

Design and Construction of an RFID-Based System for Increasing Inventory Reliability Levels

Echeverri-Arias, Jaime A. ¹, Ramirez-Marín, Juan F. ², Ayala-Villegas, Maria P. ³, & Arias-Serna, María A. ⁴
& Montes- Gómez. Luis F. ⁵

¹ Facultad de Ingeniería, Ingeniería de sistemas, Universidad de Medellín, Medellín, Colombia. jaecheverri@udemedellin.edu.co,

² Crystal, Dirección de proyectos, Carrera 48 # 52 sur 81 Sabaneta, Colombia. jframmar@crystal.com.co

³ Crystal, Dirección de proyectos, Carrera 48 # 52 sur 81 Sabaneta, Colombia. mapayala@crystal.com.co

⁴ Facultad de Ingeniería, Ingeniería financiera, Universidad de Medellín, Medellín, Colombia. marias@udemedellin.edu.co,

⁵ Facultad de Ingeniería, Ingeniería de sistemas, Universidad de Medellín, Medellín, Colombia. lfmontes@udemedellin.edu.co

ARTICLE INFO

ABSTRACT

Received: 30 Dec 2024

Revised: 19 Feb 2025

Accepted: 27 Feb 2025

This paper explains the functioning, benefits, and key outcomes derived from the integration of Radio Frequency Identification (RFID) technology across 18 stores within the fashion retail sector in Colombia. The exposition provides an exhaustive analysis of the fundamental architectural principles, the primary equipment employed, and the comprehensive process from the moment a product is tagged and dispatched from the distribution center until its final sale to the end customer. The findings show that the incorporation of RFID technology has led to significant improvements in visibility, traceability, and inventory reliability. Additionally, it increases operational efficiency and reduces instances of out-of-stocks within the store, thereby ensuring enhanced product availability for customers and streamlining omnichannel sales.

Keywords: RFID; retail; inventory, label; product availability indicator.

I. INTRODUCTION

To address the challenges that fashion retail companies face in enhancing the shopping experience for their customers within an increasingly competitive and demanding marketplace, it has become imperative for them to adopt omnichannel shopping strategies. In this context, Radio Frequency Identification (RFID) technology emerges as a valuable tool to meet this need. RFID is an electronic tagging technology that facilitates the automatic identification of objects, places, or individuals without the need for direct line of sight, employing an electromagnetic call-and-response exchange [1] and [2].

Systems integrating RFID technology predominantly comprise RFID labels (tags), RFID readers, and specialized software [3]. These RFID tags are composed of a microchip, a radio translator, and an antenna, enabling the identification, reading, and storage of data without the necessity of direct contact or line of sight between the reader and the tagged element [4].

The readers, which comprise an antenna, a transceiver, and an encoder, are of critical importance in the emission of a radio frequency signal. This signal activates the tags within its reading area, simultaneously capturing and decoding the radio signals emitted by the aforementioned activated tags. A variety of reader types are available to meet specific needs, including both static and portable devices. Subsequently, specialized software is employed to receive and process the information acquired by the readers. The processed data is then stored in databases, thereby facilitating the generation of reports and key performance indicators for the overall process. This functionality enables, for instance, the tracking of out-of-stock items through purchases and the monitoring of the remaining inventory on the shelves and in the store. Managers benefit from a real-time overview of ongoing operations. The software performs a detailed analysis of the data, maintaining a comprehensive record of the information.

Businesses engaged in consumer goods transactions must implement a robust quality control system, particularly for retailers facing the risk of stock shortages for essential items. A well-designed inventory control system serves as a proactive tool that alerts retailers when it is time to reorder [3] and [5].

A 2020 report from Accenture [6] highlights the ongoing expansion of RFID technology in the retail sector. North America leads the way, with 93% of retailers surveyed incorporating RFID. Moreover, when considering the overall adoption rates of North America, Europe, and Asia Pacific, all three regions have experienced substantial growth compared to the results prior to that year.

The numerous advantages of technology, including non-line-of-sight massive reading, unique identification, reduced reading time, and efficient product search, facilitate operational efficiency, achieve traceability, ensure singular visibility of products, improve inventory reliability, and attain superior inventory management. Substantial growth in the adoption of RFID technology is expected in the near future. This growth is attributed to the role of RFID in improving inventory accuracy and process efficiency, as well as its status as a key technology for analyzing customer behavior throughout the purchasing process. By delving into the buying process, which includes the exploration of popular categories, the identification of high-interest items, the examination of correlated products, the establishment of trending categories, and the recognition of products appealing to customers, RFID facilitates the extraction of valuable insights. For example, correlated products are those that are frequently purchased together with the initial items, providing retailers with valuable insights into customers' purchasing patterns. This information enables retailers to implement wholesale strategies effectively, which ultimately enhance profitability [7] and [8]. In general, this information helps retailers to develop strategies for the seamless transition of items from the point of customer interest to the final purchase.

This paper outlines the operational aspects, advantages, and key outcomes resulting from the incorporation of RFID technology in 18 fashion retail stores across Colombia. It details the architectural framework employed throughout the entire process, from product labeling and shipment to the final sale to the end customer. The implementation of RFID technology has resulted in a 5% increase in product availability within the store, thereby guaranteeing that at least one Stock Keeping Unit (SKU) is visible to the customer.

The remainder of this article is structured as follows: Section 2 delineates the methodology used to implement RFID technology, detailing the processes within the distribution center, and explaining the RFID processes within the retail stores. Section 3 provides a comprehensive overview of the key components necessary to implement RFID technology, offering valuable insights into the architecture employed in stores equipped with RFID technology. Section 4 provides an in-depth assessment of the outcomes achieved through the implementation of RFID technology. This includes a meticulous examination of the reliability percentage of inventories achieved through RFID in comparison to the theoretical inventory for each store. Furthermore, this section presents the results of the RFID processes in the distribution center and retail stores, including key indicators such as product availability within the store and space profitability. In conclusion, the article presents a summary of its key findings.

II. METHODS

Loire To introduce RFID technology into the company's retail outlets, a series of preliminary pilot programs were conducted to assess the project's feasibility, implement any necessary adjustments, and subsequently proceed with its full-scale implementation. The implementation process comprised a number of key activities including the dispatching of products from the distribution center with RFID tags, the tagging of existing inventory within the stores, the adaptation of RFID readers at payment stations, the installation of the RFID application on mobile readers, and the setup of portals for movement tracking, security monitoring, and dressing room access control.

The successful integration of RFID technology requires that all products entering the stores be equipped with an RFID tag. Consequently, the process begins at the distribution center, where each purchase order is assigned an RFID tag. These tags are meticulously engraved and coded with their corresponding EAN (European Article Number) and serial number, ensuring that each product within the store is uniquely identified. The execution of this critical activity involves the use of dedicated workstations, each equipped with an RFID printer, a PC running the serialization application, a barcode reader, and trained personnel.

In-store tagging is performed exclusively when the implementation is initiated in a store with pre-existing inventory that lacks RFID tags. This process involves the creation and attachment of RFID tags to individual items or garments. Once all items have been confirmed as unique and serialized a comprehensive reading is conducted using mobile

RFID readers. Subsequently, the acquired data is uploaded to the company's inventory management system for further processing.

The process enabled by RFID technology for tracking the product in the warehouse is carried out in two phases: product reception and intelligent replenishment. This approach guarantees product availability, reduces management times and optimizes the use of personnel in tasks such as inventory management, product search, payments and returns.

Once the reception process is complete, which involves thorough verification to all deliveries are complete and in line with their theoretical counterparts, merchandise replenishment or restocking can begin. This process aims to transfer items from the warehouse to the sales floor or point of sale, to mitigate out-of-stock situations and ensure consistent product availability within the store. An out-of-stock scenario occurs when a product is physically present in the warehouse but not displayed.

The implementation of RFID technology has yielded positive results, with an increase in product availability within the store of over 5%. This implementation ensures that at least one Stock Keeping Unit (SKU) remains visible to the customer, thus enhancing the shopping experience and reducing instances of product unavailability. One of the key areas where RDID can make a significant impact is inventory management. The adoption of RFID technology facilitates more frequent and efficient inventory checks compared to traditional barcode methods. RFID technology streamlines the process, as mass reading allows for faster execution, optimizing store resources. In contrast, traditional barcode inventories require time-consuming, one-by-one readings, leading to increased investment in both time and resources. The implementation of RFID has notably elevated inventory reliability, achieving a rate of over 99%.

Moreover, RFID technology optimizes the product retrieval process within the store, particularly advantageous in large retail spaces. Once the customer has made their selection and proceeded to the payment stations, an RFID reading is conducted for each product. This process captures the EAN along with its corresponding serial number, thereby ensuring deactivation. This measure guarantees that when the products pass through the security gates located at store exits, no alarm is triggered. Furthermore, it provides an additional layer of security to prevent theft within the premises.

Distribution Center

The distribution center begins operations upon receipt of a purchase order through an enterprise resource planning (ERP) system. The purchase order is then transmitted to the warehouse management system (WMS). The WMS then assigns one or more deliveries to each purchase order and transmits these orders to the RFID printing stations in the distribution center for fulfillment.

Once the production has been serialized, it is transported via an RFID tunnel or portal to guarantee the entire shipment is accounted for and each item is tag with an RFID tag. As shown in Fig. 1, if these conditions are not met, an alert is triggered to identify the incomplete production and start the printing and encoding process.

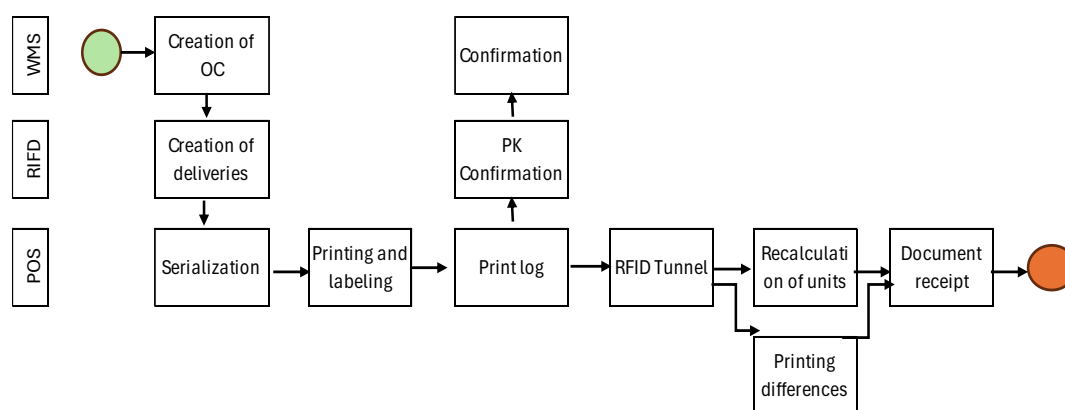


Fig. 1. RFID process flow diagram in the distribution

Source: Prepared by the authors

The RFID process within stores can be divided into three main activities: merchandise reception, inventory management, and sales. Once the merchandise arrives at the designated store, the reception process begins. To verify the complete arrival of ordered quantities, the system uses a mobile application together with an RFID reader, the system verifies the complete arrival of ordered quantities. Should any discrepancies emerge, the application immediately reports the new information to facilitate any necessary inventory adjustments.

By contrast, inventory activity involves the reading or recording of items within the store. This is accomplished by means of a RFID application and mobile terminals, which allow the comprehensive capture of information stored in the RFID tags attached to each product. To improve efficiency, it is advisable to divide the store into two distinct areas: the sales floor and the warehouse. This division allows the RFID system to report the physical presence of products within the store, even if they are not displayed on the sales floor or point of sale.

Fig. 2 illustrates the main flowchart of the RFID inventory application, which has been integrated with the company's ERP system based on RFID readings.

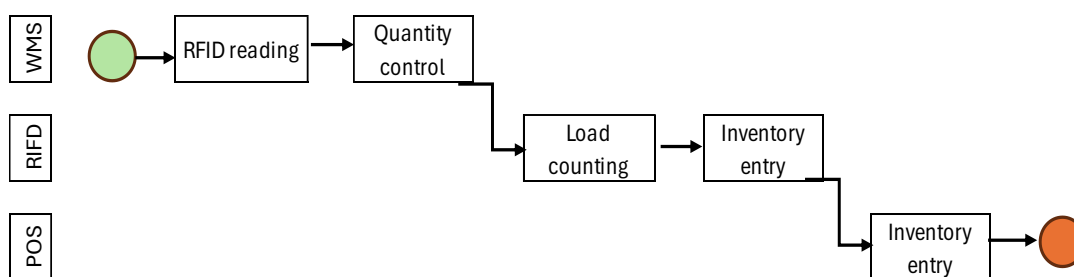


Fig. 2. Flow chart of the inventory process in RFID stores.

Source: Prepared by the authors

Fig. 3 provides an overview of the RFID sales process. The customer selects the items they wish to purchase, each of which is identified by an EAN and a serial number. Upon passing through the RFID reader, these details facilitate the registration process. Once the transaction is complete, the products marked for removal from the inventory are verified. Then the RFID tags associated with these items are then deactivated, ensuring that as the products in question pass through the security portal at the exit of each store, no alerts are triggered.

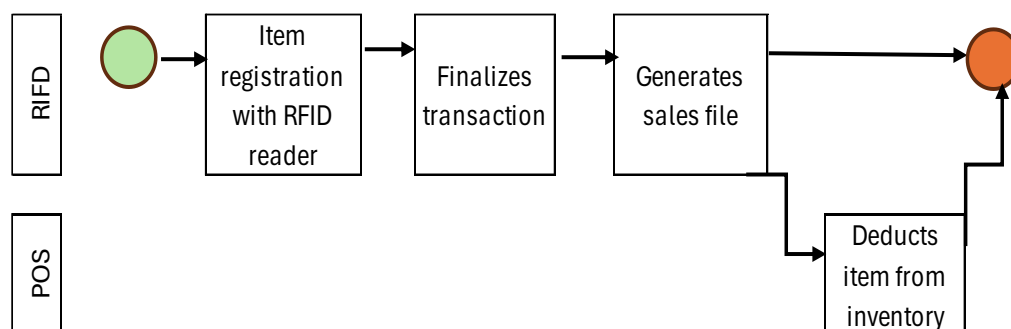


Fig. 3. Flow chart of the sales process in RFID stores.

Source: Prepared by the authors.

III. MATERIALS

A. Equipment

The key components used to implement RFID technology in company-owned stores are: Server that processes and stores the information, RFID reader connected to a mobile device for mass reading of RFID tags, Article surveillance system and identification of possible thefts, generating an audible alert, RFID tag printer and fixed reader portals connected to antennas for mass capture and reading of RFID tags. There are several in-store security control options

available on the market. For this RFID case study, a specific design was developed that included two pedestals positioned on either side of the store entrances. Two antennas and the reader were installed on one pedestal, while the other pedestal housed the remaining two antennas. To ensure effective assembly and installation of RFID antennas, it is critical to consider the radiation pattern associated with these antennas. This consideration is essential for identifying both the highest and lowest reading zones.

B. Architecture

Fig. 4 illustrates the implemented architecture for RFID-enabled stores, which includes the following components:

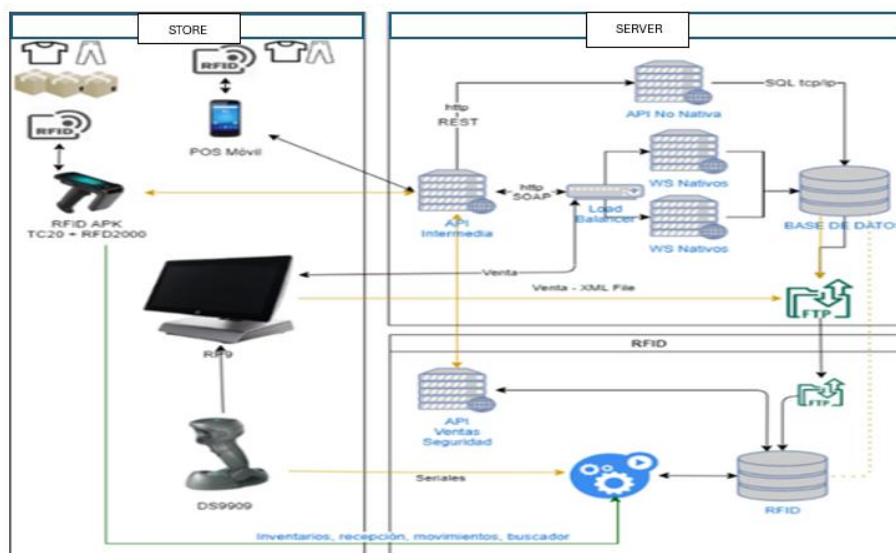


Fig. 4. RFID architecture.

Source: Prepared by the authors

1) RFID Engine: This software component is responsible for receiving, filtering, and processing information from RFID readers and other data collection devices.

2) RFID API: This component handles incoming requests from external systems.

Web Services: Responsible for receiving requests from clients and acting as an interface between the device and the database server.

3) FTP File Exchange: All events recorded by the Point of Sale (POS) are transmitted asynchronously to the RFID system through FTP files.

IV. RESULTS

The following results represent a case study involving the implementation of RFID technology in 18 stores in four cities in Colombia: Medellin, Bogota, Cali, and Barranquilla. The project began in 2018 with a pilot store. In 2019, two additional stores were opened, followed by six more in 2020, bringing the total to 18 stores by 2021.

A. Inventory Accuracy

Inventory accuracy measures the reliability percentage of RFID-generated inventory compared to each store's theoretical inventory. Due to the significant mass reading benefits of RFID technology, the total inventory frequency of these stores is least once a month, as opposed to the annual inventory frequency of non-RFID stores. The following data represents average results derived from inventories conducted from go-live through July 2021.

Fig. 5 shows the inventory reliability results obtained by comparing each store's initial inventory to the average of the previous month's results. Specifically, stores numbered 4168, 4108, 4261, 4019, 4107, 4014, 4025, 4016, and 4062 performed their initial inventory in June 2021. As a result, their inventory accuracy is comparatively lower than that

of stores with earlier start dates, where the percentage of inventory reliability exceeds 99%. This underscores the fact that the implementation of RFID technology enables greater reliability, periodicity of reading, meticulous control of all inbound and outbound product movements within the store, and improved visibility and traceability of inventory.

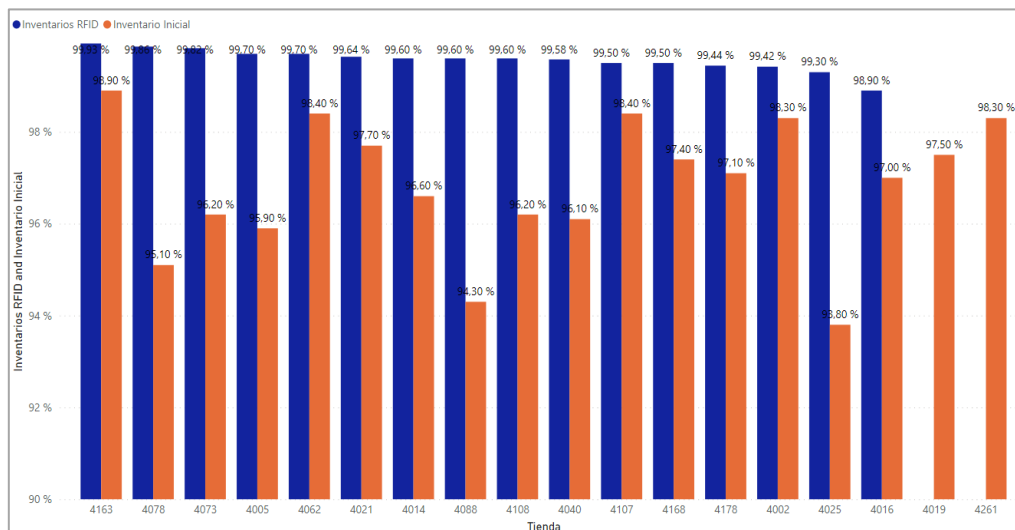


Fig. 5. Inventory accuracy in RFID stores.

Source: Prepared by the authors

B. Product availability indicator in the store

This indicator shows the percentage of product availability in the store, as well as out-of-stock. Ensuring consistent in-store product availability and reducing out-of-stocks is the main goal of this indicator. Fig. 6 illustrates the percentage of product availability on the sales floor by comparing the results before the integration of RFID technology with the averages recorded in the months following its implementation, starting in July 2021. As can be seen, the adoption of RFID technology leads to a significant improvement in in-store product availability. This enhancement allows the point-of-sale manager to more effectively monitor inventory and, in turn, provide customers with better shopping experience.

It is important to note that the stores identify by 4168, 4108, 4261, 4019, 4107, 4014, 4025, 4016, 4062 had their first inventory assessment in June 2022. As a result, the increase in availability percentage through July 2022 is not observable due to the recent implementation of the inventory assessment process.

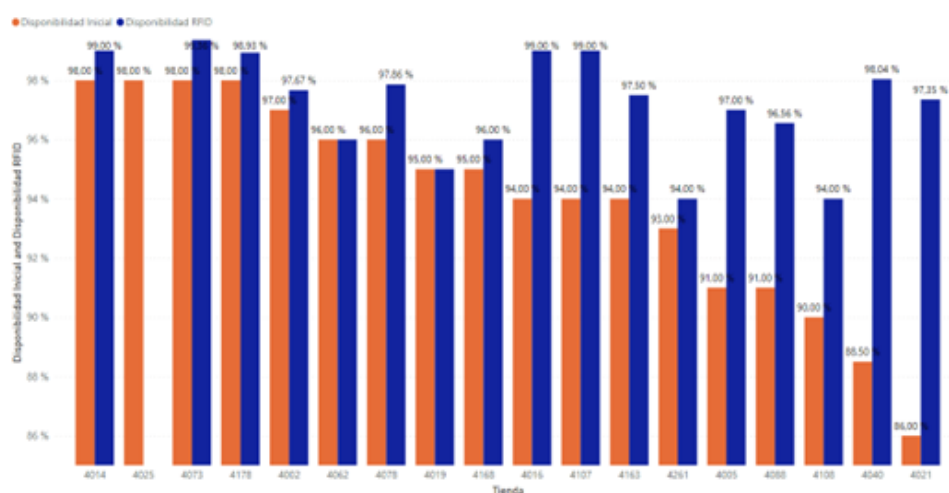


Fig.6. Percentage of product availability on the floor in RFID stores

Source: Prepared by the authors

C. Space Profitability Indicator

This indicator illustrates the sales generated in different areas of the store, including both the storefront and other display points within the establishment. It is used to determine, from a business perspective, whether adjustments or maintenance to the displays are necessary. The main goal of this indicator is to support the commercial strategy by pinpointing strategic areas within the store and scrutinizing customer behavior. Each zone is meticulously documented to track the products associated with each location following a sales transaction. Fig. 7 shows the variation in sales behavior across different store zones as a result of display changes. It also highlights the best- and worst-selling references corresponding to specific zones and dates.



Fig. 7. Sales variation by zones in RFID stores.

Source: Prepared by the authors

The space profitability indicator enables the generation of store heat maps that provide insight into specific zones that may be underperforming. This information is valuable for making informed decisions about display adjustments. Fig.8 illustrates a heatmap of an RFID-enabled store, with individual zones tracked for reference.



Fig. 8. Heatmap of the different zones of an RFID store.

Source: Prepared by the authors

The control panel associated with this indicator provides detailed information for each of the zones, delineating the highest and lowest selling references. This data is critical for both the store and the display area, facilitating an analysis of products within sections that do not rotate. It helps determine whether these products are positioned next to more attention-grabbing items, assess the need for repositioning, or identify potential issues such as sizing, fit, color, etc., that may be contributing to a lack of customer interest in a particular reference.

V. DISCUSSION

The integration of RFID technology into an ecosystem that is aligned with a company's strategic initiatives contributes significantly to improving business intelligence and transforming the customer shopping experience in an omnichannel environment. Key benefits of integrating RFID technology into fashion retail stores include:

- 1). Achieve inventory reliability greater than 99%. Regular inventory assessments improve accuracy, resulting in fewer out-of-stocks, increased sales, streamlined logistics processes, and better support for omnichannel scenarios.
- 2). Realization of more than 5% increase in in-store product availability after RFID implementation. This ensures that at least one unit of each out-of-stock product reference is prominently displayed, improving customer access to desired items.
- 3). Reduce out-of-stocks by ensuring that the units entering stores match physical inventory. Any discrepancies trigger timely system alerts, enabling rapid replenishment and preventing potential lost sales.
- 4). Improve inventory visibility and traceability by assigning uniqueness to each product within the physical store. This approach ensures accurate tracking and monitoring of individual items, contributing to overall inventory efficiency.

REFERENCES

- [1] K. Conneely, "Managing corporate assets with RFID," *Assembly Automation*, vol. 29, p. 112–114, 2009.
- [2] J. De las Morenas, A. García, F. Martínez and P. García Ansola, "Implementación del Control en Planta de un Centro de Distribución Automatizado mediante Agentes Físicos y RFID," *Revista Iberoamericana de Automática e Informática Industrial RIAI*, vol. 12, no. 1, pp. 25-35, 2015.
- [3] F. Seco, K. Koutsou and F. Ramos, "Localización personal en entornos interiores con tecnología RFID," *Revista Iberoamericana de Automática e Informática Industrial RIAI*, vol. 10, no. 3, pp. 313-324, 2013.
- [4] Y. A. Pastor, "Application to a warehouse environment of a tracking system based on RFID and free software," *RFID SysTech 2011: 7th European Workshop on Smart Objects Systems Technologies and Applications*, pp. 1-7, 2011.
- [5] M. T. Islam, "Flexible Radio-Frequency Identification (RFID) Tag Antenna for Sensor Applications," *Sensors* 2018, pp. vol. 18, no. 12, p. 4212, Nov. 2018, 2018.
- [6] Accenture, 2020. [Online]. Available: <https://www.accenture.com/us-en/insights/retail/new-era-rfid>.
- [7] A. G. S. Rallapalli, "Enabling physical analytics in retail stores using smart glasses," *MobiCom '14, (New York NY, USA)*, p. 115–126, 2014.
- [8] J. Liao and C.-Y. Ho, "Intelligence IoT(Internal of Things) Telemedicine Health Care Space System for the Elderly Living Alone," *IEEE Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS) Okinawa, Japan, may 2019*, pp. 13-14, 2019.
- [9] JSA, "JSA," [Online]. Available: <https://www.forwardvision.net/wp-content/uploads/SML-Case-Study-Redesign.pdf>.