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Internet of things and radio frequency identification based embedded system to reduce shopping time in supermarkets

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ABSTRACT

Doing daily shopping in a Peruvian supermarket means a large investment of time for many people, usually due to inaccurate and faulty scanning of products by barcodes at supermarket checkout counters. For this reason, an embedded system based on internet of things (IoT) and radio frequency identification (RFID) is designed to reduce shopping time in a supermarket. The system uses an ESP32 development board with embedded hardware specialized in IoT projects and firmware development based on C language and real-time operating systems (FreeRTOS) through espressif's IoT development framework (ESP-IDF). RFID tags were used to scan the products and IoT with message queuing telemetry transport (MQTT) communication protocol are implemented to a local database in real time. The system achieves a significant reduction in terms of scanning time compared to self-service checkouts using barcodes, which allows to statistically analyze the reduced time per quantity of products and the linear trend of the 2 samples.

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1. INTRODUCTION

Currently, shopping in supermarkets can pose several challenges such as delays due to long queues and checkout lines causing considerable waiting time for customers [1]. Therefore, optimizing this time using current technologies, modernizing the traditional shopping system, can drastically reduce this problem [2], benefiting customers by providing them with peace of mind and convenience when shopping. On the other hand, entrepreneurs, modernizing their businesses and causing a greater influx of customers.

Different systems were developed based on various approaches. One of these is to ease the challenge of pushing a shopping cart by designing a prototype that follows the movement of the customer alleviating the need to push it [1], [3], this is important as it is based on the welfare of people with special motor needs, however, in terms of the problem of their research it does not involve a general problem for most people who go to a supermarket as it is the high shopping time. Also, other research focuses on implementing an automatic billing system with the help of internet of things (IoT). Subudhi and Ponnalagu [4] developed prototype was connected to the servers of a real-time payment system called unified payments interface (UPI), developed by the National Payments Corporation of India (NPCI) and used daily in that country through a mobile application. However, in [5]-[7] this approach is completely experimental, since the implementation requires access to payment services through payment gateways and banking credentials which are totally private in many countries. On the other hand, researchers focus mostly on addressing the process of automatic product detection, mostly using radio frequency identification (RFID) which improves product detection and drastically reduces its scanning time compared to classical barcode detection, which due to physical damage or foreign elements interferes and delays its detection [2], [8], [9]. Also, a system capable of directly reading the barcodes already present in the products is also presented through a scanner incorporated in the system [10]-[13], disagreeing with the use of the mentioned scanning methods. But, it is counterproductive since the previous articles mention the detection problems presented by barcodes, then this system would also present the same detection problems and consequently, delays in the purchase.

Regarding the development tools used, the Arduino development board is the most widely used to realize the proposed systems based on product RFID and data manipulation to display relevant information to the user through a liquid crystal display (LCD) and add it to their payment list through a database [6], [8], [14]-[20]. However, the operating response is very slow and the LCD display does not generate a good interface for the customer. On the other hand, a Raspberry Pi-based system was developed also based on RFID, IoT, and LCD interface, but adding a camera oriented to detect a customer's tag and follow its movement by driving motors attached to its tires [1], [3] and Wi-Fi communication [21]. Although, Raspberry Pi is oriented to develop systems that require high processing power by having a microprocessor, this system can be developed with a low-cost microcontroller and obtain the same results. On the other hand, another research uses a low-cost Bolt Esp8266 chip exclusively to facilitate the developer to quickly deploy the system towards IoT including dedicated servers [10]. Although, using the private servers of the Bolt IoT manufacturer is risky since the information gets into the hands of third parties.

In addition, the tools used for wireless data transfer in the proposed systems involve an important technological aspect. On the one hand, some researches use IoT technology, accessing them through the cloud [2], [5], [6], [8], [15], [16], [18], [19], [21]-[23]. On the other hand, other researchers chose to use transmitter modules such as global systems for mobile communications (GSM) [17], network modules using XBee/ZigBee communication protocol [7]-[9], [20], and nRF24 model wireless transceivers [1], [24]. These communication tools are very limited, since they are based on point-to-point communication limiting the transmitter to a single receiver or in this case to a single box in the facility, therefore it is convenient to use the IoT as a wireless data transfer tool.

About results, most researches present implementation prototypes [1]-[3], [5]-[10], [14]-[19], [25]. However, a comparison was presented regarding the shopping time experienced by a customer with the traditional system of the store versus the proposed system, considering the total number of products, scanning time, bagging time and payment time by [16]. This was achieved by providing the point of sale with a system connected to the research database, resulting in a zero scanning time which reduces the purchase time by 50%.

After analyzing the previously developed research, the most important weaknesses were identified. For example, Arduino is known worldwide for providing embedded systems development through high-level programming, which is focused on the hobbyist community, using this environment for a formal and academic research work can bring hardware and software problems. Now, it is important to provide the user with an adequate visualization stage, so it is outdated to use an LCD as a visual medium because it limits the information of the product to be acquired. Similarly, it is important to provide the data not only to the stores' pay stations, but also to the customers so that they can efficiently manage the items they wish to purchase. Therefore, these weaknesses are taken as an opportunity for improvement in the development of this research.

Finally, this research, through the design of an embedded system based on IoT and RFID to reduce shopping time in a supermarket, statistically compares the time that a customer, using the system, presents when scanning a given amount of products versus the time it takes to scan the same amount with barcodes at self-service checkout counters. Therefore, the study aims to demonstrate a considerable reduction in scanning time and, consequently, in purchasing time. Also, to provide an improvement in specialized hardware aspects for IoT projects and a suitable user interface.

2. METHOD

The method designed in this research is carried out experimentally, since the scanning time will be the manipulated variable that, by means of statistical parameters, will be compared when using 2 different environments, the self-service checkouts, which allow the customers of a supermarket to scan a maximum of 10 products to reduce their shopping time, and the designed embedded system. First, the scanning times present in a self-service checkout were timed and a statistical analysis of the data was performed. Then, the proposed embedded system, the database and the algorithm necessary for the operation of the system are proposed. So, to obtain the result of the research, the scanning times with the designed system will be found and analyzed statistically in order to compare the scanning times based on the distance between the points of the arithmetic mean graphs corresponding to the self-service checkouts and the proposed system.

2.1. Collection and statistical analysis at self-service checkout counters

At this stage, a sample of 144 measurements distributed by a number of products greater than 3 is considered, since from this quantity the time is considerable. This collection was carried out by simple inspection at the self-service checkout of a supermarket for a frequency of 18 measurements per product quantity as shown in Table 1. For the statistical analysis of the times, the arithmetic mean and standard deviation of the times per quantity of products, defined by (1) and (2), are considered. Where n is the total number of measurements per quantity of products and x is the time measured. For the data presented, the calculated parameters are shown in Table 2 and the data resulting from the mean and standard deviation allow us to obtain the graph that describes their evolution with respect to the number of products in Figure 1. The graph shows that for 5, 6, 7, 9, and 10 products, there is a significant deviation of the arithmetic mean in the scanning times of the products, this is due to the speed of the person scanning their products or the delay caused by the inaccuracy of barcode scanning.

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

$$S = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{X})^2}{n-1}} \tag{2}$$

Table 1. Scanning times measured by number of products at self-service checkout counters

Quantity of products	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18
3	13.7	13.3	13.2	13.6	15.1	14.2	12.9	13.9	14.1	14.5	13.9	14.1	15.2	14.4	13.2	13.3	12.9	14.9
4	15.3	17.1	16.3	15.9	15.7	16.5	16.1	15.8	16.9	15.2	15.8	15.6	15.7	16.1	16	15.5	15.9	15.9
5	22.3	22.4	23.9	21.8	24.2	24.7	20.8	22.1	24.5	25.1	23.7	22.2	23.8	24.9	22.3	22.6	23.5	25.8
6	26.6	27.1	26.5	27.8	27.1	28.9	27.6	26.7	27.5	28.3	27	27.2	27.5	28.3	26.4	26.9	26.5	28.8
7	36.1	33.8	33.4	35.3	36.4	34.7	33.5	34.4	35.1	35.5	32.9	34.5	35.8	34.1	33.2	34.3	34.1	35.9
8	37.4	38.9	38.1	38.4	37.6	39.4	37.2	38.8	38.2	39.1	37.9	38.2	37.6	39.9	38	38.2	39.2	39.7
9	42.6	40.5	42.5	41.9	44.7	43.6	45.8	43.1	44.6	45.2	41.7	41.9	43.7	43.8	44.4	43.9	43.6	45.5
10	47.6	47.1	48.6	47.3	49.7	47.4	49.8	50.1	48.3	48.1	48.3	46.9	48.5	47.2	49.5	50.2	49.3	48.9

(Header row: "Measured time (s)" spans columns T1–T18.)

Table 2. Mean and standard deviation of self-service checkout data

Quantity of products	Mean ($\bar{x}$)	Standard deviation (S)
3	13.91	0.717
4	15.96	0.496
5	23.37	1.360
6	27.37	1.412
7	34.61	1.056
8	38.43	0.797
9	43.50	1.441
10	48.49	1.093

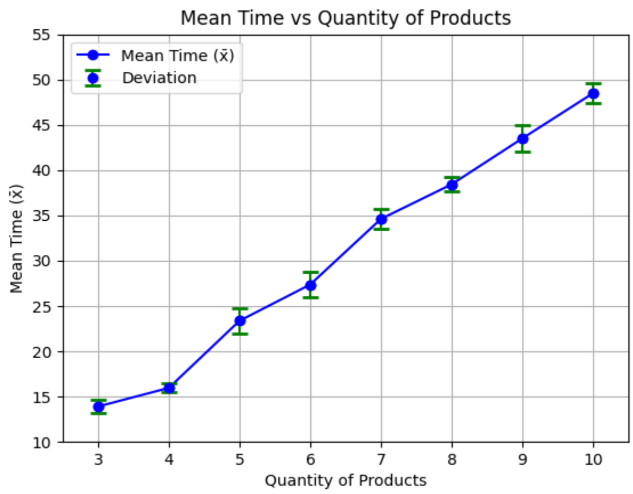


Figure 1. Mean time and deviation of self-service checkout scan times

2.2. Embedded system components

At this stage, a sample of 144 measurements distributed by a number of products greater than 3 is considered, since from this quantity the time is considerable. This collection was carried out by simple inspection at the self-service checkout of a supermarket for a frequency of 18 measurements per product quantity as shown in Table 1. In this study, an embedded system dedicated to IoT application and proper use of multitasking such as constantly sending and receiving information with a database connected to the internet, performing RFID tag scanning and managing the display stage for the user is required. Therefore, the ESP-32 development board is used which has a wide variety of advantages and features for the research such as a dual-core ESP32-D0WDQ6 microcontroller with a clock frequency of up to 240 MHz providing high processing capacity, a built-in antenna for wireless communications and support for programming based on real-time operating systems (FreeRTOS) through ESP-IDF being ideal for projects with the need to have the execution of multiple tasks in parallel.

About components interconnected to the microcontroller, the RFID tag reader module RC522, the 2.4" TFT LCD display ILI9341 and 3 pushbuttons for user interaction are used as shown in Figure 2. An RFID module RC522, which operates at a frequency of 13.56 MHz and is based on the MFRC522 chip [4], is used to scan the products. In addition, the presented design uses the serial peripheral interface (SPI) communication interface to the ESP-32 through 7 pins detailed in Table 3. For the display of the scanned products a 2.4" color TFT LCD display with 320×240 pixels resolution is used, which uses a bidirectional 8-bit data bus from the ILI9341 controller to the ESP-32 of the display. The controller uses 16 Bit (RGB565) to control a pixel display, so it can display up to 65000 colors per pixel, where the pixel address setting is done in row by column order and the increment and decrement direction is determined by the scanning mode. The display method is performed by setting the address and then setting the color value. The wiring connection between the display and ESP-32 is detailed in Table 4.

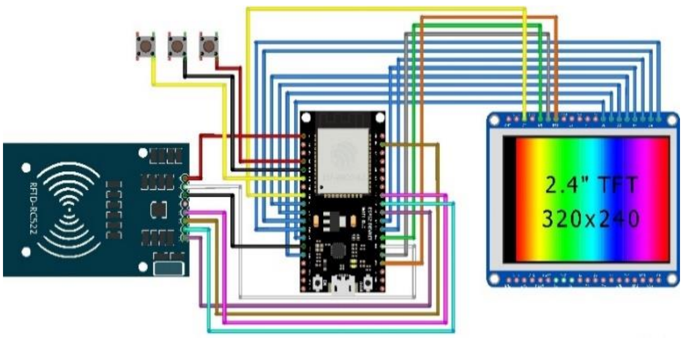


Figure 2. Schematic diagram of the designed embedded system, own elaboration

Table 3. Wiring connection between RC522 RFID module and ESP32

RC522 pins	ESP32 pins
VCC	+3.3 V
RST	+3.3 V
GND	GND
IRQ	Not connected
MISO	GPIO 19
MOSI	GPIO 23
SCK	GPIO 18
SDA	GPIO 5

As for the inputs to the ESP-32, these correspond to the reading of the unique ID (UID) of the RFID tags. Additionally, because the maximum number of items in a self-service checkout is 10, the same amount of passive RFID tags is used, which, being passive, do not require power for its operation, but the reader by means of an electromagnetic field induces an electric current that energizes the tag [13]. In addition, 3 pushbuttons are established for user interaction, which are start, delete and end, these pushbuttons are located correspondingly in GPIO 35, 34, and 39. On the other hand, the outputs of the ESP-32 correspond to the information sent to the database and user interface, which displays the product information on the screen, providing the information to the user in an optimal way. The flow of inputs and outputs can be observed through the general block diagram of the system in Figure 3.

Table 4. Wiring connection between ILI9341 2.4" TFT LCD display and ESP32

LCD TFT 2.4” ILI9341 pins	ESP32 pins
D0	GPIO 12
D1	GPIO 13
D2	GPIO 26
D3	GPIO 25
D4	GPIO 17
D5	GPIO 16
D6	GPIO 27
D7	GPIO 14
CS	GPIO 33
WR	GPIO 4
RD	GPIO 2
RS	GPIO 15
RST	GPIO 32

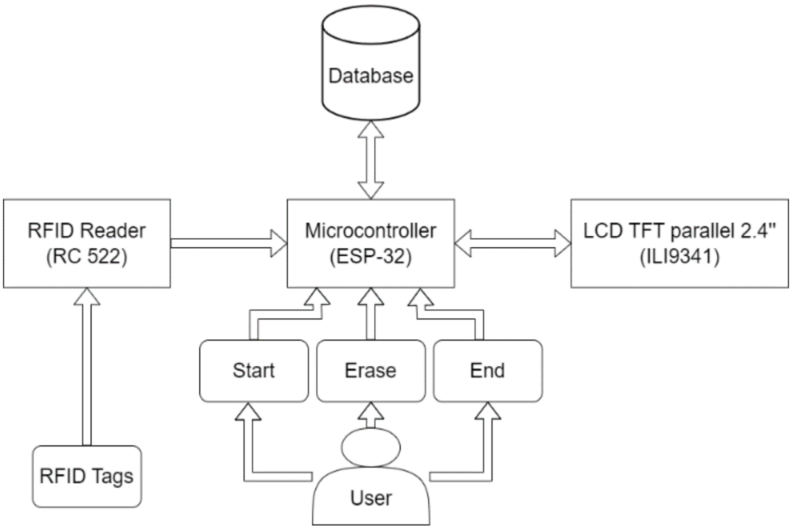
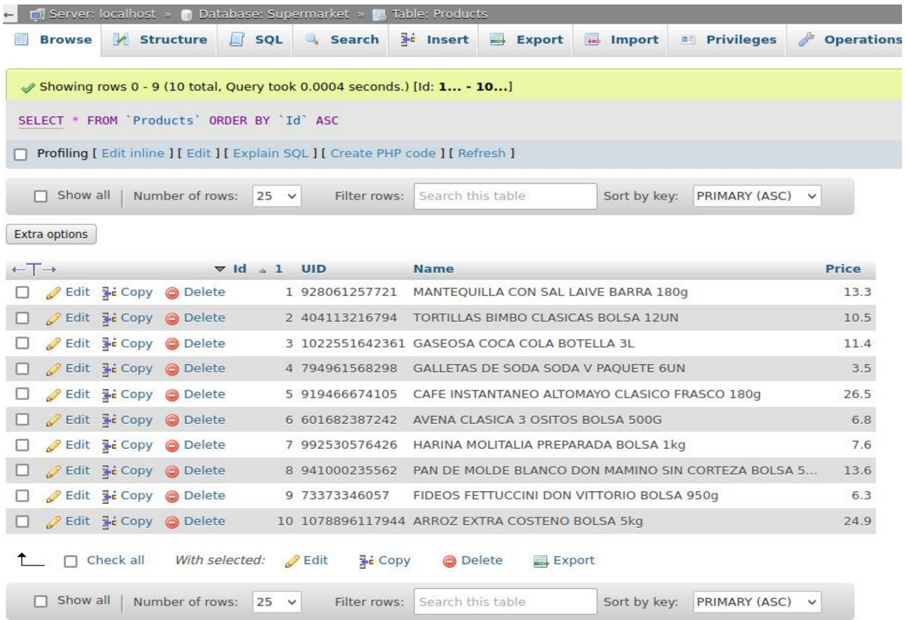


Figure 3. General system diagram. Own elaboration

2.3. Database design and connection

The design and connection stage with a database that supports the information of the existing products and the purchase records of each user is vital for the purpose of the research. That is, the connection between the embedded system and the database must be reliable, fast and low latency, using an environment that can implement such a connection and generate the necessary logic to efficiently manipulate the data stored in the database. Therefore, for the connection between the embedded system and the database, the MQTT communication protocol is used through TCP port 1883 via Wi-Fi connection in the ESP-32. This protocol is efficient for IoT applications, since it presents low bandwidth consumption and latency, allowing a reliable connection and exchange of information with the database through the method of subscription and publication to topics through a broker, in this case the free broker Mosquitto is used.

Likewise, the database is implemented with phpMyAdmin as a tool for data administration and my structured query language (MySQL) for data management. The former provides a friendly user interface allowing to create databases with their respective tables in a fast and intuitive way and the latter allows to configure the local server and port 3306 as MySQL service. Because, in the research it was defined to use 10 RFID tags for the scanning of products, a database named "Supermarket" is created with the table "Products" of 10 supermarket items which contains: Id, an integer value of the row to which the product corresponds; UID, a character string of the unique identifier of the RFID tag; name a string of characters corresponding to the name of the product; and Price a floating value for the price of a product based on current prices in different supermarkets. These characteristics are inserted into the table through the graphical interface or can also be manipulated through queries with SQL commands, for a set of products detailed in Figure 4. In addition, additional tables are included which will be created from the unique purchase code generated per user, where the same columns as in "Products" are included and will contain the products that users will scan.



Id	UID	Name	Price
1	928061257721	MANTEQUILLA CON SAL LAIVE BARRA 180g	13.3
2	404113216794	TORTILLAS BIMBO CLASICAS BOLSA 12UN	10.5
3	1022551642361	GASEOSA COCA COLA BOTELLA 3L	11.4
4	794961568298	GALLETAS DE SODA SODA V PAQUETE 6UN	3.5
5	919466674105	CAFE INSTANTANEO ALTOMAYO CLASICO FRASCO 180g	26.5
6	601682387242	AVENA CLASICA 3 OSITOS BOLSA 500G	6.8
7	992530576426	HARINA MOLITALIA PREPARADA BOLSA 1kg	7.6
8	941000235562	PAN DE MOLDE BLANCO DON MAMINO SIN CORTEZA BOLSA 5...	13.6
9	73373346057	FIDEOS FETTUCCINI DON VITTORIO BOLSA 950g	6.3
10	1078896117944	ARROZ EXTRA COSTENO BOLSA 5kg	24.9

Figure 4. Table of products from supermarket database

About the environment capable of implementing MQTT communication and manipulating database features, Node-RED is used because, through its nodes or programming blocks based on JavaScript, it integrates the "mqtt in" and "mqtt out" nodes, where the first one subscribes and the second one publishes to a specific topic of the broker. It also integrates the "mysql" node, which allows accessing the database of a host server and its port in a configurable way. Through the function nodes in Node-RED, JavaScript code is implemented to manipulate the data received by the subscription nodes and the data to be sent to the ESP-32 by the publication node and SQL queries to the database configured in the mysql node through the properties of the "msg" object such as "msg.payload" and "msg.topic". The SQL queries will be those corresponding to extract data from the products table, create the users table, insert data in it and delete a specific product.

2.4. System flowchart

The flowchart in Figure 5 shows the algorithm implemented in the system, for a better understanding the 2 stages of the system, ESP-32 and Node-RED (My SQL) are placed specifying the topic to which the mentioned stages are published or subscribed for the exchange of information. Regarding the programming environment used for the implementation of the algorithm, the espressif IoT development framework software development kit (ESP-IDF SDK) is used, configured as an extension in the visual studio code editor, since it is the official programming environment provided and supported by the ESP-32 espressif card manufacturer, allowing maximum use of the microcontroller features and applying dynamic memory allocation techniques for advanced data structure management such as the use of linked lists in the form of dynamic stacks. First, a unique purchase code is created for each user and published through the topic "esp32/user" to create a table in the database containing the name of the previously generated code. Then, the UID of the RFID card is read and published to Node-RED through the topic "esp32/uid" where it will verify if it exists in the product table, if it exists it publishes the characteristics of the item to the ESP-32 through the topic "nodered/features" and adds the product to the user table, otherwise through the screen it indicates to the user that the product was not found and returns to the tag scanning process.

Then, the product characteristics received in the microcontroller are saved in a dynamic stack and will be displayed on the LCD screen. Finally, if the user wants to finalize his purchase, he must enable the end of purchase button and show his code at the cash register and then the microcontroller will clear the memory where the dynamic stack was saved and show the total amount, otherwise the user can continue adding products or if he wants to delete a product he must enable the delete button and scan that product which will be published by MQTT through the "esp32/erase" topic to be deleted from the user table. Additionally, Figure 6 shows the flow design made in Node-RED which contains the nodes with respect to MQTT, the database and the functions required to manage them.

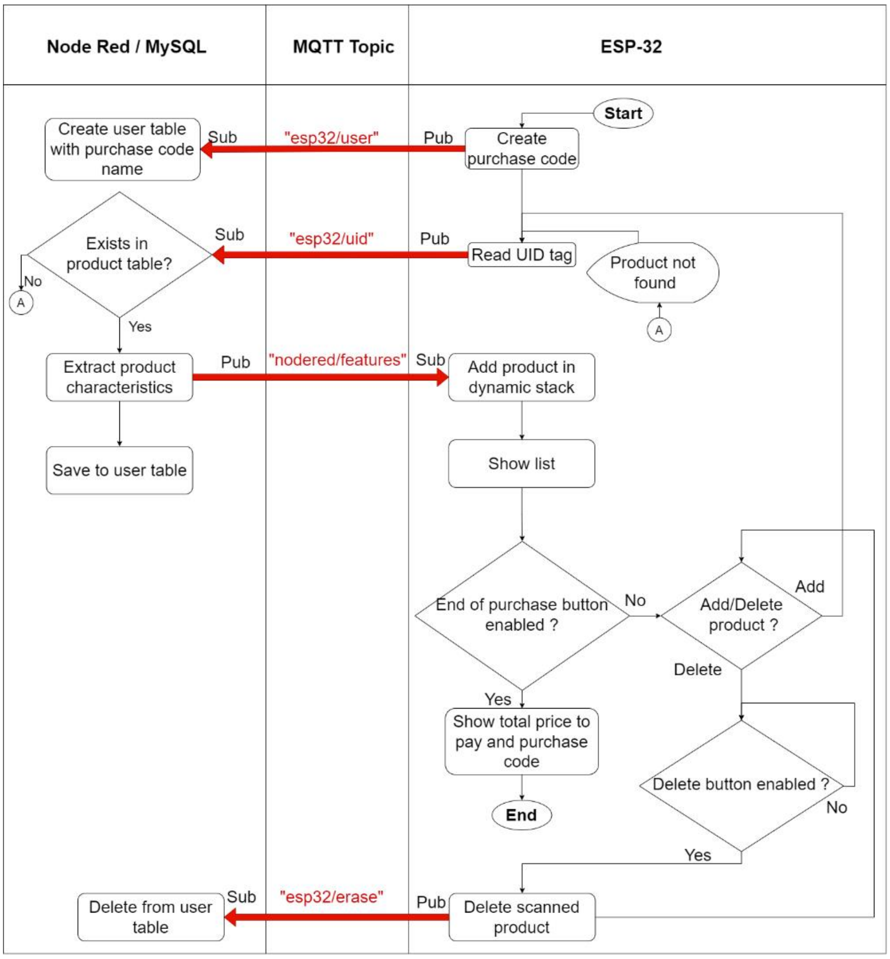


Figure 5. System flowchart

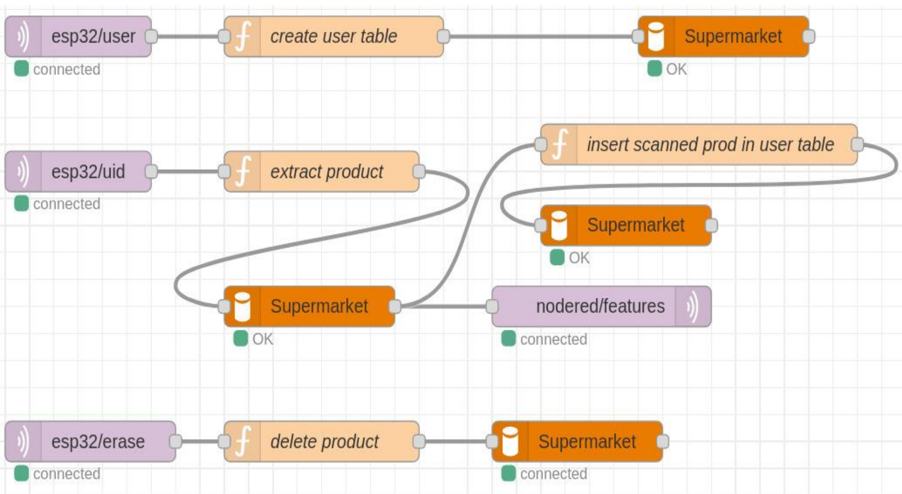


Figure 6. Node-RED flow

3. RESULTS AND DISCUSSION

This section presents the results of the implementation of the prototype of the designed embedded system. First, the prototype of the embedded system is described. In addition, we present the analysis and comparison of the scanning times between the self-service checkouts of a supermarket and the proposed system based on IoT and RFID.

3.1. Embedded system prototype

The prototype of the embedded system was designed to meet the needs set out at the beginning of the research. Figure 7 shows the implementation of the ESP-32 microcontroller with the RFID module, the TFT LCD screen and the 3 push buttons for user interaction. Also, Figure 8(a) shows the first event corresponding to the start of the system by pressing the start button, where the screen displays a welcome message, the unique purchase code generated for the user, in this case "t_96437" and the indexes corresponding to the quantity of products, name and price. Figure 8(b) shows the task in charge of displaying the dynamic stack stored in the microcontroller as the UIDs of the products with RFID tags are scanned and at the same time inserted in the user table of the database named with the corresponding purchase code as shown in Figure 8(c) and Figure 8(d) shows the event corresponding to the end of the purchase, where the user's total amount to be paid, his code and a farewell message are displayed and also clears the dynamic memory spaces that were used to store the user's stack.

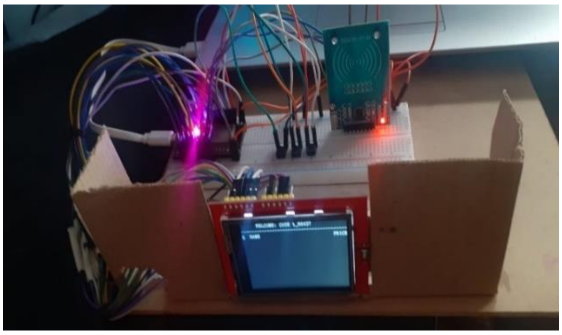


Figure 7. Embedded system prototype

(a)

(b)

UID	Product	Price
1078896117944	ARROZ EXTRA COSTENO BOLSA 5kg	24.9
992530576426	HARINA MOLITALIA PREPARADA BOLSA 1kg	7.6
919466674105	CAFE INSTANTANEO ALTOMAYO CLASICO FRASCO 180g	26.5
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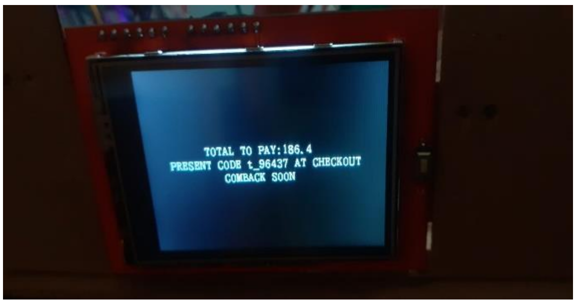
(c)



(d)

Figure 8. Events and tasks; (a) start system event, (b) display stack task, (c) user table, and (d) end of purchase event

3.2. Measurement and statistical analysis of scan times of the proposed system

After performing the measurement of scan times with the proposed system shown in Table 5, the metrics obtained are statistically analyzed using the same size of measurements and the arithmetic mean and standard deviation formulas previously defined in (1) and (2). This analysis is important because it allows describing the behavior of the designed system by means of the graph in Figure 9 and comparing it with the graph obtained in self-service checkouts. The arithmetic mean and deviation results are shown in Table 6. These results show a minimum deviation of 0.572 and a maximum of 0.887.

Table 5. Scanning times measured by number of products with the proposed system

Quantity of products	Measured time (s)																	
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18
3	7.7	7.7	8.62	7.5	9.1	8.3	9.9	8.9	8.1	8.5	8.7	7.3	8.2	7.7	8.07	8.6	7.75	7.96
4	10.9	9.8	10.5	11.6	10.6	11.5	10.4	11	11.5	11.2	11.4	10.8	11.5	10.9	11.4	12.3	11.5	11.2
5	13.9	13.1	14.3	14.2	13.9	13.0	13.7	13.9	13.5	14.7	14.4	14.7	15.0	14.2	14.9	13.9	15.4	14.6
6	16.7	17.4	17	17.6	16.3	15.9	16.3	16.0	16.2	15.8	17.8	18.9	17.2	16.3	16.7	16.3	16.8	17.3
7	18.6	19.8	19.5	19.7	19.5	20.0	20.4	19.6	19.5	19.0	18.0	19.1	19.6	20.4	19.9	21.2	20.7	19.6
8	23.9	23.8	24.7	24.2	23.6	25.7	24.8	23.8	25.3	25.7	25.2	24.9	23.7	25.2	26.0	26.1	25.6	24.9
9	27.4	27.7	27.7	27.3	26.3	27.0	26.1	27.8	27.7	29	28.9	28.6	28.1	27.1	28.5	29	28.6	28.2
10	31	29.8	30.5	31.3	31.6	30.2	31.4	32.1	29.5	31.2	31.7	31.9	31.4	32	30.6	32	30.1	32.7

Figure 9. Mean time and deviation of proposed system scan times

Table 6. Mean and standard deviation with proposed system data

Quantity of products	Mean ($\bar{x}$) (s)	Standard deviation (S)
3	8.26	0.647
4	11.13	0.572
5	14.20	0.647
6	16.83	0.841
7	19.69	0.756
8	24.83	0.848
9	27.84	0.863
10	31.16	0.887

3.3. Measurement and statistical analysis of scan times of the proposed system

The comparison of the arithmetic means of the scanning times is performed to verify the main objective of the research. The comparison of arithmetic means can be seen in Figure 10. The graph shows the reduction of the scanning time, and it tends to be more linear. This tendency can be analyzed by means of the average of the slopes of a straight line in consecutive points starting from the first one, mathematically stated in (3). Where "x" corresponds to the quantity of products from 3 to 10, "y" corresponds to the average time per quantity of product and "n" to the total of ordered pairs (x,y) forming a straight line.

$$T = \frac{\sum_{i=4}^{n+2} \frac{(y_i - y_3)}{(x_i - x_3)}}{n-1} \quad (3)$$

The arithmetic averages obtained allow us to calculate the reduced time per quantity of products and to analyze the linear trend of the 2 samples. The time reduced per product quantity can be observed in

Table 7 and the linear trends through the average of slopes in Table 8. In this case, the developed embedded system has a lower average slope which denotes a higher linear trend than the self-service checkouts.

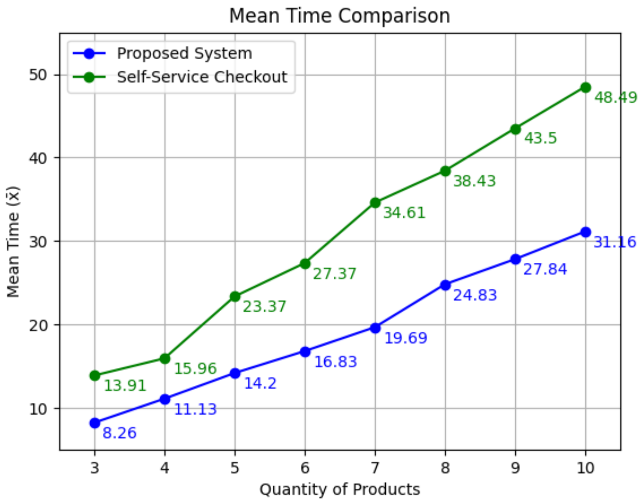


Figure 10. Mean time comparison of proposed system and self-service checkout

Table 7. Reduced scanning time using the proposed system

Quantity of products	Reduced time (s)	Percentage of time reduced (%)
3	5.65	40.61
4	4.83	30.26
5	9.17	39.23
6	10.54	38.50
7	14.92	43.10
8	13.60	35.38
9	15.66	36.00
10	17.33	35.70

Table 8. Linear trend of the graphs

	Self-service checkout	Developed embedded system
Average slopes	4.63	3.23

4. CONCLUSION

The main contribution of the research work is based on the deep analysis of the results obtained based on the comparison of scanning times and behavior of each of the samples obtained, since few researches deepen the behavior of their systems and how the purchase time is really reduced in their research. In addition, a comparison of purchasing times with the traditional barcode method versus the system developed by in the research has previously been presented. However, that work considers the scanning times as 0, which is not accurate, since there is a time from the scanning of the first product to the last one, as can be observed in this research. Also, the design and implementation of an improved embedded system in terms of hardware and software to reduce shopping time in a supermarket is presented. This system by means of RFID technology, improves the scanning of products, the connectivity of the system through IoT and the use of a TFT LCD screen improves the visualization stage for users and the use of programming in FreeRTOS allows execution times of tasks and events in parallel avoiding delays in the system.

In terms of linear trend, the embedded system, having a higher linear trend, has lower average slopes compared to the self-service checkouts, indicating that the changes in scan times per product quantity in the embedded system are more consistent and calmer than in the self-service checkouts. This is denoted by the disparity shown in the scan time reduction results, caused by the low linearity of the scans at these checkouts, reinforcing the inefficiency of barcode scanning. In conclusion, the developed embedded system reduced the scanning time by a weighted average value of 37.27% for a maximum of 10 products and, since it has a higher linear trend, it speeds up and improves the shopping time in supermarkets. In addition, the linear trend it presents allows to approximate the scanning time that a certain amount of products will have. However, for this purpose it is recommended to use other more accurate prediction methods such as linear regression. Additionally, a SPI or I2C type of communication is recommended for the TFT LCD, since it limits the number of GPIOS available in the ESP-32 and with a higher number of pixels.

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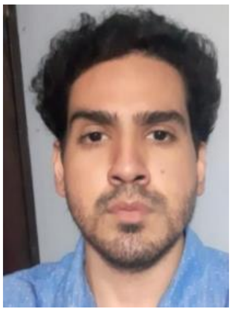

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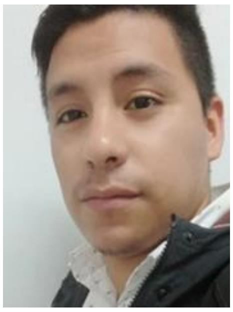

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