Implementation of the Boyer-Moore Majority Vote Algorithm in an Internet of Things-Based Inventory Management System

Implementasi Algoritma Boyer-Moore Majority Vote pada Sistem Manajemen Inventory Berbasis Internet of Things

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Abstract – Gold jewelry stores have to deal with various problems involving inventory control and inventory analytics in their day-to-day operations. Many Indonesian gold retailers tackle these problems by using a paper-based recording method. This method is not time efficient and adds more workload into the inventory management processes, such as stocktaking and popular item category classification. Stocktaking gets more difficult as more items are added to the inventory. These added workload and time increase the risk for items to go missing without being immediately documented. This paper proposes an Internet of Things solution that makes inventory stocktake more streamlined by introducing an RFID system with a web application that allows an operator to identify items during a stocktake instantly. In addition, store managers can also find trends in item categories using the Boyer-Moore majority vote algorithm. Our evaluation show that this system can effectively record data items in one scan with an average accuracy of 93.16% for a tray of 5 up to 25 items.

Keywords: Boyer-Moore Majority Vote, gold jewelry, Internet of Things, inventory management, RFID system

***Abstrak** – Toko perhiasan emas menghadapi berbagai masalah yang melibatkan pengendalian inventaris dan analitik inventaris dalam operasi sehari-hari mereka. Banyak pengecer emas Indonesia mengatasi masalah ini dengan menggunakan metode pencatatan pada kertas. Metode ini tidak efisien dan menambah beban kerja ke dalam proses manajemen inventaris, seperti inventarisasi dan klasifikasi kategori barang populer. Inventarisasi menjadi lebih sulit karena lebih banyak item ditambahkan ke inventaris. Penambahan beban kerja dan waktu ini meningkatkan risiko barang hilang tanpa segera didokumentasikan. Makalah ini mengusulkan solusi Internet of Things yang membuat inventaris lebih efisien dengan memperkenalkan sistem RFID dengan aplikasi web yang memungkinkan operator untuk mengidentifikasi item selama inventarisasi secara langsung. Selain itu, manajer toko juga dapat menemukan tren kategori barang menggunakan algoritma Boyer-Moore Majority Vote. Evaluasi menunjukkan bahwa sistem ini dapat secara efektif merekam item data dalam sekali scan dengan akurasi rata-rata 93,16% untuk baki yang terdiri dari 5 hingga 25 item.*

***Kata Kunci:** Boyer-Moore Majority Vote, perhiasan emas, Internet of Things, manajemen inventaris, sistem RFID, inventarisasi*

INTRODUCTION

Gold jewelry retailers that operate in industrial sector can get benefit from integrating an inventory management system into their daily operations. This involves a combination of technology (hardware and software), processes, and procedures for monitoring inventory, i.e. stocked goods. Inventory management is the process tied to the handling, using, ordering, and storing a company's inventory (Veeqo, 2020). Inventory is considered a current asset on the balance sheet because it can be sold and converted into cash. However, items in stock tie up money that can be used for other purposes. In addition, inventory also requires additional costs for storage. The three main reasons companies still keep inventory regardless of the shortcomings are time, uncertainty, and economies of scale (Rossi, 2021).

A gold jewelry retailer must carry out a storage procedure where all gold inventory grouped into trays must be put back into a secured metal safe after ensuring that the number of physical inventory in the tray is according to the balance sheet. This process is called a stocktake and is performed at the end of every business day. The problem with stocktakes is that many stores still carry out this procedure using a paper-based recording method (Sriyanto, Purwanggono, &

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Nugroho, 2012). Paper-based records are inefficient in time and workload, thus making daily operations less streamlined (Ayesha, Qamar, & Khalid, 2019), especially when gold inventory has accumulated to a large number where stocktaking is increasingly prone to input errors.

The Internet of Things (IoT) is defined as an infrastructure consisting of interconnected entities such as people, systems, and information resources together with services that process and react to information from the physical and virtual worlds (Gould, 2019). IoT finds applications in many aspects of our lives, including home and building automation, smart cities, smart grids, smart agriculture, and Industry 4.0 (Cirani, et al., 2019). Based on the definition of inventory management system and IoT, an IoT-based inventory management system can be defined as an inventory management system consisting of an infrastructure of interconnected entities along with services that process and react to information from the physical and virtual worlds.

IoT-based inventory management systems gather data from sensors, barcodes, and Radio Frequency Identification Device (RFID) tags to give up-to-date and accurate information about inventory usage, levels, and expiration dates. There are two methods used to assess inventory: periodic and continuous. During continuous inventory review, the inventory level must be continually checked and reported (Mashayekhy, et al., 2022).With RFID technology, inventory inaccuracy can be reduced by 20-30%, thus operational expenses and shortage levels can be decreased (Sun & Shu, 2021).

RFID is an identity communication device. In order to be identified and tracked in the future, things are tagged to these devices. Therefore, they can be monitored and controlled through the internet (Kamal, 2017). An RFID system has tags and readers. A tag has limited communication range and computing power. A reader has significant computing power and a dedicated power source. The price of an RFID tag is very cheap, therefore it is negligible to the price of an item it is attached to (Liu, et al., 2018a). The use of RFID together with IoT for inventory management has gained significant attention in the last decade (Tan & Sidhu, 2022). One of the research gaps identified by Mashayekhy, et al. (2022) in IoT-based inventory management systems is forecasting future customer demand (Mashayekhy, et al., 2022).

In this paper, we design and implement a web-based inventory management system for a gold jewelry store integrated with IoT. Our contribution is the inclusion of the Boyer-Moore majority vote algorithm in the system to suggest the best-selling jewelry category. The main goal of this system is to assist store managers by streamlining storage procedures and indicating trends in the form of inventory categories. These in turn help store managers to get a smoother operational process that can increase their ability to compete.

Boyer-Moore majority vote is a linear time algorithm that finds a majority element from a sequence of elements. Boyer-Moore describes majority elements as elements of a given set that consist of more than half of the total elements of that particular set. The Boyer-Moore majority vote algorithm is used to indicate that a category of gold items is in very high demand, so it can be used as a factor when purchasing new stock. This algorithm performs this task without requiring the elements to be in a sorted state while having a linear time complexity of $T(2n)$ and constant space complexity of $S(1)$ (Khurshid & Sen, 2011; Durocher, et al., 2013).

The term IoT is inconsistent with various experts and organizations who have different opinions on its definition, thus prompting ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission) to issue a standard labelled ISO/IEC 30141 in 2018. The standard defines IoT as an infrastructure of interconnected entities, people, systems and information resources together with services which process and react to information from the physical world and the virtual world (Gould, 2019).

LITERATURE REVIEW

This paper uses several similar studies as a reference. The studies in question involve inventory management, RFID technology, IoT, microcontrollers, and their implementation in gold jewelry stores. One similar study was conducted by Tejesh & Neeraja (2018) who discussed IoT-based inventory management systems in warehouses and how RFID technology was the most suitable wireless communication technology for warehouses in 2018 (Tejesh & Neeraja, 2018). This work examined problems in warehouses, namely inventory management, goods tracking, and costs associated with implementing wireless systems. The authors used an RFID reader em-18 connected to a

NodeMCU ESP8266 microcontroller to act as an RFID reader. Also, they used a Raspberry Pi 3 as a web server that connected to all RFID readers. The system can record inventory data in a warehouse accurately, while keeping implementation costs low.

Paul, et al. (2019) conducted a literature study on IoT-based inventory management implementation throughout the supply chain. They intended to design a simulation of an IoT-based supply chain system within the scope of manufacturing and sales (Paul, Chatterjee, & Guha, 2019). The object of interest in this study was IoT-based inventory management in supply chain systems. This study mentions no specific tools, hardware, or software. It analyzed the constant demand for product diversity that overwhelms traditional inventory management models due to heavy workloads and low efficiency. It proposed an efficient field-ready supply chain simulation system based on IoT technology.

Zhang, et al. (2011) made a report on the inventory management policy of gold jewelry stores. They analyzed the policy adopted by many Chinese gold jewelry stores in 2011 and proposed a new policy to increase inventory turnover (Zhang, et al., 2011). They also pointed out inefficiencies in retailer practices then recommended efficient versions of practices ranging from inventory replenishment strategies, strategic partnerships with suppliers, and scientific forecasts of future demand. This study used a combination of quantitative and qualitative methodologies. It did not involve any digital tools but mentioned several reporting tools that can be executed on paper or digitally. It also addressed market problems involving competition and various consumer criteria. The aims of this study were to update traditional practices of gold jewelry retailers in China to stay ahead of the competition while reducing costs and increasing profits.

Duangekanong, et al. (2021) investigated the effect of RFID technology on Thailand's gold supply chain (Duangekanong, Pibulcharoensit, & Cleesuntorn, 2021). They highlighted the value of RFID in improving supply chain efficiency and the traceability of minerals. They also examined the conceptual framework of the barriers and benefits of implementing RFID in the retail gold supply chain by surveying 237 gold retail experts in Thailand. Their findings suggested that fragmented supply chains, gold traceability, supply chain efficiency, depreciation, and inventory control are significant factors in the adoption. This study used a combination of quantitative and qualitative methodologies. It mentioned no specific tools, hardware, or software. It analyzed the gold supply chain and its issues to identify the barriers and advantages of applying RFID technology. It also analyzed potential facilitators and barriers in RFID technology adoption on Thailand's gold supply chain. This analysis was accomplished by surveying retail gold experts on their supply chain efficiency and traceability of minerals.

Liu, et al. (2018b) conducted a literature study on RFID technology to strengthen a case study that organized a large-scale warehouse system framework (Liu, et al., 2018b). The subject of their case study was a supermarket chain in China – Yonghui Superstore – and its inventory problems. This study used passive RFID tags with a frequency of 13.56 MHz and various sensors ranging from the RFID reader, temperature, pressure, humidity, smoke, GPS, cameras, photoelectric, laser-based distance, and localization vision-based sensors. It addressed the problems of traditional warehouse management systems that limit Yonghui's rapid development. It also proposed changes that improve the existing warehouse system with the means to solve Yonghui Superstore warehouse management problems.

RESEARCH METHOD

The followings are the stages that are used in developing the IoT-based inventory management system.

1. Identify the Problem
   At this stage, the problem is identified to determine the RFID scanner tool and the algorithm that will be implemented.
2. Analysis
   At this stage, all data needed to design the RFID scanner tool and the algorithm are collected and then analyzed.
3. Design
   At this stage, the database, interface, program modules, wirings and workflow are designed based on the results of the analysis carried out in the previous stage.
4. Implementation
   At this stage, the construction of the RFID scanner tool and the implementation of the algorithm are carried out based on the analysis and design stages.
5. Testing

At this stage, testing is carried out on the RFID scanner tool and the algorithm and that have been created based on test objectives, test criteria, test cases, test implementation, and then analysis of the test results is carried out.

DESIGN AND IMPLEMENTATION

The system block diagram shows the relationship (wired and wireless) between two subsystems: the web-based application (software) and the NodeMCU ESP8266 microcontroller (hardware), which is connected to two-component modules, namely LCD I2C 16x2 and RFID-RC522. The connection between these two subsystems uses an MQTT broker from Eclipse called Mosquitto (Eclipse Foundation, 2021) to allow web clients to access the data generated by the RFID reader. The system design that is shown in Figure 1 can be described as follows.

The system flow starts with establishing a connection between the NodeMCU ESP8266 and the web application via the MQTT broker. After that, the user selects the desired operation and then enters the tag data by bringing it closer to the RFID-RC522 sensor. The data is then passed to the NodeMCU and web application via the MQTT broker and wires, where it will be displayed through the RFID reader LCD and the web application's user interface.

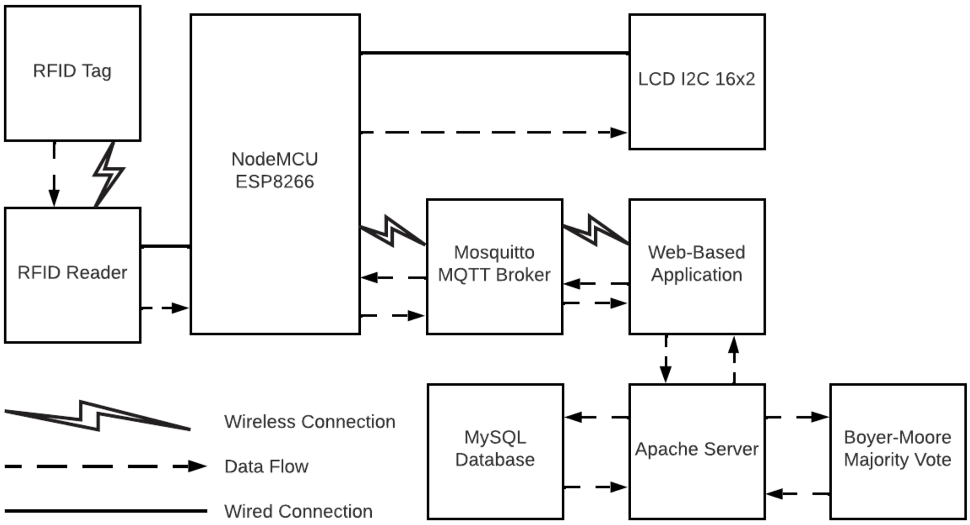


Figure 1 The System Bloc44k Diagram

The wiring diagram shows all cable positions of hardware components such as microcontroller, LCD display, and RFID reader. Table 1 shows a list of hardware specifications used in the system implementation. The microcontroller used is NodeMCU ESP8266, the LCD display used is I2C 16x2, the RFID reader used is RFID-RC522, and the tags are 13.56 MHz. The wiring of these hardware components are summarized in Table 2, where basically the RFID reader and the LCD display are attached to the microcontroller.

Table 1 Hardware Specifications

Name	Specification
Microcontrollers	NodeMCU ESP8266
LCD Display	I2C 16x2
RFID Reader	RFID-RC522
Tag	13.56 MHz

The following is the wiring for the RFID-RC522 module with NodeMCU ESP8266. The main purpose of this connection is to read and transmit RFID tag's UID data. The RFID reader's 3.3 V power pin and GND pin are attached to NodeMCU's 3.3 V power pin and GND pin, respectively. Then, NodeMCU's D3 to D7 digitals pins are connected to the RFID reader's RST, SDA, SCK, MISO, and MOSI pins.

The following is the I2C 16x2 LCD wiring diagram with NodeMCU ESP8266. The main purpose of this connection is to display short messages so that users can interact with the RFID reader. The LCD display's VCC power pin and GND pin are attached to NodeMCU's Vin power pin and GND pin, respectively. Then NodeMCU's D1 to D2 digitals pins are connected to the LCD display's SCL and SDA pins. The RFID reader wiring diagram is shown in Figure 2, while the real hardware implementation can be seen in Figure 3.

Table 2 RFID Reader Component Wiring

NodeMCU	RC522	LCD
3.3 V	3.3 V	-
GND	GND	-
D3	RST	-
D4	SDA	-
D5	SCK	-
D6	MISO	-
D7	MOSI	-
Vin	-	VCC
GND	-	GND
D1	-	SCL
D2	-	SDA

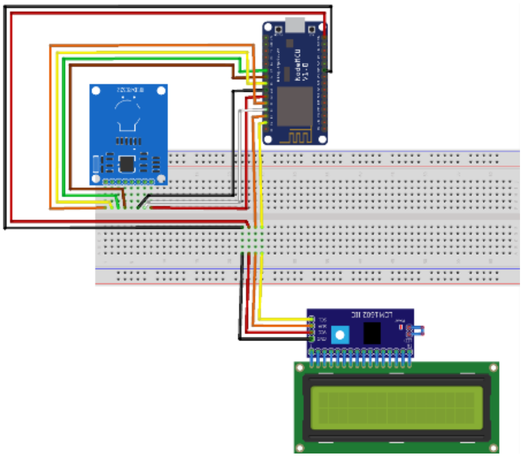


Figure 2 RFID Reader Wiring Diagram

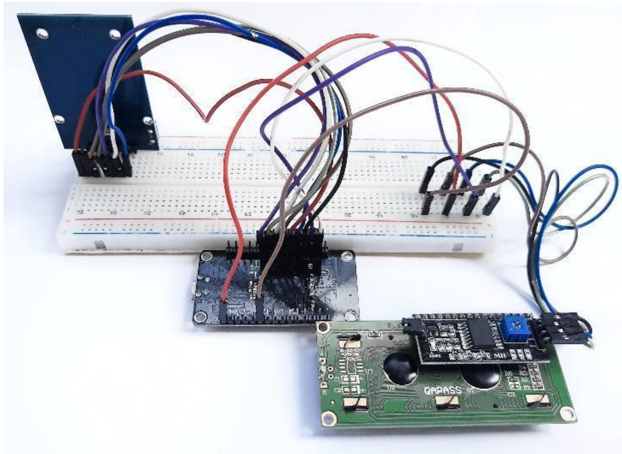


Figure 3 Hardware Implementation

We use a flowchart modelling tool to describe the flow, i.e. the inbound stock flowchart, the stocktake flowchart, and the outbound stock flowchart. The flowchart in Figure 4 describes the process of inputting newly stocked items. Before a user scans a tag, he must change the RFID reader mode to add item mode and select the add item button. When the user scans a tag, it will display that the tag is read successfully and if the tag's UID data is sent to client, the user can input the item's information. If the data newly stocked item will be saved in the database if the information entered by the user is valid and there are no duplicate tag's UIDs.

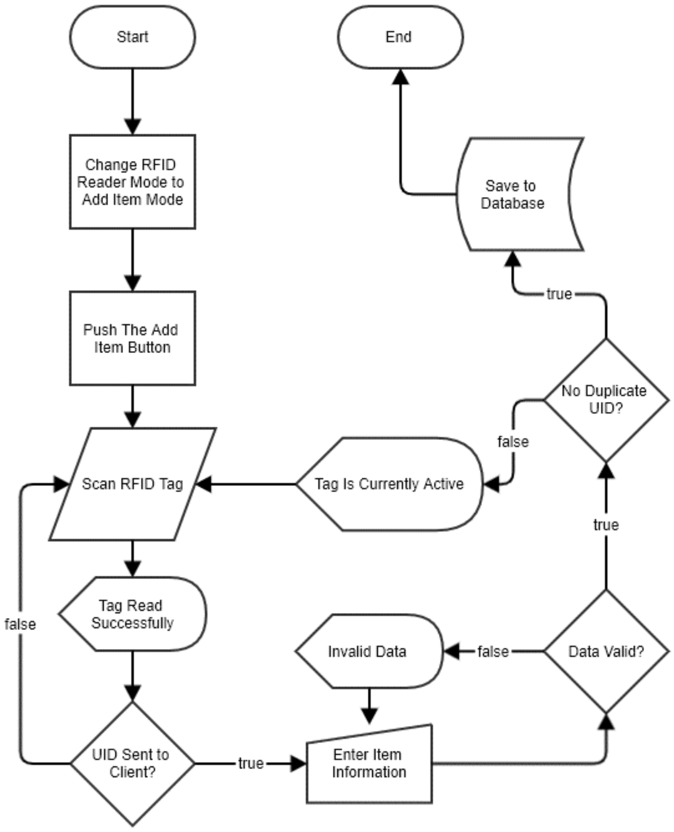


Figure 4 Inbound Stock Flowchart

The flowchart in Figure 5 describes the system's workflow when performing stocktakes. First, the user must pick a tray, change the RFID reader mode to stocktake mode, get items that belongs to that tray, and reset the items' status to "not scanned". When the user scans a tag, it will display that the tag is read successfully. Then if the tag's UID data is sent to client and the item's status is "not scanned", it will display that the tag is scanned successfully and the item's status is set to "scanned". If all tags have been scanned, the database is updated. If the finish button has been clicked and some items are still "not scanned", their status will be changed to "missing".

The flowchart in Figure 6 describes the system's workflow when registering outbound stock via the web application. Before the user scans a tag, he must change the RFID reader mode to outbound mode and select the add item button. When the user scans a tag, it will display that the tag is read successfully and if the tag's UID data is sent to client, the tag's UID is not duplicate, and the tag is registered in the database, it will display that the tag is successfully added. If there are no more tags to scan, the users can select the post report button and the outbound stock will be saved in the database.

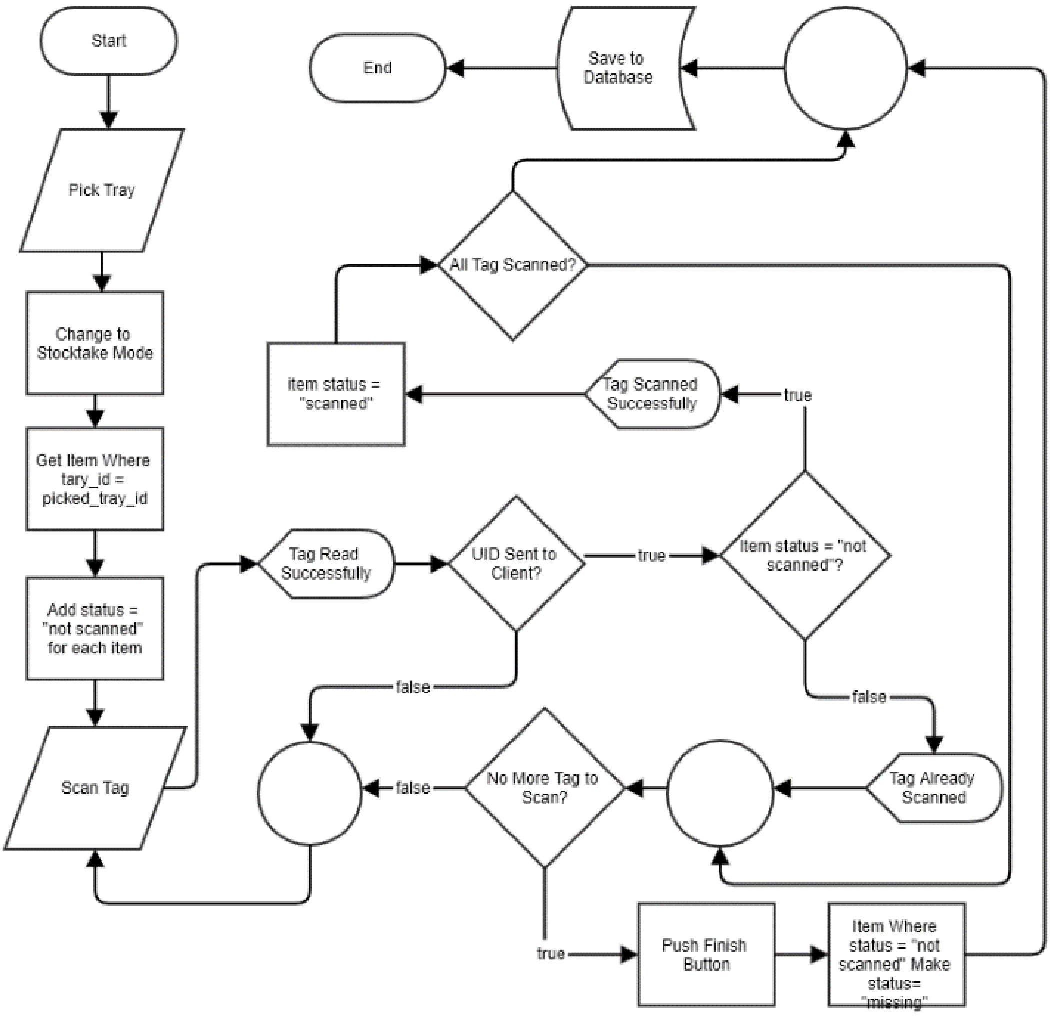


Figure 5 Stocktake Flowchart

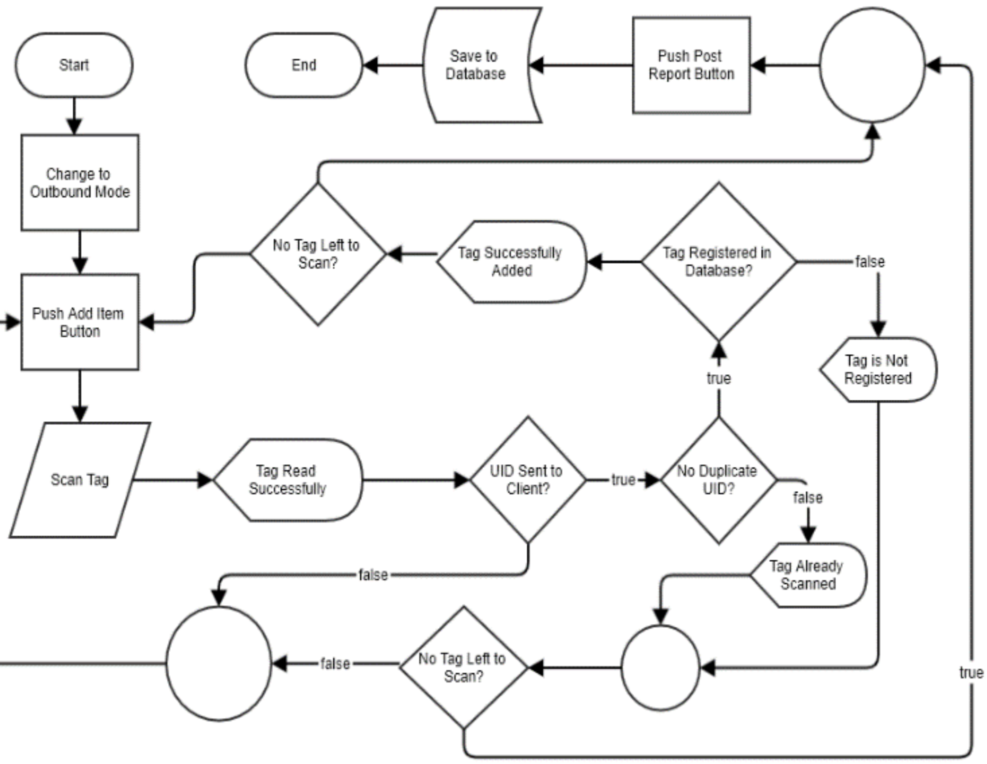


Figure 6 Outbound Stock Flowchart

The database is designed using the Crow's Foot Entity Relationship Diagram (ERD) modelling tool and implemented using MySQL as the Database Management System (DBMS). Database administration is done through the PHPMyAdmin administration tool. Figure 7 is the ERD that models the entity's relationships and attributes. There are eight tables in total, i.e. user, tray, item, item_check_repot_detail, item_check_report, supplier, outbound_report, and outbound_report_detail. The attributes and relationships are shown in Figure 7.

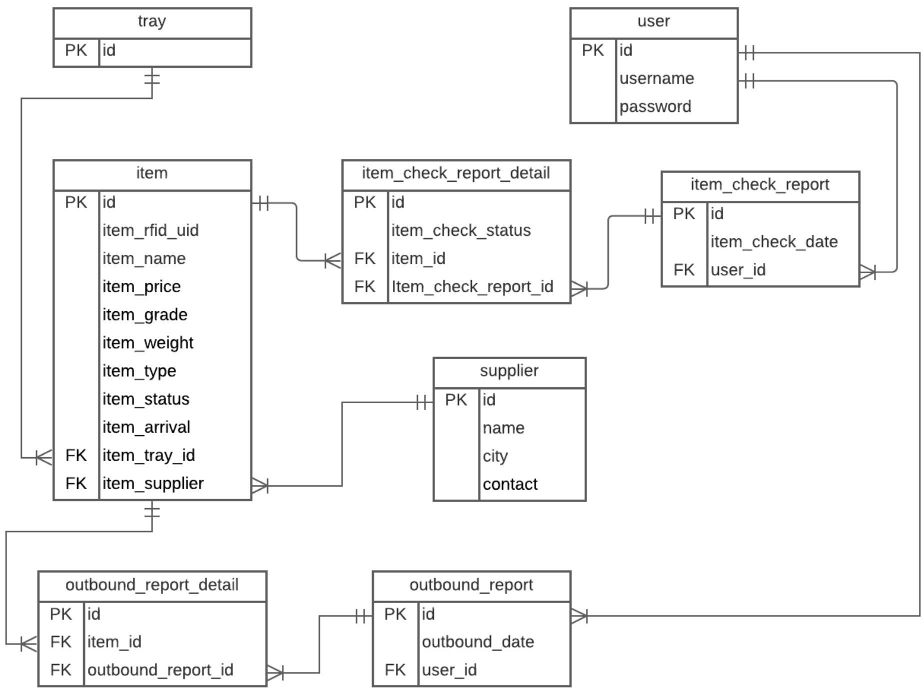


Figure 7 Entity Relationship Diagram

RESULTS

This section utilizes the system and interface designs and turns them into a fully working hardware and software by implementing critical functions and displaying data through a user-friendly interface. The following figures are the results of implementing the designs of the web-based application.

Figure 8 is the result of the implementation of the dashboard design. This page consists of three components: datepicker, majority card, and historical stock chart. The datepicker is responsible for defining and showing the timeframe of data sample in the database that the algorithm will process. Meanwhile, the majority cards and historical stock chart are responsible for displaying the gold item category that makes up the majority of outbound stock and charting outbound stock data based on the period specified in the datepicker component. The primary function of this page is to display the results of data analysis performed using the Boyer-Moore majority vote algorithm.

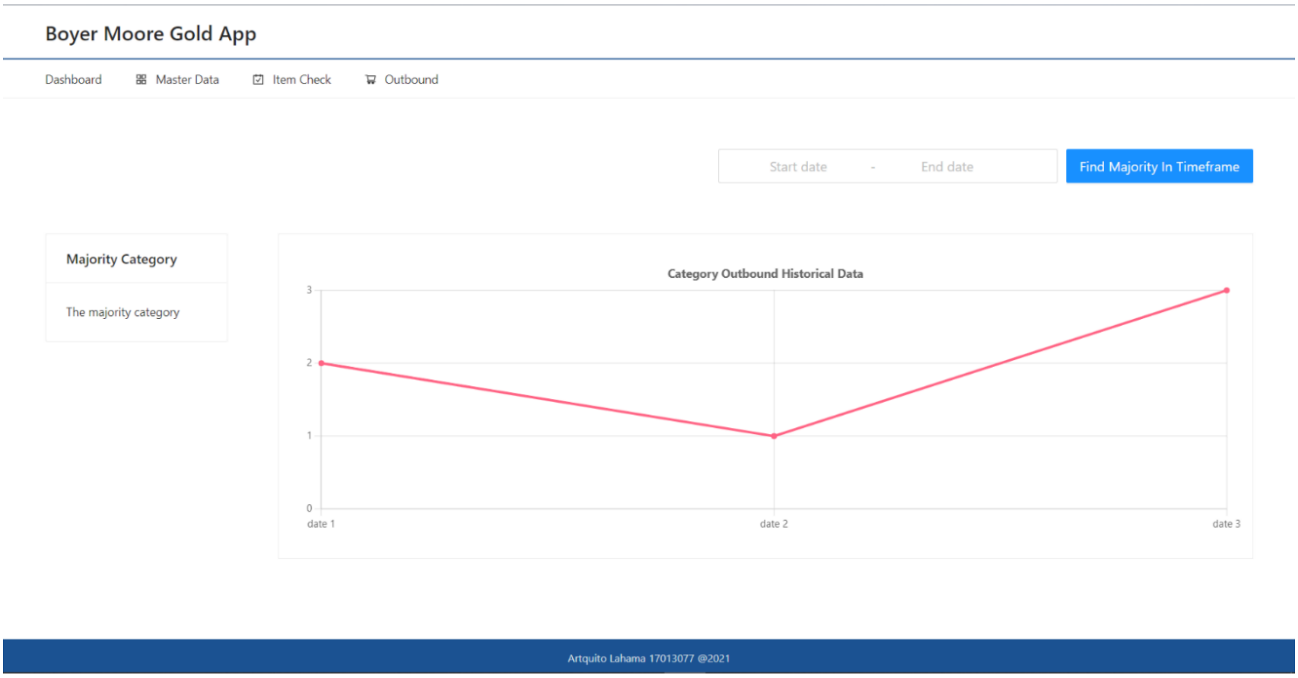


Figure 8 Dashboard

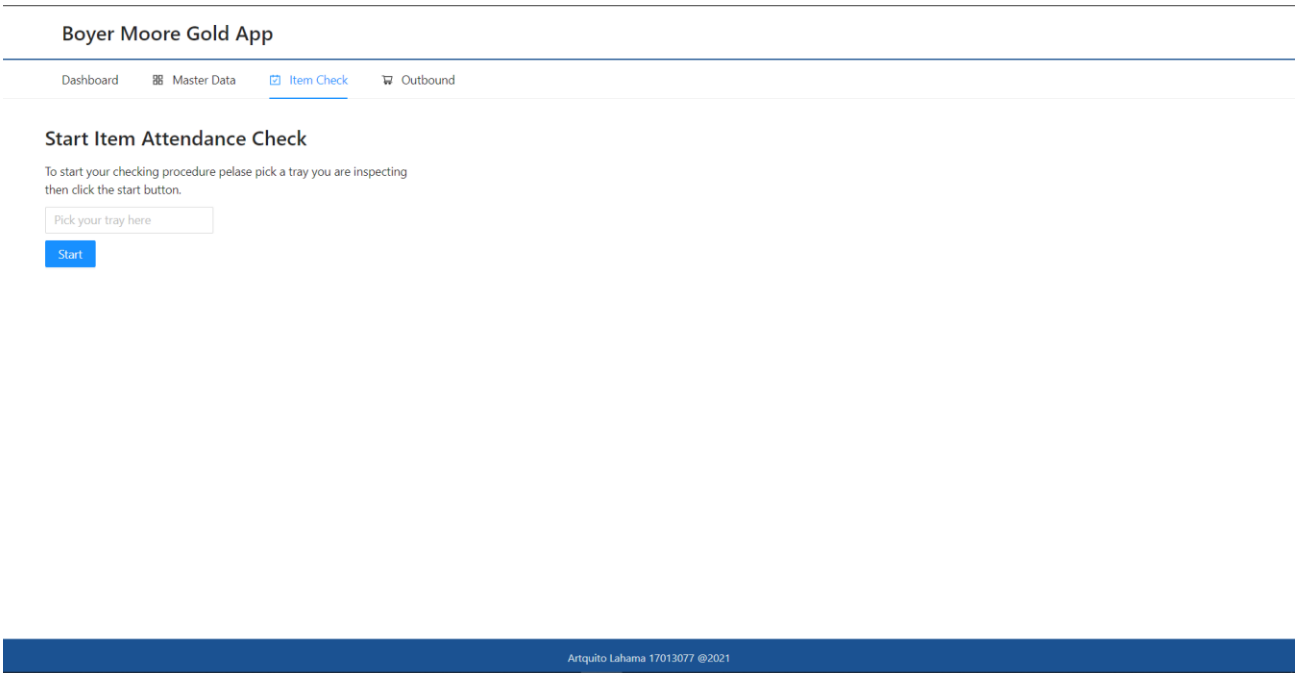


Figure 9 Tray Picker View

Figure 9 shows the result of implementing the tray picker view design. The tray picker view is a collection of components in the stocktake page displayed when the page first opens. In this view, users can select a gold tray for inventory review. This view shows several interface components such as explanatory text and a tray selector component consisting of an input field and a confirmation button.

Figure 10 shows the results of the design implementation of the item list view. Like the tray picker, the item list view is a collection of components serving a particular purpose, displaying a list of items stored in the selected tray and the status of items, whether they are "scanned" or "not scanned." The item list view shows data through a table and the RFID reader is the only device that can manipulate the table's data. A user is able to click on the "finish scan" button to end the tray check. After inspecting all items, the stocktake page will return to the tray picker view and then store the inspection data in the application's database.

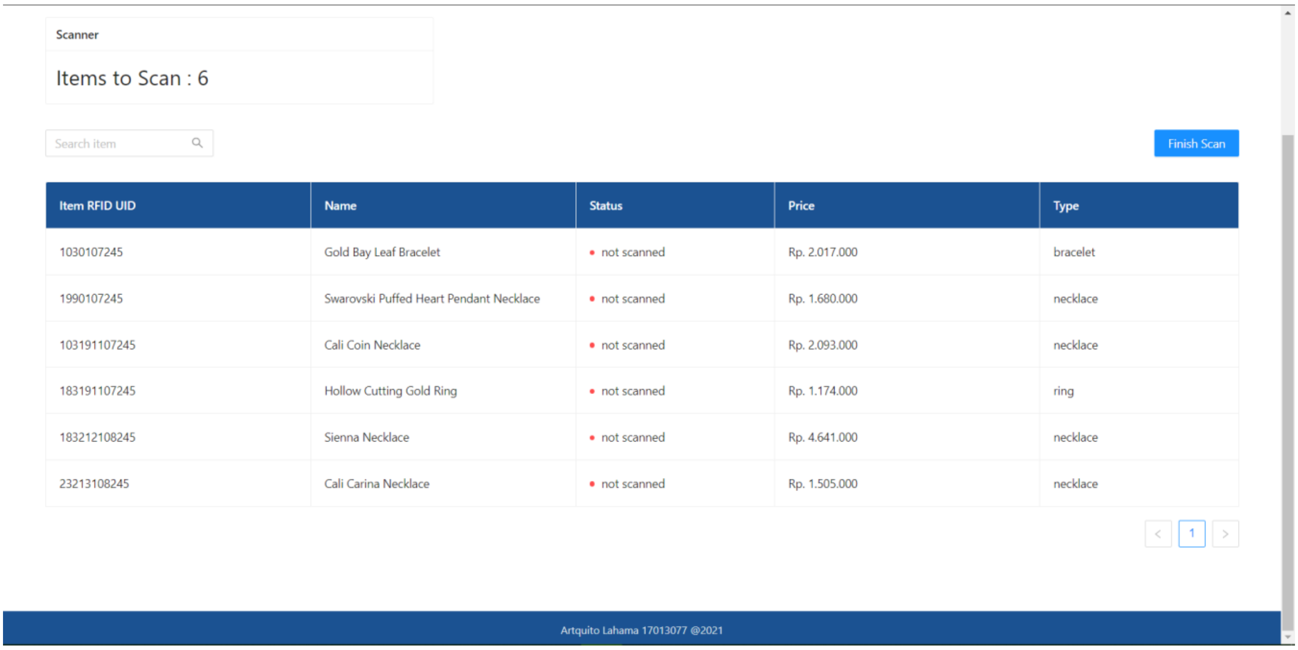


Figure 10 Item List View

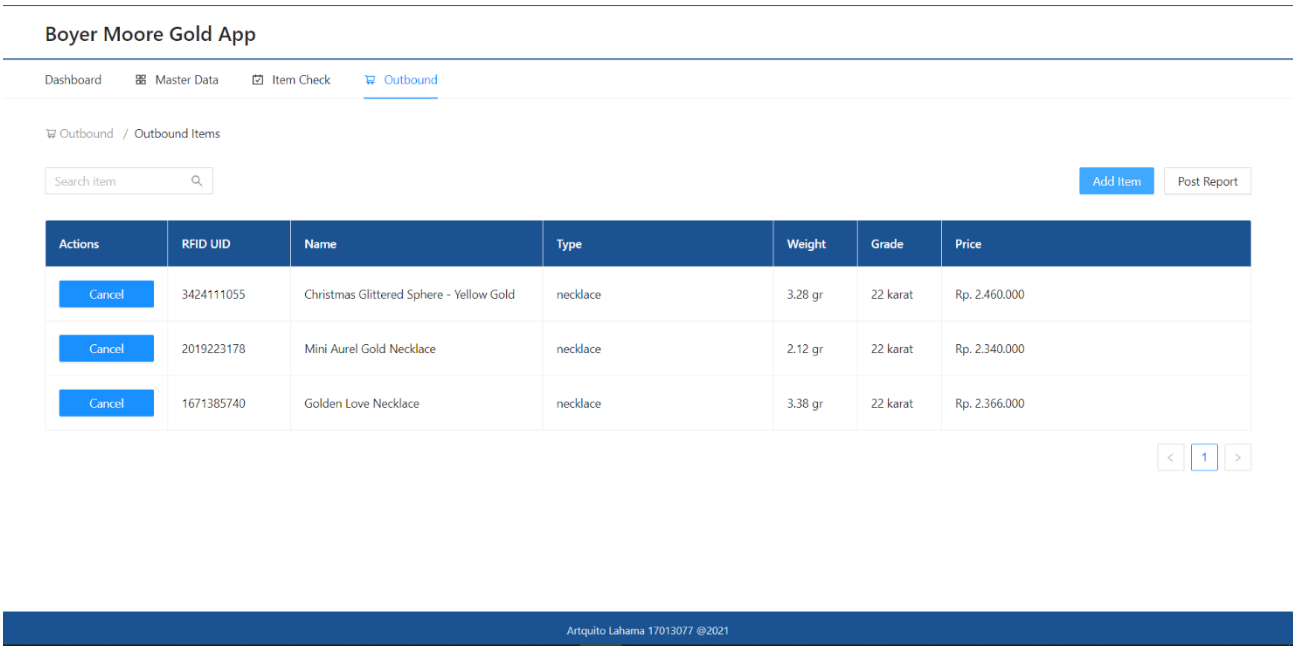


Figure 11 Outbound Page

Figure 11 shows the result of implementing the outbound page design. This page communicates with the MQTT broker to capture tags' UID data detected by the RFID reader. The primary function of this page is to store and classify data items that are outbound from storage.

Then, we did some tests to provide insight into the capabilities and limitations of the IoT-based Boyer-Moore inventory management system consisting of an RFID reader and a web-based application. The following are the criteria for testing the Boyer-Moore IoT-based inventory management system.

1. The RFID reader must be able to send data to the MQTT broker, which will forward the data to a client using the Google Chrome browser.
2. The RFID reader should be able to scan a lined set of tags and work well in the Google Chrome browser.
3. Web-based applications must be able to run using the following three browsers, namely Google Chrome, Microsoft Edge, and Mozilla Firefox, with the latest versions at the time of testing.

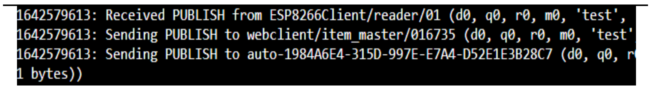
Table 3 Test Case

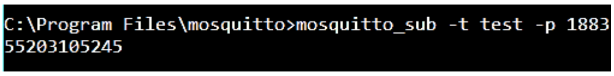
Testing Scenario	Details
Test involving data delivery from the RFID reader to the broker and the broker to the client.	Before starting the experiment, activate the Eclipse Mosquitto MQTT broker. After the broker runs and the RFID reader is connected, the RFID reader scans the RFID tag to initiate data transmission. Next, the broker will receive the data showing its activity through the command line application. After that, the broker will forward the data to the client. A command line application from Mosquitto will simulate the client by showing the received data packet in the broker. Scanning 20 unique RFID tags is the execution method used for this test.
Test RFID reader accuracy when scanning multiple RFID tags.	For each test, N RFID tags are selected and placed in a row, where $N = \{5, 10, 15, 20, 25\}$. After that, the RFID reader scans the collection of RFID tags. For each N, five trials were performed, in which N was randomly selected in each trial.
Test different browser compatibility.	The application is tested using Google Chrome, Microsoft Edge, and Mozilla Firefox browsers.

Table 3 is a table of all scenarios and details of the test cases performed on the system. The first test to be performed is the data delivery test. This test evaluates the connection between the RFID reader and the web application and determines whether the tag's UID data transmission is working as intended. The data delivery test uses an eclipse command line application to monitor broker activity and simulate a client listening for incoming data from the RFID reader.

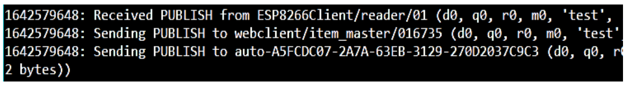
Table 4 Data Delivery Test Results

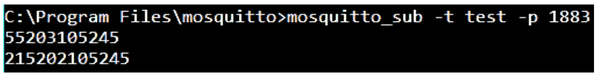
Test Pictures and Description



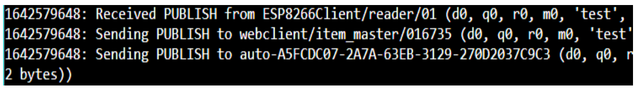


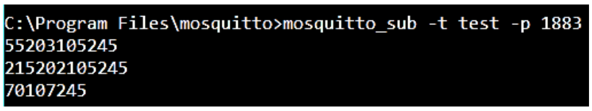
The broker successfully received the first RFID tag's UID data and forwarded it to the client, who displayed the RFID tag data with the UID 55203105245.



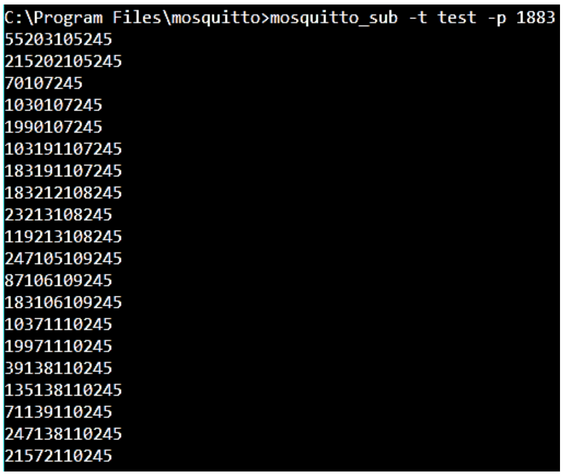


The broker successfully received the second RFID tag UID data and forwarded it to the client, who displayed the RFID tag data with the UID 215202105245.





The broker successfully received the third RFID tag UID data and forwarded it to the client, who displayed the RFID tag data with the UID 70107245.



The broker received 20 RFID tag UID data and forwarded all of them to the client.

The test in Table 4 showed that the RFID reader could read the RFID tag and forwarded it to the broker, then the broker passed it to the listening client.

The RFID reader accuracy test's main purpose is to measure the accuracy of the RFID scanner when scanning multiple RFID tags in one pass. A total of N RFID tags were selected randomly, where $N = \{5, 10, 15, 20, 25\}$. After that, a set of tags was lined in parallel on a flat surface then scanned quickly. These randomization, alignment, and scan process were repeated five times for each N. When the RFID reader sent data to the broker, the data were forwarded to all listening clients. Then the clients updated the display so that the user could observe the number of items that had not been scanned.

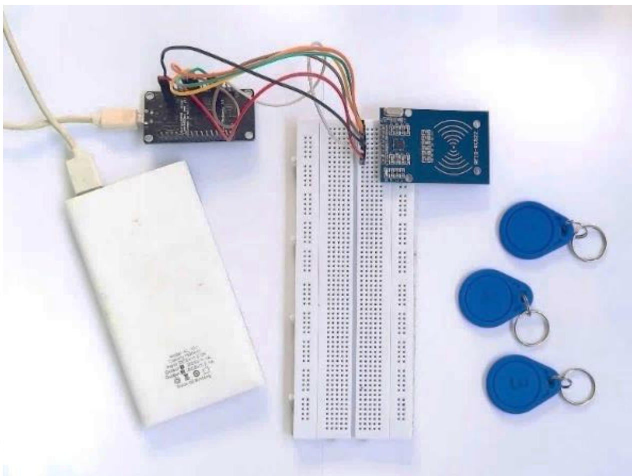


Figure 12 RFID Reader Accuracy Test

Table 5 RFID Reader Accuracy Test Data

No	Number of RFID Tags	Number of Successfully Read Tag	Percentage of Successfully Read Tag (%)
1	5	5	100%
2	5	5	100%
3	5	3	60%
4	5	5	100%
5	5	5	100%
6	10	10	100%
7	10	10	100%
8	10	10	100%
9	10	10	100%
10	10	10	100%
11	15	15	100%
12	15	15	100%
13	15	15	100%
14	15	15	100%
15	15	15	100%
16	20	20	100%
17	20	20	100%
18	20	13	65%
19	20	20	100%
20	20	20	100%
21	25	10	40%
22	25	17	68%
23	25	25	100%
24	25	24	96%
25	25	25	100%
Average			**93.16%**

The details of the test data in Table 5 showed that the accuracy of the RFID reader has an average of 93.16% from 25 scan trials. The causes of some inaccurate scans might be due to:

1. RFID tags blocked each other's data transmission signal to the RFID reader. This occurred when two or more RFID tags were stacked on top of each other.
2. The RFID reader components and cables were not put into a casing. This led to physical interference during operation, resulting in data transmission inconsistencies.
3. The distances between the RFID reader antenna and the RFID tags exceeded the reading distance limit.
4. The scan processes were too fast. Therefore, the RFID reader did not have enough time to read the tags it passed by.

In the browser compatibility test, the application was run on three different browsers, namely Google Chrome, Microsoft Edge, and Mozilla Firefox. Browser specifications at the time of the test can be seen in Table 6. Based on the test results, the user interfaces shown on the three browsers were according to the design, and the function of retrieving and inputting data worked as intended. Therefore, it was concluded that the application could run on the three browsers.

Table 6 Browser Specifications

Browser	Version	System Type
Google Chrome	97.0.4692.71	64-bit
Microsoft Edge	96.0.1	64-bit
Mozilla Firefox	97.0.1072.62	64-bit

DISCUSSION

The implementation of the Boyer-Moore algorithm must produce the same output as the manual calculation. Therefore, firstly we tested the algorithm's output with a majority element. The output of the algorithm in the web application was compared to the result of the manual calculation in order to test if the two outputs are the same. Secondly, we test the algorithm's output without a majority element. The output of the algorithm in the web application was compared to the result of the manual calculation.

The data used in the first test, i.e. with a majority element, is presented in Table 7. The Boyer-Moore majority vote algorithm compared the item category data to determine if the data set had a majority element. After the majority candidate had been elected, the Boyer-Moore majority vote algorithm calculated the number of votes of the majority candidate. After that, it determined if the number of votes received by the candidate had exceeded the number of items divided by two. Since the number of votes obtained by the candidate reached a total of four votes (higher than 6/2 = 3), the result had a majority element, that is the "Necklace" item category as seen in Table 8. Figure 13 shows the result of the Boyer-Moore majority vote test in the web application to classify the majority element, which is the same as the manual calculation.

Table 7 Test Data With Majority Element – Comparison Stage

No	Category	Number of Votes	Candidate
1	Bracelet	1	Bracelet
2	Necklace	0	Bracelet
3	Necklace	1	Necklace
4	Necklace	2	Necklace
5	Ring	1	Necklace
6	Necklace	2	Necklace
Majority Candidate		**Necklace**	

Table 8 Test Data With Majority Element – Calculation Stage

No	Category	True/False	Vote Counter
1	Bracelet	False	0
2	Necklace	True	1
3	Necklace	True	2
4	Necklace	True	3
5	Ring	False	3
6	Necklace	True	4
Total Votes		**4**	

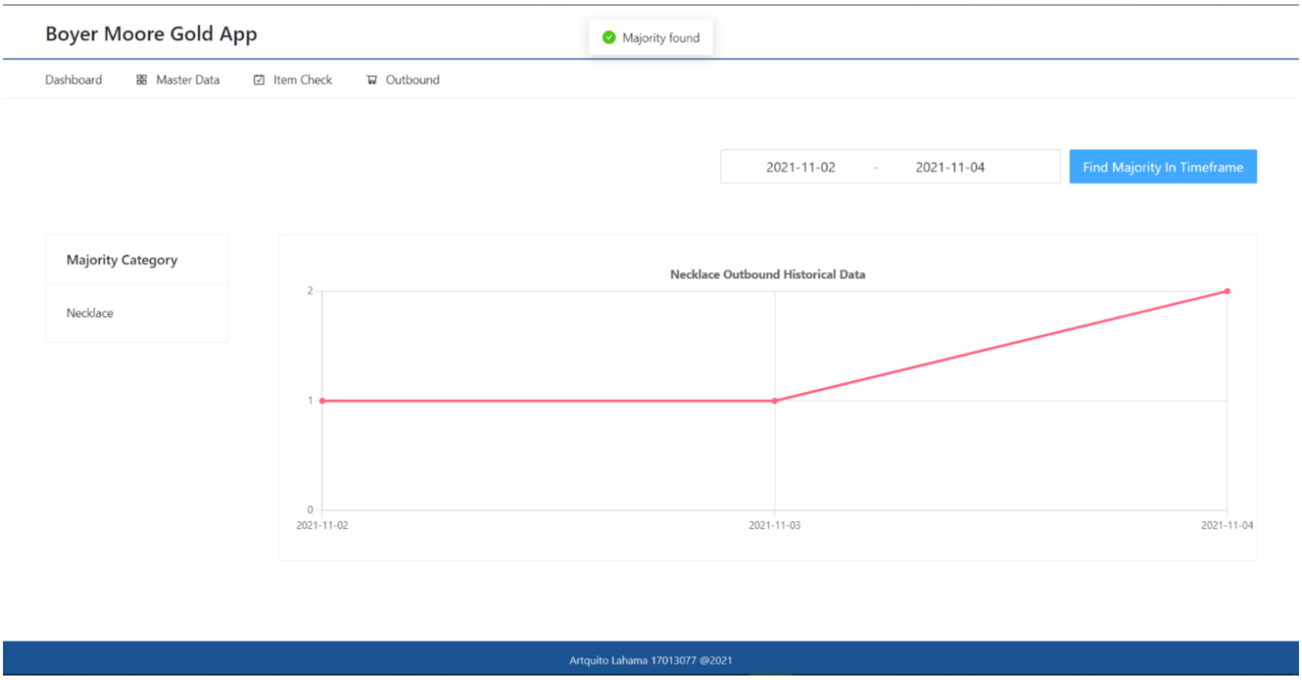


Figure 13 Boyer-Moore Majority Vote Test Result (With Majority Element)

The second test was to use data without a majority element. The algorithm's output was tested by comparing it with the result of manual calculation. The data used in this test is shown in Table 9. The Boyer-Moore majority vote algorithm compared the item category data to determine if the data set had a majority element. After the majority candidate had been elected, the Boyer-Moore majority vote algorithm calculated the number of votes of the majority candidate. After that, it determined if the number of votes received by the candidate had exceeded the number of items divided by 2. Because the number of votes obtained by the candidate reached a total of two votes (lower than 6/2 = 3) as seen in Table 10, the algorithm displayed a message to the user informing them that the data set did not have a majority element. Figure 14 shows the result of the Boyer-Moore majority vote test in the web application. This test indicates that the result in the web application is the same as the manual calculation.

Table 9 Test Data Without Majority Element – Comparison Stage

No	Category	Number of Votes	Candidate
1	Necklace	1	Necklace
2	Ring	0	Necklace
3	Ring	1	Ring
4	Bracelet	0	Ring
5	Necklace	1	Necklace
6	Bracelet	0	Necklace
Majority Candidate		**Necklace**	

Table 10 Test Data Without Majority Element – Calculation Stage

No	Category	True/False	Vote Counter
1	Necklace	True	1
2	Ring	False	1
3	Ring	False	1
4	Bracelet	False	1
5	Necklace	True	2
6	Bracelet	False	1
Total Votes		**2**	

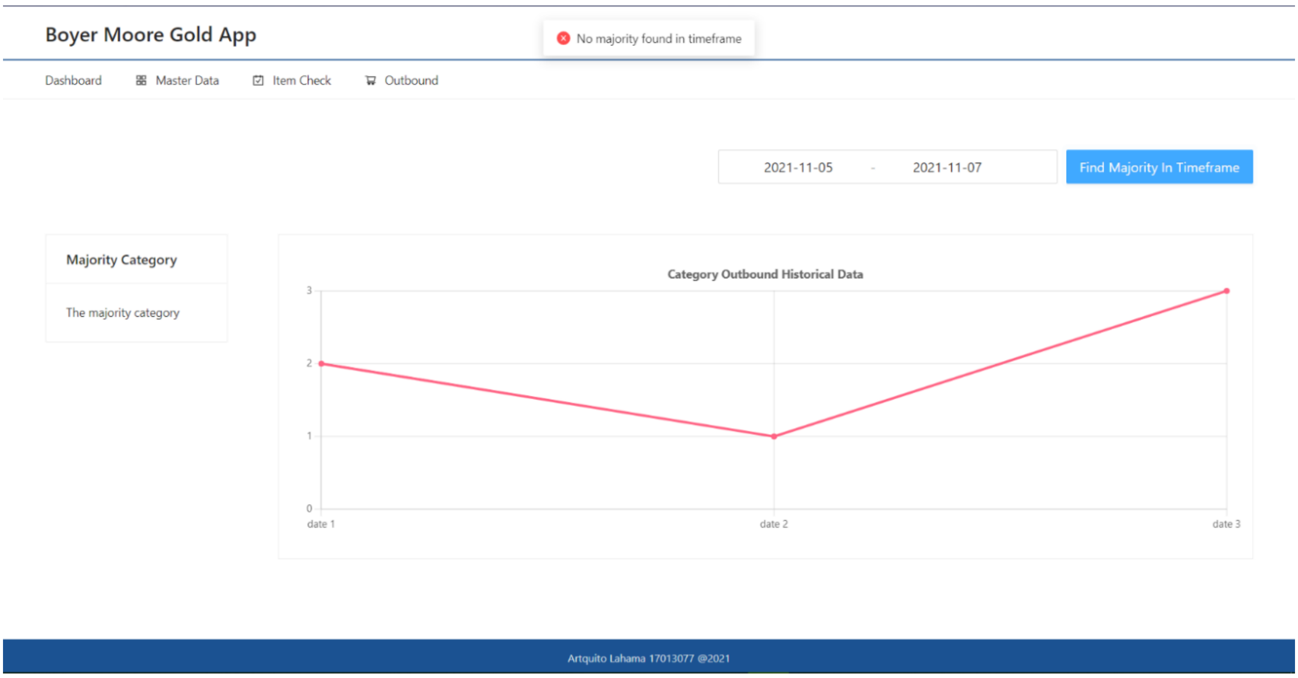


Figure 14 Boyer-Moore Majority Vote Test Result (Without Majority Element)

The closest work, which is discussed in the literature review section, to this paper is the inventory management system using IoT by Tejesh & Neeraja (2018). While their system did not implement any algorithms to support decision making, the inventory management system proposed in this paper utilizes the Boyer-Moore majority vote algorithm to indicate a category of gold items that is in very high demand, i.e. the best-selling jewelry category. Hence, this kind of information can be used as a factor when purchasing new stock.

Conclusions

This paper implements an IoT-based inventory management system for gold jewelry stores to simplify two essential processes: item storage and inventory analysis. It utilizes the Wi-Fi module on NodeMCU ESP8266, which allows gold jewelry stores to send stock data via sensors on an RFID reader connected to an MQTT broker. The RFID reader accuracy test showed that the device can achieve 93.16% accuracy when many tags were scanned quickly. This IoT system can reduce employees' workload that was previously done using the paper-based recording method. Critical functions in the web application, such as the Boyer-Moore algorithm's classification of popular item category, can run well on Google Chrome, Microsoft Edge, and Mozilla Firefox, as shown in the browser compatibility test. This shows reliability of the software side of the system. This paper, through multiple tests, has proven that the system has met the requirements of an effective IoT-based inventory management system in a gold jewelry shop.

The following are some suggestions for future works. The inventory management system can be integrated with a sales system to complement each other during operation, where gold price is adjusted daily based on the gold market price. In addition, from the software development point of view, one can try to use a broker that is hosted in the cloud.

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