading time increases to about 0.57 seconds. This happens because the tilt angle affects the efficiency of signal reception between the tag antenna and the reader, so that the more tilted the position, the weaker the received signal and the reading time increases. Based on the results of the linear regression analysis shown in the figure 7, the regression equation results are $y = 0.003x + 0.423$.

Table 3. Testing based on RFID label sticker position

Sticker Label Position	Status	Reading Time (s)
0°	read	0.44
	read	0.46
	read	0.50
	read	0.35
	read	0.39
15°	read	0.44
	read	0.51
	read	0.49
	read	0.48
	read	0.50
30°	read	0.49
	read	0.51
	read	0.48
	read	0.52
	read	0.55
45°	read	0.53
	read	0.55
	read	0.49
	read	0.58
	read	0.57



Gambar 6. RFID Label sticker testing with various positions, (a) 0° (b) 15° (c) 30° (d) 45°

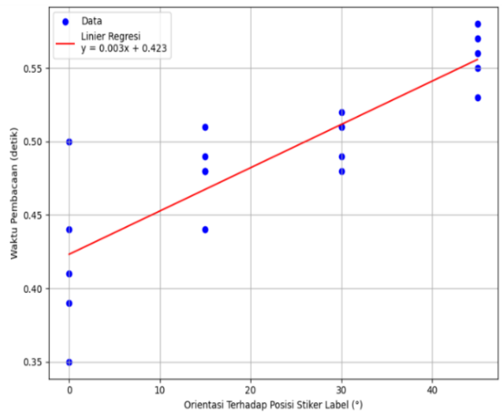


Figure 7. Regression plot between position and time

the regression results show that every 1 degree increase in angle has the potential to increase the average reading time by 0.003 seconds. This correlation is positive, which means that the greater the angle of inclination between the label and the sensor, the greater the time taken to read the ID. The modest value of the regression slope indicates that while there is an effect of angle on reading time, it is still relatively weak but consistent. Interestingly, despite the variation in time due to angle changes, the reading success rate still reached 100%, indicating that the RFID system was able to accurately detect all tags in all four tested position angles.

Table 4. Reading testing based on RFID label sticker distance

Reading Range (s)	Status	Reading Time
0	read	0.26
0	read	0.83
0	read	0.58
0	read	0.46
1	read	0.48
1	read	2.23
1	read	0.68
1	read	0.76
2	read	0.99
2	read	0.89
2	read	0.87
2	read	0.83
3	read	7.17
3	read	6.53
3	read	8.03
3	read	8.12

In the table 4, 16 tests have been carried out to determine the maximum distance the RC-522 RFID can read RFID sticker labels. Testing is done with several conditions, namely with a different range between 0-3cm. In the test results, it was found that the fastest reading occurred at a distance of 0 cm with a reading duration of 0.53 seconds. In addition, the RC522 RFID Reader is only able to read RFID label stickers in a distance range of less than 3 cm. This is because the RFID module uses electromagnetic induction-based wireless communication technology, where distance is greatly influenced in reading RFID label stickers because the closer the distance, the stronger the signal received. Based on the linear regression analysis in the figure 8, the regression equation results are $y = 2.065x - 0.615$.

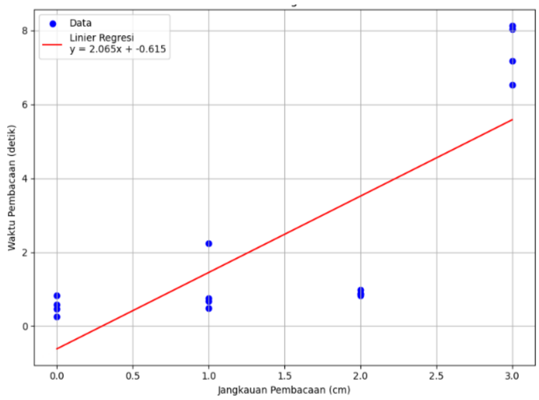


Figure 8. Regression plot between distance and time

This equation indicates that every additional 1 cm of distance can cause an increase in the average reading time by 2.065 seconds. The large regression coefficient indicates a strong positive relationship between distance and reading time. This means that the greater the distance between the tag and the reader, the longer the time required for the reading process. The correlation is positive and quite strong, which means that an increase in distance tends to be followed by an increase in reading time. Such a relationship is consistent with the theory of electromagnetic wave propagation in RFID systems, where distance affects the signal strength between the reader and the tag. The greater the distance, the weaker the received signal, so the reading time tends to increase [2].

Table 5. RFID label sticker reading test with different physical conditions and distances

Physical Conditions	Distances (cm)	Status	Reading Time
good condition	0	read	0.26
Physical Conditions	Distances (cm)	Status	Reading Time
good condition	1	read	0.48
good condition	2	read	0.76
good condition	3	read	7.17
vertically folded	0	read	0.83
vertically folded	1	cant read	-
horizontally folded	0	read	0.58
horizontally folded	1	read	2.23
horizontally folded	2	cant read	-
wet	0	read	0.46
wet	1	read	0.68
wet	2	read	0.99
wet	3	cant read	-

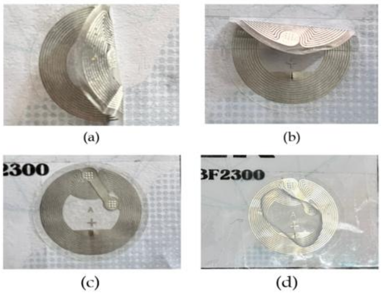


Figure 9. Physical condition of RFID label stickers, (a) vertically folded (b) horizontally folded (c) good condition (d) wet

In the table 5, the results of testing the reading of RFID label stickers with different physical conditions have been obtained. In figure 9, the condition of the RFID label sticker can be seen in the picture above, namely when the label sticker is vertically folded, horizontally folded, good and wet. At a distance of 0 cm with the condition of the label sticker in good condition, the fastest is 0.26 seconds. At a distance of 1 cm, the horizontally folded label sticker can still be read, while the vertically folded condition cannot be read. This is because the aluminum part of the label sticker is closed when the condition is folded vertically, so that the signal from the RFID reader cannot be received optimally. Vertical folds tend to block the electromagnetic field from reaching all parts of the antenna on the tag, resulting in a failed reading process. Meanwhile, when the RFID label sticker is wet, the reader is still able to read it. This is due to the waterproof nature of the label sticker, and because the water on the label surface does not interfere with the internal metal elements. The water on the surface of the white label does not cover the aluminum part of the RFID label sticker, so the signal transmission process between the reader and the tag can still take place properly.

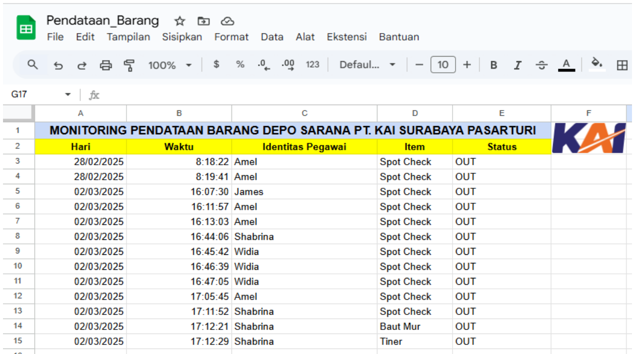
Testing Data Delivery to Google Spreadsheet

This test serves to determine whether the data read by the keypad and RFID sensor can be sent and stored in Google Sheet automatically, without any errors or missing data and to find out the time it takes for the system to send item data. The test results are in the table 6.

Table 6. Testing sending data to google spreadsheet

Testing No.	User NIPP and Data Delivery	Data Sent Status	Reading Time (s)
1	123, complete data	sent	3.28
2	124, complete data	sent	2.03
3	125, complete data	sent	2.51
……….	……….	……….	……….
……….	……….	……….	……….
15	127, complete data	sent	2.70
Average			**3.01**

In the data transmission test above, the fastest time taken by the system to transmit data was 2.03 seconds. The data transmission process takes place quickly thanks to a stable network. On the other hand, the longest data transmission time is 3.96 seconds, if the data transmission process takes longer, it is due to network instability. The average time taken to send data to Google Sheets was 3.01 seconds. Based on statistical calculations, it is known that the standard deviation of data transmission time is 0.51 seconds. This value indicates that the spread of data against the average is not too large, or in other words, the variation in delivery time is quite low. This means that the system has a consistent and stable performance, with fluctuations in delivery time that are still within reasonable limits. Meanwhile, the percentage of success obtained from this test is 100%. This means that all data was successfully sent without any failures, which indicates that the system has high reliability. The results of the data collection of goods on Google Sheets can be seen in the figure 10.



	A	B	C	D	E
1	MONITORING PENDATAAN BARANG DEPO SARANA PT. KAI SURABAYA PASARTURI				
2	Hari	Waktu	Identitas Pegawai	Item	Status
3	28/02/2025	8:18:22	Amel	Spot Check	OUT
4	28/02/2025	8:19:41	Amel	Spot Check	OUT
5	02/03/2025	16:07:30	James	Spot Check	OUT
6	02/03/2025	16:11:57	Amel	Spot Check	OUT
7	02/03/2025	16:13:03	Amel	Spot Check	OUT
8	02/03/2025	16:44:06	Shabrina	Spot Check	OUT
9	02/03/2025	16:45:42	Widia	Spot Check	OUT
10	02/03/2025	16:46:39	Widia	Spot Check	OUT
11	02/03/2025	16:47:05	Widia	Spot Check	OUT
12	02/03/2025	17:05:45	Amel	Spot Check	OUT
13	02/03/2025	17:11:52	Shabrina	Spot Check	OUT
14	02/03/2025	17:12:21	Shabrina	Baut Mur	OUT
15	02/03/2025	17:12:29	Shabrina	Tiner	OUT

Figure 10. Google spreadsheet test results

Table 7. Testing data delivery to google spreadsheet

Testing No.	User NIPP and Data Delivery	Data Sent Status	Reading Time (s)
1	123, notification sent	sent	2.78
Testing No.	User NIPP and Data Delivery	Data Sent Status	Reading Time (s)
2	124, notification sent	sent	2.68
3	125, notification sent	sent	2.56
……….	……….	……….	……….
……….	……….	……….	……….
15	127, notification sent	sent	3.00
Average			**3.08**

In the Telegram notification sending test in table 7, the time required by the system to send notifications with the fastest time is 2.45 seconds. The fast or slow process of sending Telegram notifications is influenced by the stability of the internet network connected to the system, where if the network is stable then the time needed to send notifications will be faster and vice versa. From the data, it can be seen that the average time used to send notifications on Telegram is 3.08 seconds. From the statistical calculation, the standard deviation of 0.46 seconds shows that the variation in sending time is very small and tends to be stable. This value indicates that most of the sending times are close to the average value and do not experience large fluctuations. The correlation between low standard deviation and system stability reinforces the conclusion that the Telegram notification delivery system can work well under relatively stable network conditions. Although the percentage of success obtained from this test is 100%, this value shows that the system is able to send notifications consistently without any failures. The results of sending notifications for the Telegram application can be seen in the figure 11.

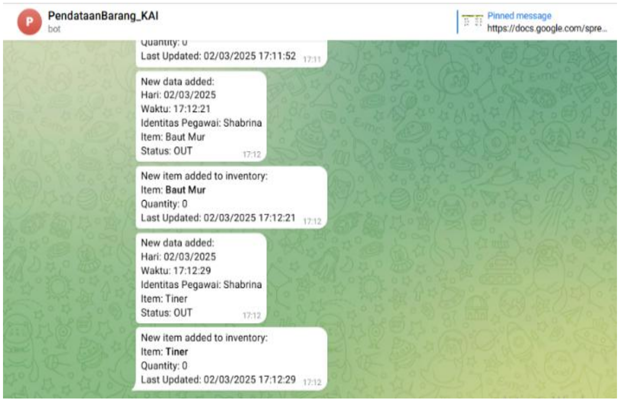


Figure 11. Telegram test results notification sent

IV. CONCLUSION

The research entitled "IOT-Based RFID System for Automated Inventory Management at Depo Train Surabaya Pasarturi" has been successfully completed. The designed system uses RFID technology to identify goods, Telegram as a real-time notification medium, and Google Sheets as a medium for automatic data storage. This system is designed to overcome various problems in the management of goods in the warehouse, such as recording errors, data discrepancies, information delays, and lack of efficiency in monitoring stock items. By utilizing RFID, the process of identifying goods becomes faster and more accurate, while integration with Google Sheets allows real-time data recording. Automatic notifications via Telegram also ensure that every data collection activity is immediately known by officers, thus speeding up the process and minimizing the risk of errors. The test results show that the system has a 100% accuracy rate with an average update time of 3.01 seconds and a standard deviation of 0.51 seconds, indicating that the system is quite stable. The test of sending Telegram notifications to 15 items also showed a 100% success rate with an average time of 3.08 seconds and a standard deviation of 0.46 seconds. Overall, the system proved to be reliable, consistent, and able to improve the efficiency of inventory management in the warehouse.

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