SmartCart Project: Adding Intelligence to Shopping Carts

Carlos Eduardo Bezerra Mendes Silva[1], Marcos Eduardo Araújo de Lima[3], Thiago José Alves de Souza[1], João Pedro Mafaldo de Paula[1], Marcondes Ricarte da Silva Júnior[1], João Marcelo Xavier Natário Teixeira[2,3]
[1]Centro de Informática - UFPE
[2]Departamento de Eletrônica e Sistemas
[3]Centro de Tecnologia e Geociências - UFPE
Recife, Brasil
{cebms, meal, tjas, jpmp, mrsj, jmxnt}@cin.ufpe.br

***Abstract*—The retail sector has been experiencing a transformation in which the incorporation of technologies into the shopping process is becoming increasingly common, aiming to provide a better experience for consumers. In this context, this paper seeks to propose a solution that uses embedded hardware in shopping carts to enhance the shopping experience, primarily speeding up the payment process by allowing customers to scan the barcodes of desired products without having to face long queues. It also aims to provide a supermarket map, indicating the current position of the cart. To achieve these objectives, computer vision was used to recognize QR codes attached to the ceiling. Following this methodology, satisfactory results were obtained, with paths for improvement and possible changes to be made in the project to achieve greater accuracy in estimating the cart's location.**

***Keywords*—Indoor localization; embedded computer vision; artificial intelligence of things.**

I. Introduction

Society faces a significant transformation in the way people interact with the retail sector. Not too long ago, shopping was predominantly done in-person at local supermarkets. However, the use of digital platforms for this purpose is becoming increasingly common. In response to this situation, retailers have been exploring strategies aimed at enhancing the consumer experience and, consequently, increasing their sales.

In this context, technology plays a fundamental role as a catalyst for change, possessing the ability to reshape the shopping sector landscape. Thus, it is possible to combine computer vision and robotics technologies, which have the potential to redefine consumer interaction with the retail space, in order to elevate the standard of customer service, creating a more interactive, personalized, and efficient environment.

Given the described scenario, a solution proposal focused on supermarkets is presented, aiming to be integrated into shopping carts, streamlining the process of searching for and purchasing products in supermarkets. This idea originated as a project for a national embedded systems competition in Brazil, which had some requirements to be met by all teams: the use of standard hardware - the ESP32-S3 EYE board from Espressif - and only open-source software tools.

This project had as objectives:

1) Promoting the sales sector with a focus on agility and convenience.
2) Proposing a cost-effective solution without exceeding expenses on equipment, energy, and drastic changes to the establishment's infrastructure.

To achieve this, the main strategies adopted in this project were the mapping of the shopping cart's position and the bar-code reading of the products. An embedded hardware is used in each shopping cart with the aim of being the primary point of interaction between the customer and the system. This device provides the location of the desired products and guides the consumer on the most efficient route to collect the items, reducing the time spent searching through the aisles.

In parallel with the mapping, the device should be responsible for reading the barcodes of the products placed in the cart. This way, when completing the purchase, the total value of all products is already calculated, and a QR code could be generated for digital payment of the products or taken to a checkout counter that will only handle the payment, diminishing the need for long queues. This avoids all the time wasted on scanning each item at the checkout and significantly speeds up the payment process.

The remainder of this paper is organized as follows. Section II describes the problem being tackled, while Section III presents some related works found. Section IV details the methodology used during the development of the proposed solution, while Section V analyzes the results obtained with the implementation and summarizes some of the difficulties faced. At last, Section VI concludes the work and provides some future work directions.

II. Problem description

Time spent in long queues at supermarkets is one of the key factors considered by consumers when deciding how and where to do their shopping. This is evidenced by a report from Waitwhile, a platform specialized in customer flow management, which reveals that approximately 70% of customers are willing to wait a maximum of 15 minutes in a line to purchase an item or service. The study also highlights that individuals between 18 and 44 years old are more likely to abandon a queue before being served [1]. Complementing this perspective, the 2018 European Retail Report [2] identifies three essential pillars in a shopping experience: convenience, context, and control. Surprisingly, 38% of consumers consider a wait of more than five minutes to be excessive.

Another issue arises as the retail sector grows and supermarkets expand, making internal navigation increasingly complex and challenging in terms of efficiency. This becomes a challenge for new users to visit a supermarket.

In this context, the focus of this work expands, proposing not only strategies to minimize waiting times but also to optimize the overall shopping experience, ensuring that consumers find what they are looking for quickly and efficiently.

III. Related work

The problem question addressed in this paper is a recurring topic in various other works. Therefore, it is crucial to conduct a study and review of the available related literature.

An extensively employed approach to tackle the issue of time spent in supermarket queues is the application of RFID technology. Several studies explore the use of RFID sensors integrated into shopping carts, where customers take on the responsibility of "scanning" each product as they add it to the cart [3]. Although RFID simplifies product identification, it is worth noting that it is essential for all products to be pre-equipped with RFID tags for its effective utilization.

There are also studies dedicated to implementing the smart-cart system, where the focus goes beyond the end-user perspective and encompasses the entire architecture required to make the system functional. In this context, comprehensive infrastructure is crucial, including Wi-Fi connectivity in all carts, the implementation of a database, as well as communication between the embedded system and a web platform used by the supermarket to update product prices. Additionally, a database management system is employed to store critical information such as the quantity of products in each cart, product prices, and inventory levels [4].

In order to address issues caused by the use of Wi-Fi, such as congestion, signal loss, and interference, another approach utilizes ZigBee networks [5]. This way, a kind of mesh is created among all the supermarket's devices, which ultimately communicate with a central server where the database is stored [6].

A different approach, although considerably more sophisticated, is Amazon Go, which consists of a cashier-less convenience store concept developed by Amazon. The key feature of Amazon Go is its "Just Walk Out" technology, which allows shoppers to enter the store, pick up the items they want, and simply walk out without going through a traditional checkout process. The store is equipped with a network of cameras and sensors that track the movements of customers and items on the store's shelves. As customers pick up items, the cameras and sensors automatically detect the items and add them to the customer's virtual shopping cart in real-time. There are no traditional checkout counters. Customers can simply exit the store when they have finished shopping.

Implementing the "Just Walk Out" technology can be expensive, both in terms of installing the necessary hardware and developing the software. These costs may deter smaller retailers from adopting similar systems. Amazon Go's model is best suited for small to medium-sized convenience stores or retail locations with a limited range of products. It may not be practical for larger supermarkets or stores with more complex product categories.

IV. Methodology

With the proposed objectives in mind, an IoT system was developed to map the user's position, plot routes from that position to the location of the next desired product, and scan the product codes. Therefore, it is necessary for the system in question to have the capability to receive user input and visually provide them with instructions, identify product bar codes, and check their prices. The elaborated architecture is illustrated in Figure 1.

It is noted that an essential step for the solution to work is the recognition of the current position of the cart within the physical environment of the supermarket. With this purpose, the SmartCart uses a computer vision solution to recognize QR code markers, which are intended to uniquely and accurately identify a specific location within the interior of the store. Such markers should be placed on the supermarket ceiling so that a camera on the cart can view these markers, ensuring that common obstructions in crowded environments, such as other customers or promotions in the aisles, do not interfere with the system's detection capability.

Compared to traditional SLAM algorithms, the use of QR codes offers an advantage in terms of simplicity and accuracy. SLAM algorithms face challenges in dealing with the constant need to correlate sensor data in dynamic environments like a supermarket, which can introduce uncertainties and errors.

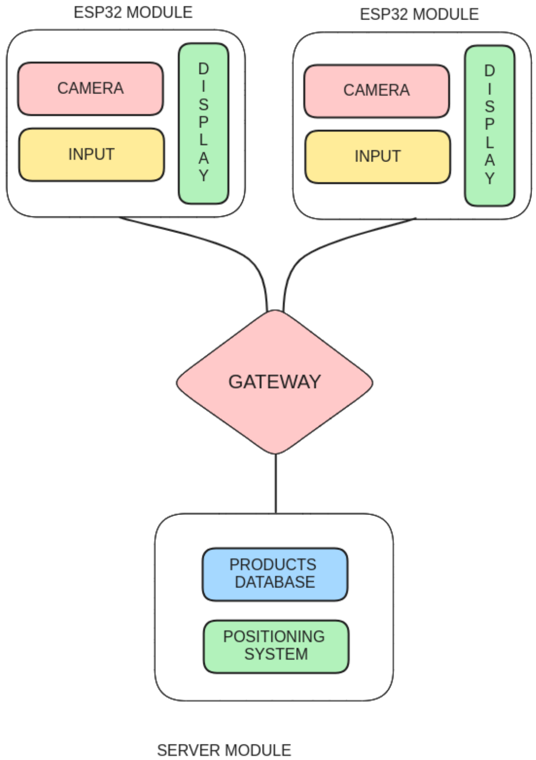

Figure 1: Proposed solution architecture.

By using QR codes as fixed reference points, several sources of imprecision are eliminated, making the localization more straightforward and less susceptible to cumulative errors.

The choice of QR codes as markers presents additional advantages. The first one is the existence of an specific open-source code available for the ESP32-S3-EYE that identifies this type of marker with high efficiency. Furthermore, QR codes are robust to lighting variations and can store essential information such as a spatial ID. This feature ensures that the system recognizes and differentiates each marker, providing an exact understanding of its spatial arrangement in the environment.

In laboratory tests, QR codes were strategically distributed on the ceiling, as illustrated in Figure 2. The markers were spaced approximately 1 meter apart, facilitating the simultaneous detection of up to two markers in the camera's field of view. Each QR code measures 30x30 cm and was installed so that when the camera is perpendicular to it, there is a vertical distance of about 2 meters from the cart to the ceiling, as shown in Figure 3.

Another requirement for conducting the tests was mounting the ESP32-S3-EYE on an office chair to simulate the movement and dynamics of a supermarket shopping cart. In Figure 4,

Figure 2: QR codes placed on the laboratory ceiling.

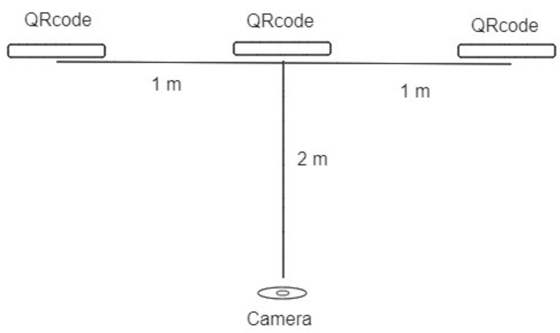

Figure 3: Distance between the system and the markers placed on the ceiling.

it is possible to observe the board in the mounting position. The LCD display shows the graphical representation of the environment, where the blue dot indicates the current location of the consumer, the green dot marks the position of the desired item, and the brown rectangle simulates an obstacle, in this specific case, a central table. In Figure 4, the green LED lit next to the camera is the power indicator of the module.

The movement of the chair symbolizes the customer's movement in the environment, updating the point representing the consumer based on data collected by the integrated inertial sensors. However, the system has the capability to correct any discrepancies or accumulated errors in the trajectory. When the camera detects the QR code positioned on the ceiling, the consumer's location is recalculated, ensuring an accurate representation of the customer's position in the simulated environment.

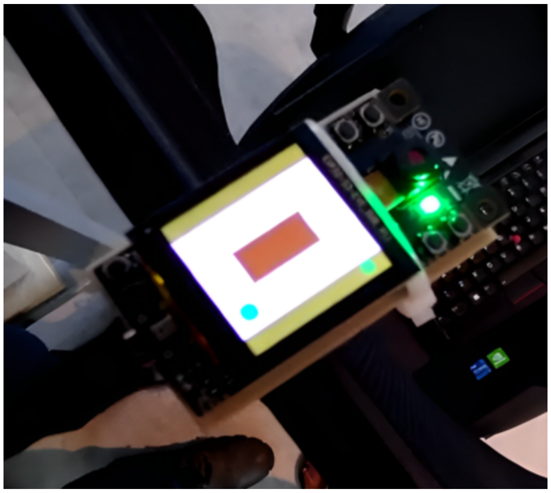

Figure 4: Board display representing the user position within the laboratory.

V. Analysis of the Proposed Solution

The first aspect to be considered regarding the adopted structure is related to which device should be responsible for processing the mapping and navigation algorithms. In this regard, two possible approaches are noted: performing all the steps at the edge, i.e., on the hardware present in the shopping cart itself, or distributing part of these steps to another system, which then returns the result to the requesting device. Both paths have advantages and disadvantages that should be taken into account in the construction of the project in question.

Regarding the first approach mentioned, processing pathfinding algorithms at the edge offers the advantage of not requiring wireless connections to other devices, such as a central server, adding greater flexibility to the solution since there would be no concerns about signal loss or network-related issues. However, this approach presents challenges when it comes to monitoring supermarket inventories. All devices would need to maintain the same version of the inventory among themselves, and changes in the placement of products would require updates to be made in all individual mappings of each cart because there is no centralization of such mapping.

The second approach has the advantage of centralizing the supermarket's inventory control in a single location, facilitating maintenance and, consequently, reducing the work required during changes in inventory organization. However, this approach requires the use of some wireless communication protocol between the carts and the gateway, in addition to being able to handle the possibility of this communication failing at some point.

To achieve the proposed objectives, in addition to the ESP32-S3 EYE, the use of various hardware options available in the market is possible, such as Intel NUC, NVIDIA Jetson Nano, Raspberry Pi, among others. The integration of these devices can be evaluated in later stages of the project, opening up the possibility of implementing functionalities that require more robust hardware.

As a direct result of the current work, a functional prototype of the proposed system was obtained. Although it contains the key functionalities described earlier, it does not yet encompass all the objectives proposed by this paper. Tests were conducted in a laboratory, which consists of a spacious room with controlled lighting.

During test phase, the localization system worked well; however, it was not as reliable. Due to the user's movement speed, the embedded system could not cope with the motion blur generated in the image from the onboard camera. This resulted in the user's position not always updating accurately on the map.

Regarding the product scanning process, the vision system performed as expected. As for the systems that could not be implemented, there is the target product selection system. The decision not to implement it was due to the need to add new hardware such as a microphone or keyboard that would serve as user interface, in addition to a new processing unit in the case of more complex systems like voice detection. Furthermore, it was also not possible to implement the route instructions system due to the lack of an audio output system for the user to receive instructions.

For the implementation of the system to be technically feasible, it is necessary to use different hardware that provide more development interfaces, support all functionalities, and at the same time do not increase the implementation cost of the solution.

One solution is to replace the embedded system in each cart with a mobile application that can be downloaded and used on customers' smartphones, as they are always present with people, have sufficient performance for most of the described tasks, and allow for the addition of new features such as integration with shopping lists.

Feature	Result
Location system	Performed sufficiently well in a controlled environment
Product bar-code scanning	Performed as expected
Target product input system	To be implemented

Table I: Features and respective results.

VI. Conclusion

Seeking reduction in queues size, time spent in them, and the efficiency of the shopping process in supermarkets, this work proposes a hardware solution for shopping carts, which serves two main functions: estimating the current position of the consumer and scanning the barcodes of the products they wish to purchase, in order to enable a cashier-less payment. Following the described methodology, it was possible to obtain preliminary results that allow for an initial evaluation of the proposed system.

Based on the results obtained, it is clear that the development of the proposed solution through a functional prototype system represents a significant step towards creating an innovative solution to enhance the shopping experience in retail environments. Although some challenges have been identified, such as limitations in the location system due to motion blur and the inability to implement certain features due to the need for additional hardware, these issues provided valuable insights for future iterations of the project.

With the validation of the acquisition of customer's and product's position within the map, the proposed system offers a significant opportunity for expansion and improvement. One of them is to design an optimized path to the item, avoiding unnecessary routes. After completing this route, the customer has the option to scan the product's bar-code. When this action is performed, the display is filled with a green color, as shown in Figure 5, indicating that the process has been successfully completed. Subsequently, the system automatically updates the map, removing the product that has already been added to the cart. A complete demonstration video can be accessed in LINK.

Additionally, there is the possibility of developing a mobile application. Customers could prepare a shopping list even before arriving at the supermarket. Installed on the user's smartphone and communicating with the cart's hardware via Bluetooth, this application would guide the customer step by step. For example, after indicating the desired purchases, the system would direct the customer to the first item on the list, and once the item is scanned, the procedure described before would occur, and the map would update, but now indicating the position of the next item on the list, guiding the customer once again. This system provides a more interactive and efficient experience, ensuring that the customer follows an optimized path.

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Figure 5: Scanning process of the desired product

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