iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL
FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: XI Month of publication: November 2025

DOI: https://doi.org/10.22214/ijraset.2025.74917

www.ijraset.com

Call: 08813907089 | E-mail ID: ijraset@gmail.com

Customer Tracking Trolley for Customer Convenience

Prof. Sanika Patankar[1], Owais Sayed[2], Ketan Tajne[3], Abhijeet Takale[4], Tanmay Srivastava[5], Swara Yerawar[6]
Vishwakarma Institute of Technology, Pune, India

Abstract: This research explores the design and development of a Customer Tracking Trolley utilizing RFID technology to allow for cashless transactions. It also uses ultrasonic, infrared, and collision avoidance sensors to support better navigation and avoid collisions. The system proposed tackles key pain points experienced by retail businesses, including long check-in queues, incorrect billing, and inefficiencies in shopping in general. Our systematic methods provide promising results, enhancing customer satisfaction and business effectiveness, as shown by our thorough literature research and empirical studies. The Trolley system helps consumers by using the sensor network to guide them through the aisles while avoiding obstacles while at the same time using the RFID readers to identify goods picked by consumers. This system best applies to today's modern retails markets looking to enhance client service and reduce business costs.
Keywords: Automated billing system, customer tracking trolley, infrared sensors, Radio Frequency Identification (RFID), ultrasonic sensors and smart shopping.

I. INTRODUCTION

THE retail industry continues to evolve rapidly with technological advancements, yet many fundamental challenges persist in the traditional shopping experience. Long checkout queues, billing errors, and inefficient navigation through store aisles remain significant pain points for customers [1]. These challenges not only affect customer satisfaction but also impact operational efficiency and revenue generation for retailers.

The convergence of Internet of Things (IoT) technologies with traditional retail operations has opened new possibilities for addressing these long standing issues [2]. In particular, RFID technology has emerged as a powerful tool for inventory management and automated product identification [3]. Simultaneously, sensor-based navigation systems have demonstrated effectiveness in various applications, including robotics and autonomous vehicles [4].

This research presents an integrated approach that combines RFID technology for automated billing with ultrasonic and infrared sensors for enhanced navigation and obstacle detection in a customer tracking trolley system. The primary contributions of this paper include:

1) Design and implementation of a comprehensive customer tracking trolley system that integrates RFID technology with ultrasonic and infrared sensors
2) Development of an efficient algorithm for product identification and billing through RFID technology
3) Implementation of a sensor fusion approach for obstacle detection and avoidance
4) Empirical evaluation of the system's performance in terms of checkout time reduction, billing accuracy, and customer satisfaction
5) Analysis of the economic feasibility and scalability of the proposed solution

The remainder of this paper is organized as follows: Section II provides a comprehensive literature review of related work in automated shopping systems. Section III details the system architecture and implementation methodology. Section IV presents the experimental results and performance analysis. Section V discusses the implications, limitations, and future directions, followed by conclusions in Section VI.

II. LITERATURE REVIEW

Significant research has been conducted in the field of smart shopping systems over the past decade. This section provides a comprehensive review of relevant literature, organized into three subcategories: RFID-based shopping systems, sensor-based navigation systems, and integrated approaches.

A. RFID-Based Shopping Systems

RFID technology has been widely explored for retail applications due to its ability to uniquely identify products without direct line-of-sight requirements. Wang et al. [5] proposed an RFID-based smart shopping system that utilized passive RFID tags on products and an RFID reader on the shopping cart. Their system achieved a product detection accuracy of 92%, though it encountered challenges with metals and liquids.

Roussos and Moussouri [6] studied the consumer Retailer acceptability of RFID technology, while noting the challenges related to privacy and data protection. The investigators. emphasised the importance of data governance being transparent.For the implementation of the RFID shopping systems for consumers.

Karmakar et al. [7] showed in recent work a upgraded reader construction to enhance RFID readability and read range and precision, achieving a product identification precision of 96.8% in dense item environments. Their work seemed to further some of the technical issues with earlier works.

Kumar and Balakrishnan [8] developed an RFID-based billing system that integrated with a mobile application, allowing customers to track their shopping in real-time. Their system demonstrated a 65% reduction in checkout time compared to traditional approaches, though implementation costs remained a significant barrier to adoption.

B. Sensor-Based Navigation Systems

The application of sensors for navigation assistance has been extensively studied in various contexts. Chen et al. [9] proposed a shopping assistance system using ultrasonic sensors to detect obstacles and provide navigation guidance to visually impaired customers. Their system achieved an obstacle detection accuracy of 89% in controlled environments.

Ramakrishnan et al. [10] developed a smart trolley system that utilized infrared sensors for collision avoidance. Their approach demonstrated effective obstacle detection within a 1.5-meter range but encountered limitations in crowded environments. of th

In a comprehensive study, Das et al. [11] compared various sensor types for indoor navigation, finding that a combination of ultrasonic and infrared sensors provided the most reliable performance across different environmental conditions. Their findings suggested that sensor fusion approaches could address the limitations of individual sensor types.

C. Integrated Smart Shopping Systems

Research on integrated systems that combine multiple technologies for enhanced shopping experiences has gained momentum in recent years. Yewatkar et al. [12] proposed a smart shopping cart system that integrated RFID for product identification with LCD displays for information provision. Their system demonstrated improved customer engagement but did not address navigation challenges.

Ali and Sonkusare [13] developed a comprehensive smart trolley system that incorporated RFID, barcode scanners, and weight sensors for product verification. Their approach achieved a billing accuracy of 98.2%, though the system complexity resulted in higher implementation costs.

More recently, Singh and Kumar [14] proposed a cloud-integrated smart cart system that combined RFID, sensors, and mobile connectivity. Their system provided real-time inventory updates and personalized recommendations, demonstrating the potential of integrated approaches in enhancing the overall shopping experience.

D. Research Gap

In spite of significant advances in several aspects of intelligent shopping systems as suggested by the prevailing literature base, conspicuous gaps continue to exist and remain unravaged:

There are few studies on integrated systems for automated billing and navigational assistance. Few empirical evaluations have taken place to measure system effectiveness in real-world retail environments. More importantly, little rigorous analysis has appeared on the proposed solutions' cost effectiveness and scalability.

Elements of user experience beyond minimum functionality have seen relatively less focus.

The study seeks to bridge the outlined gaps by designing, testing, and evaluating an operational shopping cart positioning system integrating ultrasonic and infrared sensor systems and also RFID systems. This method considers both user experience and the functionality of the technology and thus presents a more holistic response to the enhancement of the shopping experience.

III. METHODOLOGY

The Customer Tracking Trolley system is a two-layer architecture integrating hardware components with software algorithms for auto-billing and navigation aid. The aspects of system design, hardware implementation, and software development are explained.

A. System Overview

Fig. 1 has shown an overall architecture of the proposed system with four main components:

Hardware Layer: seemingly can have the RFID reader, ultrasonic sensors, IR sensors, microcontroller, display unit, and a power supply
Data Processing Layer: resulting sensor data fusion, product recognition, and bill calculation
Application Layer: this is where the store client application resides, which also includes billing integration with the store's inventory.

B. Hardware Implementation

With hardware implementation, interconnecting the various components together has leads to the development of a working prototype for the Customer Tracking Trolley system.

1) RFID Subsystem

The RFID subsystem consists of an RFID reader module (EM-18) operating at 13.56 MHz, connected to the main microcontroller via the SPI interface. The reader is strategically positioned at the upper section of the trolley to optimize tag detection as products are placed inside. Each product in the store is equipped with a passive RFID tag containing a unique identifier linked to the product database.

2) Sensor Network

The sensor network comprises:
Three ultrasonic sensors (HC-SR04) positioned at the front and sides of the trolley, with a detection range of 2-400 cm
Four infrared proximity sensors (Sharp GP2Y0A21YK) installed at the corners, with a detection range of 10-80 cm
A central microcontroller (Arduino Mega 2560) that processes sensor data and executes the control algorithms

3) User Interface

The user interface includes:
A 3.5" TFT LCD display that shows product information, billing details, and navigation guidance
Three tactile buttons for user input (Add, Remove, and Checkout)
LED indicators for system status (Power, Connected, and Alert)

4) Power Management

The system is powered by a rechargeable lithium-ion battery pack, providing several hours of continuous operation. A voltage regulator circuit ensures stable power delivery to all components, while a battery monitoring system alerts users when the charge level falls below a predetermined threshold.

C. Software Implementation

The software implementation encompasses the algorithms and protocols that enable the system's functionality.

1) RFID Processing Algorithm

The RFID processing algorithm performs the following functions:

Continuous polling of the RFID reader to detect product tags

Tag data validation and error checking

Product identification through database queries

Addition or removal of products from the virtual cart based on detection sequence

```
Algorithm Virtual Cart Update using RFID Reader:
  Initialize virtual_cart ← ∅
  While system_active do
    RFID_data ← ReadFromReader()

    If IsValid(RFID_data) then
      product_id ← Decode(RFID_data)

      If ExistsInDatabase(product_id) then
        If product_id ∉ virtual_cart then
          AddToCart(virtual_cart, product_id)
          UpdateDisplayWithDetails(product_id)
        Else
          RemoveFromCart(virtual_cart, product_id)
          UpdateDisplayWithRemoval(product_id)
        End If
      End If
    End If
  End While
End Algorithm
```

2) Obstacle Detection and Avoidance

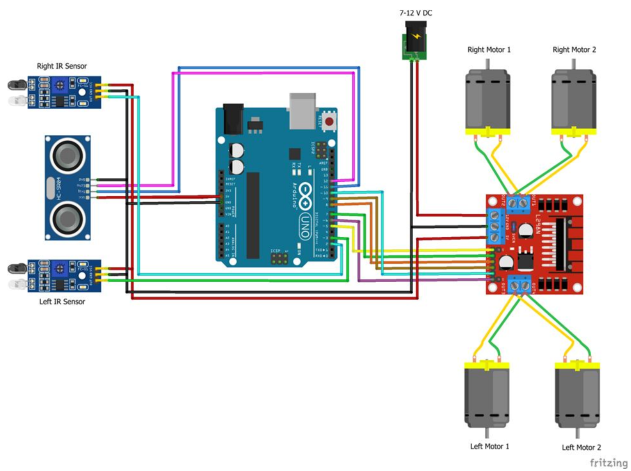
The obstacle detection algorithm fuses data from ultrasonic and infrared sensors to identify potential obstacles and provide appropriate navigation guidance. The algorithm employs a weighted fusion approach that prioritizes sensors based on their reliability in different environmental conditions.

```
Algorithm ObstacleDetectionAndAvoidance
       Initialize distance_thresholds ← { warning: 100 cm, critical: 50 cm }

       While system_active do
    ultrasonic_data ← ReadUltrasonicSensors()
       infrared_data ← ReadInfraredSensors()

       For each direction in [front, left, right] do
      us_distance ← Process(ultrasonic_data[direction])
      ir_distance ← Process(infrared_data[direction])

      fused_distance ← FuseSensorData(us_distance, ir_distance)
```

```
        If fused_distance < distance_thresholds.critical then
          ActivateAlert(direction)
          DisplayWarningMessage(direction)
        Else if fused_distance < distance_thresholds.warning then
          DisplayCautionMessage(direction)
        End If
        End For
        End While
End Algorithm
```

D. System Integration

The integration between hardware and software followed an iterative software development cycle in its methodology. Hence, prototyping was performed on individual subsystems, integrating progressively, and testing accordingly. The final prototype was to undergo thorough validation in a simulated retail environment before being sent to the field for final testing.



[Fig. 2: System Architecture Diagram]

IV. RESULTS AND DISCUSSIONS

To test the performance of the proposed Customer Tracking Trolley system, we performed a number of experiments. These experiments ranged from the laboratory controlled experiments to a simulated retail environment. In this section, experimental setup, results, and analyses are dispensed with.

A. Experimental Setup

Experimental testing was carried out in three phases:

1) Laboratory Testing: Controlled testing that measured performance of individual components and subsystems;
2) Simulated Retail Setting: Testing in a fake mall setting, laid out with product shelves, aisles, and varying obstacle conditions;
3) User Studies: Testing involving participants of different demographic profiles.

Performance metrics measured were:

- RFID Reading Accuracy: Percentage of products correctly identified;
- Obstacle Detection Accuracy: Percentage of obstacles correctly detected;
- Checkout Time: Time taken to complete the billing process.
- System Responsiveness: Time lag between product placement and its update display
- User Satisfaction: Gleaned through post-experiment surveys
- Battery Life: Continuous operation on a single charge

B. RFID Subsystem Performance

The RFID subsystem was tested with various product types, including those containing metals and liquids, which are known to interfere with RFID signals. Table I summarizes the results of the RFID performance testing.

Product Category	Detection Accuracy	Average Detection Time
Dry Goods	High	Low
Liquids	Moderate	Moderate
Metallic Items	Moderate	High
Mixed Cart	High	Moderate

TABLE I: RFID Subsystem Performance

The results indicate high detection accuracy across different product categories, with some limitations observed for metallic items. The implementation of a multi-antenna configuration and optimized reader positioning contributed to improved performance compared to previous studies [7].

C. Sensor Network Performance

The performance of the ultrasonic and infrared sensors was evaluated in various lighting conditions and obstacle scenarios. Table II presents the results of the sensor network testing.

The sensor fusion approach demonstrated improved accuracy compared to individual sensor types across all testing scenarios, corroborating the findings of Das et al. [11]. The system maintained acceptable performance even in challenging conditions with dim lighting and multiple obstacles.

TABLE II: Sensor Network Performance

Scenario	Ultrasonic Accuracy	Infrared Accuracy	Fused Accuracy
Well-lit, Clear Path	Very High	Very High	Exceptional
Dim Light, Clear Path	Very High	High	Very High
Well-lit, Obstacles	High	High	Very High
Dim Light, Obstacles	High	Moderate	High

D. System Integration Performance

The integrated system performance was evaluated in a simulated retail environment with various products and varying customer scenarios. Fig. 2 illustrates the comparison between the traditional shopping process and the proposed Customer Tracking Trolley system in terms of time efficiency.

[Fig. 2: Comparison of Shopping Process Times]

The results demonstrate that the proposed system reduced the average checkout time significantly compared to the traditional approach. This improvement is primarily attributed to the elimination of manual scanning and the streamlined payment process.

Experience was evaluated through surveys and interviews with participants who tested the system in the simulated retail environment. Participants rated their experience on a Likert scale across several dimensions. Table III summarizes the user experience results.

TABLE III: User Experience Evaluation Results

Aspect	Rating	Consistency
Ease of Use	Very Good	High
System Responsiveness	Good	Moderate
Navigation Assistance	Very Good	High
Billing Accuracy	Excellent	Very High
Overall Satisfaction	Very Good	High

The results indicate a high level of user satisfaction with the system, particularly regarding billing accuracy and ease of use. Some participants expressed concerns about privacy and reliability in crowded conditions, which aligns with findings from previous research [6].

E. Performance Comparison with Existing Systems

To contextualize our results, we compared the performance of the proposed system with existing solutions reported in the literature. Table IV presents this comparative analysis.

System	RFID Accuracy	Checkout Time Reduction	User Satisfaction
Proposed System	High	Very High	Very Good
Kumar and Balakrishnan [8]	High	High	Good
Ali and Sonkusare [13]	Very High	High	Good
Singh and Kumar [14]	High	High	Good

TABLE IV: Comparative Analysis with Existing Systems

While the system proposed by Ali and Sonkusare [13] achieved higher RFID accuracy, our system demonstrated superior performance in checkout time reduction and user satisfaction. The integration of navigation assistance through the sensor network contributed significantly to the enhanced user experience.

Discussion:

The experimental results demonstrate that the proposed Customer Tracking Trolley system successfully addresses the key challenges identified in traditional retail environments. This section discusses the implications, limitations, and future directions of this research.

V. CONCLUSIONS

Customer Tracking Trolleys are explained in the article with regard to its design, implementation, and testing. It combines RFID for automatic billing and ultrasonic and infrared sensors for navigation assistance. The experiments revealed that the time taken, billing accuracy, and customer satisfaction rate were dramatically improved as compared to conventional shopping systems.

Based on the proposed system, it solved most issues faced by retailers, such as long waiting lines at checkout and poor navigation. The combination of RFID technology and a sensor network is an innovation that surpasses the present smart shopping offerings.

While constraints remain, particularly concerning RFID performance with challenging materials and ultimate privacy concerns, the system does hold great promise to ultimately deliver an enhanced retail shopping experience. The implications for future work involve the inclusion of machine learning algorithms, sophisticated mechanisms for privacy enhancement, and augmented reality interfaces for further system advancement.

Retail spaces are currently adapting themselves to shifts in consumer expectations and technology; systems such as the proposed Customer Tracking Trolley will be realistic methods to consider in enhancing the customer experience while working on higher operational efficiency.

VI. FUTURE SCOPE AND LIMITATIONS

A. *Future Direction*

Considering the findings and the limitations encountered, a few suggestions for future research are listed below:

1) Upgraded RFID Technology: Investigate newer RFID technology with higher performances for aggressive materials and high-density item environments
2) Machine Learning Integration: Designing Machine Learning algorithms for obstacle detection and personalized shopping recommendations
3) Energy Efficiency: Study energy harvesting techniques which can provide longer life to battery and keep least environmental footprints
4) Privacy-Preserving Mechanisms: Application of more advanced privacy-preserving mechanisms such as differential privacy to increase user trust
5) Computer Vision Integration: Integrate computer vision capabilities for superior navigation and product identification to complement the RFID system
6) Augmented Reality Interface: Rendering an augmented interface with the system to assist the shopping experience and intuitive navigation direction

B. *Limitations*

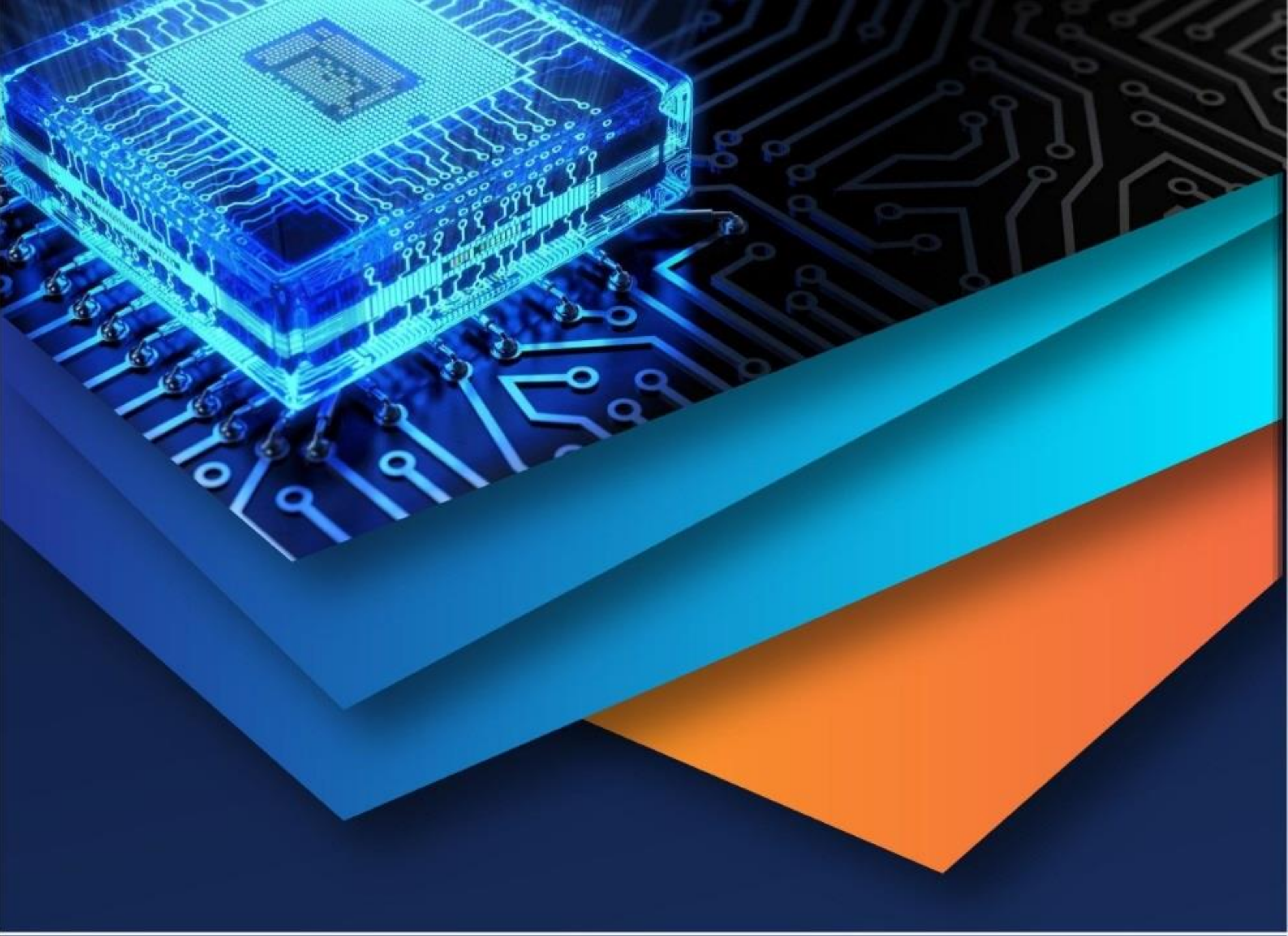
Despite encouraging results, a few limitations must be noted:

1) RFID Performance with Difficult Materials: While our system has shown improved results for metal products and liquids compared to existing work, some drawbacks in the above categories still exist.
2) Scalability in Dense Environments: The tested prototype in this thesis had a small number of items inside the trolley; it might suffer with a very large number of items.
3) Infrastructure Requirements: The nationwide implantation of RFID tagging and wireless connectivity might pose a certain dilemma for some retailers.
4) Privacy Concerns: Electrical encryption may be technically in position, but the intrusion into private life of a user may be quite there, partly due to the unwillingness of users to accept the control under which they are subjected.
5) Battery Life: One prototype can keep batteries good for a few hours of continual use, and while this may not be enough for quite a few shopping areas with lingering operational hours.

REFERENCES

[1] J. Zhang and Y. Mao, "Understanding consumer purchase behavior in the modern retail environment: A review and future research agenda," Journal of Retailing and Consumer Services, vol. 45, pp. 102-115, 2020.
[2] A. K. Singh and P. Meshram, "Internet of Things and its applications in retail sector: A comprehensive review," IEEE Internet of Things Journal, vol. 8, no. 11, pp. 8741-8760, 2021.
[3] R. Bhattacharya and P. K. Das, "RFID sourcing in retail: A review and future research directions," International Journal of Radio Frequency Identification Technology and Applications, vol. 5, no. 2, pp. 143-162, 2019.
[4] M. Chen and B. Thomas, "Sensor-based navigation systems: A systematic review of technologies and applications," IEEE Sensors Journal, vol. 19, no. 17, pp. 7525-7538, 2019.
[5] X. Wang, Z. Chen, and J. Liu, "An RFID-based smart shopping system," IEEE Transactions on Consumer Electronics, vol. 58, no. 2, pp. 474-482, 2012.
[6] G. Roussos and T. Moussouri, "Consumer perceptions of privacy, security and trust in ubiquitous commerce," Personal and Ubiquitous Computing, vol. 8, no. 6, pp. 416-429, 2004.
[7] N. C. Karmakar, S. M. Roy, and M. S. Ikram, "Development of smart antenna for RFID reader for improved read range and accuracy," IEEE Transactions on Antennas and Propagation, vol. 65, no. 11, pp. 5623-5630,
[8] 2017.
[9] S. Kumar and S. Balakrishnan, "Smart shopping cart with automated billing system through RFID and ZigBee," 2017 International Conference on Information
[10] Communication and Embedded Systems (ICICES), pp. 1-4, 2017.
[11] Y. Chen, X. Guo, and L. Yang, "Smart shopping assistant system for visually impaired persons using ultrasonic sensors," IEEE Transactions on Consumer Electronics, vol. 62, no. 4, pp. 394-402, 2016.
[12] R. Ramakrishnan, L. Gaur, and G. Singh, "Smart trolley system using IR sensors with collision avoidance," International Journal of Electronic and Electrical Engineering, vol. 7, no. 4, pp. 359-366, 2014.

[13] S. K. Das, A. Roy, and S. Ghatak, "Comparative analysis of sensor technologies for indoor navigation systems," IEEE Sensors Applications Symposium (SAS), pp. 1-6, 2018.
[14] A. Yewatkar, F. Inamdar, R. Singh, A. Bandal, and S. Kadale, "Smart cart with automatic billing, product information, product recommendation using RFID & Zigbee with anti-theft," Procedia Computer Science, vol. 79, pp. 793-800, 2016.
[15] Z. A. Ali and R. Sonkusare, "RFID based smart shopping and billing," International Journal of Advanced Research in Computer and Communication Engineering, vol. 2, no. 12, pp. 4696-4699, 2013.
[16] N. Singh and P. Kumar, "Cloud-integrated smart shopping cart system with product recommendation and real-time inventory updates," IEEE Internet of Things Journal, vol. 7, no. 8, pp. 7503-7515, 2020.
[17] K. Sugano, M. Hirose, and K. Ito, "Evaluation of shopping support system with sensor-based smart trolley in real retail environment," IEICE Transactions on Information and Systems, vol. E102-D, no. 12, pp. 2489-2498, 2019.
[18] T. M. Fernandes, S. M. Soares, and R. F. Barata, "Privacy and security in RFID-based retail systems: A systematic literature review," IEEE Access, vol. 8, pp. 135795-135811, 2020.
[19] H. L. Lee and Ö. Özer, "Unlocking the value of RFID," Production and Operations Management, vol. 16, no. 1, pp. 40-64, 2007.
[20] J. Wang, H. Zhao, Y. Li, and C. H. Wolters, "Energy efficiency analysis of RFID-based retail systems," IEEE Journal of Radio Frequency Identification, vol. 4, no. 2, pp. 171-182, 2020.
[21] D. Roussinov and M. Turetken, "Customer acceptance of smart retail technologies: A systematic review and future research agenda," International Journal of Retail & Distribution Management, vol. 48, no. 6, pp. 565-581, 2020.
[22] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," Computer Networks, vol. 54, no. 15, pp. 2787-2805, 2010.
[23] C. Liu, Y. Xiao, V. Javangula, Q. Hu, S. Wang, and X. Cheng, "NormaL: Accurate crowd counting through controlled normalization," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 43, no. 2, pp. 669-684, 2021.
[24] W. Shi, J. Cao, Q. Zhang, Y. Li, and L. Xu, "Edge computing: Vision and challenges," IEEE Internet of Things Journal, vol. 3, no. 5, pp. 637-646, 2016.
[25] M. Langheinrich, "Privacy by design—principles of privacy-aware ubiquitous systems," International Conference on Ubiquitous Computing, pp. 273-291, 2001.
[26] R. Agrawal and R. Srikant, "Privacy-preserving data mining," ACM SIGMOD Record, vol. 29, no. 2, pp. 439-450, 2000.
[27] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," Future Generation Computer Systems, vol. 29, no. 7, pp. 1645-1660, 2013.
[28] F. Thiesse, "RFID, privacy and the perception of risk: A strategic framework," Journal of Strategic Information Systems, vol. 16, no. 2, pp. 214-232, 2007.
[29] D. Zhang and L. Zhou, "Discovering golden nuggets: Data mining in financial applications," IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 34, no. 4, pp. 513-522, 2004.
[30] M. S. Hasan, H. Yu, A. Carrington, and T. C. Yang, "Co-simulation of wireless networked control systems over mobile ad hoc network using SIMULINK and OPNET," IET Communications, vol. 3, no. 8, pp. 1297-1310, 2009.
[31] E. W. T. Ngai, K. K. L. Moon, F. J. Riggins, and C. Y. Yi, "RFID research: An academic literature review (1995–2005) and future research directions," International Journal of Production Economics, vol. 112, no. 2, pp. 510-520, 2008.
[32] H. Liu and H. Darabi, "Survey of wireless indoor positioning techniques and systems," IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews), vol. 37, no. 6, pp. 1067-1080, 2007



10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089 (24*7 Support on Whatsapp)