Customer Shopping Behavior Analysis by RFID Models

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Analyzing customer shopping habits in physical stores is crucial for enhancing the retailer–customer relationship and increasing business revenue. Radio-Frequency Identification (RFID) technology has emerged as a solution and has been implemented in physical stores for purposes such as smart trolleys and analyzing customer shopping paths. Additionally, previous research has demonstrated that the phase readings and received signal strength (RSS) of RFID, combined with machine-learning algorithms, can effectively track customer activity within the physical store, including product browsing. Therefore, employing machine learning models for identifying customer behavior inside the store is crucial to enhance the efficiency of customer behavior analysis.

Keywords: RFID ; machine learning ; shopping behavior

1. Introduction

Comprehending customer behavior is essential for enterprises as it offers valuable insights into customer preferences and decision making, allowing companies to customize their offerings and marketing strategies to enhance customer satisfaction and loyalty [1]. While understanding customer shopping patterns in online stores is relatively straightforward, it becomes challenging in physical retail settings, where monitoring shopper behavior prior to checkout is complex. Utilizing Radio-Frequency Identification (RFID) technology is one approach to gaining insights into customer behavior.

RFID is a technology that uses wireless communication to identify and track objects or people using RFID tags or labels. These RFID tags contain unique identification data and are affixed to items, allowing them to be scanned and recognized by RFID readers or antennas [2]. RFID is regarded as an integral component of the Internet of Things (IoT) and finds extensive application across diverse industries, including inventory management [3], access control [4], asset tracking [5], and supply chain optimization [6], providing real-time data acquisition and enhancing operational efficiency.

RFID technology has emerged as a solution and has been implemented in physical stores for purposes such as smart trolleys [7][8][9] and analyzing customer shopping paths [10][11]. Additionally, previous research has demonstrated that the phase readings [12][13][14] and received signal strength (RSS) of RFID [15][16][17], combined with machine-learning algorithms, can effectively track customer activity within the physical store, including product browsing. Therefore, employing machine learning models for identifying customer behavior inside the store is crucial to enhance the efficiency of customer behavior analysis.

2. Customer Behavior Analysis Based on RFID

Past studies have demonstrated the versatility of RFID technology, as it can be employed for various purposes, including enhancing smart trolley systems, tracking customer activity, and analyzing customer shopping activities within physical stores. In the context of smart trolleys, RFID technology reduces checkout wait times and automatically generates bills, eliminating the necessity for customers to queue at cashier counters. Badi and Momin [7] proposed a RFID and sensor-based system to reduce the waiting time for check out in superstores. In their proposed system they also implemented machine learning algorithms such as Eclat association rule to identify frequent items purchased and use it for sales promotion sent directly to customers smart phones. In another similar study, Athauda et al. [8] designed a Smart Trolley framework to address the challenges faced by retailers such as efficient stock maintenance and shoplifting. The proposed system has used UHF circular polarized RFID readers, including antennas and hybrid couplers to efficiently trace customers picked items in the trolley by overcoming previous limitations of orientation, size, and shape of tagged shopping items in the trolley. This RFID system allows for real-time tracking and processing of shopping data, providing consumers with instant access to information via an interface. Finally, Pradhan et al. [9] introduced KONARK, an RFID-based smart shopping system centered around a customized shopping cart equipped with an RFID reader. KONARK aims to expedite item checkout and enable real-time purchase tracking, providing users with a more efficient shopping experience. Additionally, the system accurately detects user interest in specific items and offers valuable insights to shopping mall owners, demonstrating robust performance across various mobility speeds in a simulated shopping mall setting.

RFID technology facilitates the monitoring of customer movements within the store, enabling the generation and retention of shopping routes for later examination. Previous studies have shown that this can provide valuable insights into customer behavior. Nakahara and Yada [10] explores the potential of shopping path data, generated by tracking customer movements in stores, to uncover insights into customer behavior and its impact on purchasing decisions. Using LCMseq analysis on RFID real data from a Japanese supermarket, the study reveals distinctive in-store behavior patterns associated with high-value customers. In a related study, Shen et al. [11] discusses the growing use of RFID technology, particularly in retail, to track in-store customer behavior. It introduces a unified framework for RFID-based path analytics, combining in-store shopping paths and RFID-based purchase data to extract actionable navigation patterns.

While comprehending customer shopping patterns in online stores is relatively straightforward, it poses a challenge in physical retail outlets, where monitoring shopper behavior before the checkout process is complex. Phase measurement from RFID has been applied to detect customer activities, resulting in noteworthy findings. Zhou et al. [12], utilized cyber physical system of RFID tags, and readers to investigate the shopping behavior of customers to come up with effective marketing strategies for the physical shopping stores. The proposed system ShopMiner system used customer's interactions with products and leveraged backscattered time-series phase readings from RFID tags to identify popular, hot, and correlated items. Liu et al. [13] presented TagBooth, an innovative system utilizing Commercial Off-The-Shelf (COTS) RFID devices to detect product motion and uncover customer behaviors, offering valuable insights beyond typical transaction data. They employed phase measurements as input data to distinguish between different forms of customer browsing. The system demonstrates robust performance in both laboratory and real retail store environments. Shangguan et al. [14] presented ShopMiner, a framework utilizing passive RFID tags' backscatter signals to detect customer activities such as browsing, examining, and trying on items. By leveraging unique spatial–temporal correlations in time-series phase readings, ShopMiner achieves high accuracy and efficiency in identifying comprehensive shopping behaviors, as demonstrated in empirical studies conducted in typical indoor environments.

In order to understand in-store customer behavior, including activities such product browsing, researchers have employed machine learning prediction models in conjunction with received signal strength (RSS) data, leading to significant discoveries. To tackle the architectural design and privacy challenge for automated checkout systems, Hauser et al. [15] explored the implementation of an automated checkout system in fashion retail stores, aiming to improve customer experiences and reduce operational costs. The study aims to detect products as they pass through the RFID gate based on machine learning methods, i.e., logistic regression, artificial neural networks, support vector machine, and gradient tree boosting. The system employed RFID tag RSS, and its successful application and assessment in a real-world context underscore its capability in effectively managing shopping baskets. Choi et al. [16] utilized RFID tag data to classify customer browsing patterns within specific zones. RFID devices capture customer behavior and preferences to inform business decisions and tailor marketing efforts, while intelligent fuzzy screening algorithms assist in matching apparel items according to customer preferences, product design, and sales history. In summary, the system is anticipated to enhance the shopping experience through smart, personalized services, ultimately contributing to the success of the retail business. Finally, Alfian et al. [17] focuses on analyzing customer shopping behavior, particularly browsing activities, in retail stores using RFID-enabled shelves and machine learning models. RFID technology is implemented to monitor tagged product movements, and a dataset is generated from the receive signal strength (RSS) of tags for different customer behavior scenarios. The results demonstrate that the proposed MLP-based model significantly outperforms other models in terms of accuracy, precision, recall, and f-score, offering valuable insights for product placement, promotions, and personalized recommendations to customers.

A limitation observed in earlier research lies in the challenge of understanding customer shopping patterns in physical retail environments, especially in monitoring shopper behavior prior to the checkout stage, which can be intricate. While some studies have utilized machine learning models with received signal strength (RSS) data, there is room for improvement in model accuracy. Enhancing the model's precision is achievable by integrating outlier detection methods and implementing data balancing techniques.

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