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RESEARCH ARTICLE

SMART SHOPPING TROLLEY FOR HANDS-FREE RETAIL EXPERIENCE WITH AUTOMATED BILLING

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Abstract

The Smart Shopping Trolley for a Hands-Free Retail Experience with Automatic Billing is an innovative approach to transforming traditional shopping into an intelligent, efficient, and customer-centric experience. In conventional supermarkets, customers often face challenges such as pushing heavy trolleys, searching for products, and waiting in long billing queues. The proposed system addresses these limitations by integrating automation, sensing, and smart billing technologies into a single, user friendly solution. The smart trolley is designed to autonom ously follow the customer throughout the shopping area using a combination of ultrasonic sensors, infrared sensors, and microcontroller -based control systems. These sensors enable the trolley to detect the customer's movement and maintain a safe distance while avoiding obstacles in real-time. This hands-free functionality allows shoppers to move comfortably without manually pushing the trolley. For automatic billing, the system employs RFID or barcode technology to identify every product as it is placed into or removed from the trolley. The trolley's onboard microcontroller or embedded processor processes this information and continuously updates the total cost on an LCD or a mobile application interface. This eliminates the need for manual scanning at the checkout counter, significantly reducing waiting time and enhancing overall store efficiency.Theprototype implementati on involves key hardware components such as an Arduino/ESP32 microcontroller, motor driver modules, RFID readers, sensors, and DC motors for motion control. The system ensures smooth navigation, accurate product identification, and seamless billing synchronization. Additionally, the integration of wireless communication enables data transfer between the trolley and the central billing system or mobile app.

Introduction:-

In today's fast-paced world, technological advancements have significantly transformed every aspect of daily life, including the retail shopping experience. Traditional shopping methods often require customers to manully push trolleys, search for products, and wait in long queues for billing, leading to inconvenience and time consumption. To address these challenges, the concept of a Smart Shopping Trolley has emerged as an innovative solution that combines automation, embedded systems, and smart retail technology to create a hands-free and efficient shopping experience. The Smart Shopping Trolley is designed to autonomously follow the customer within the shopping area, eliminating the need to push the trolley manually. Using ultrasonic or infrared sensors and a microcontroller-based control system, the trolley detects and tracks the customer's movement while maintaining a safe distance and avoiding obstacles. This hands-free operation allows shoppers to move comfortably, focusing more on product selection rather than trolley handling. In addition to its mobility, the system integrates automatic billing using RFID or barcode technology.

Each product is equipped with an RFID tag or barcode that is automatically scanned when placed inside the trolley. The microcontroller processes the item data, updates the total cost, and displays it on an LCD screen or mobile interface in real-time. This eliminates the need for manual scanning at checkout counters, reducing waiting time and enhancing customer satisfaction. The proposed system also includes wireless communication for data synchronization with a central billing server or mobile application, enabling seamless payment options. The hardware architecture consists of an Arduino or ESP32 microcontroller, an RFID reader module, ultrasonic sensors, motor driver circuits, and DC motors for movement control. These components work together to ensure intelligent navigation, real-time tracking, and efficient billing. The implementation of such a system not only enhances convenience but also contributes to the development of smart retail environments aligned with the goals of Industry 4.0. By integrating automation and intelligent systems into retail, the Smart Shopping Trolley reduces human effort, increases operational efficiency, and paves the way for a contactless, technology-driven shopping future

Literature Review:-

The evolution of retail shopping systems has been significantly influenced by advancements in automation, Internet of Things (IoT), and embedded technologies. The concept of a smart shopping trolley integrates these technologies to provide a hands-free, efficient, and user- friendly retail experience. Several researchers have contributed to the development of automated trolleys, focusing on aspects such as customer tracking, product identification, and automatic billing. Ng et al. [1] pioneered an automatic human-guided shopping trolley capable of following the customer autonomously, minimizing the physical effort required during shopping. Their system incorporated a sensor-based navigation mechanism that ensured smooth trolley movement within aisles. This work laid the foundation for human-following trolleys that aim to improve customer convenience. Similarly, Dhaneswar et al. [10] and Arpita et al. [14] presented a master–follower concept, where multiple trolleys could follow a leading unit, thereby enhancing coordination and automation within smart retail environments. The integration of IoT and RFID technologies has further transformed the shopping experience by enabling product identification, inventory tracking, and automated billing.

Devi et al. [2], Muralidharan et al. [3], and Karjol et al. [8] proposed IoT-based smart trolley systems capable of connecting to cloud databases, allowing for real-time data synchronization and monitoring. Ali [5] introduced an RFID- based billing mechanism that automatically detects and records items placed in the trolley, eliminating the need for manual barcode scanning. Chandrasekar and Sangeetha [6] utilized RFID and ZigBee communication to implement a wireless automatic billing system, ensuring faster checkout and improved data security. Similarly, Gangwal et al. [7] employed wireless sensor networks (WSN) for communication between trolleys and billing counters, thereby reducing human intervention. In the domain of embedded systems, the Arduino microcontroller has been a preferred choice for developing low-cost smart trolley prototypes. Modi et al. [4] designed an Arduino Uno-based trolley capable of automatic item recognition and display of billing details on an LCD screen. Meghana et al. [12] and Kalaivani et al.

[11] demonstrated automated billing systems using embedded platforms that integrate sensors, RFID modules, and microcontrollers to simplify retail transactions. These systems highlight the practicality and affordability of microcontroller-based solutions for small- and medium-scale retail stores. Further, researchers have explored automated billing and payment integration using IoT and cloud-based databases. Sahare et al. [9] conducted a comprehensive review of IoT- enabled automated billing mechanisms, emphasizing how such systems can minimize

human errors, reduce checkout times, and provide real-time analytics for inventory management. Pangasa and Aggarwal [13] presented an automated billing framework for shopping malls using intelligent algorithms that optimize data processing and payment handling. Patel et al. [15] developed an intelligent trolley system that combined real-time object detection, billing, and wireless communication, marking a step towards fully automated retail systems. Despite substantial progress, existing research often addresses only individual aspects of the smart shopping process—either trolley automation, RFID-based billing, or IoT data integration. Few studies have attempted to merge all these functionalities into a single cohesive framework. Additionally, most prototypes face challenges in real-time obstacle avoidance, customer recognition accuracy, and scalability when deployed in dynamic retail environments. From the review, it is evident that the future of smart shopping lies in combining human-following robotics, RFID- based product detection, IoT connectivity, and cloud- integrated billing systems. Such integration would enable a truly hands-free and seamless retail experience, minimizing human involvement while maximizing operational efficiency. The proposed work aims to address these limitations by developing a comprehensive smart trolley system that follows the customer autonomously while supporting automated billing and product management in real time.

Methodology:-

The proposed Smart Shopping Trolley system fig 1 is designed to provide a hands-free, efficient, and automated retail shopping experience by integrating human-following technology with RFID-based automatic billing and IoT data communication. Fig 1 The overall methodology involves both hardware and software components that work in coordination to achieve real-time trolley navigation, product identification, and wireless billing.

System Overview:-

The system consists of four major functional modules:

1. Customer Detection and Tracking Module
2. Product Identification and Billing Module
3. Control and Navigation Module
4. IoT-Based Communication and Data Management Module

These modules interact through a microcontroller-based architecture to ensure synchronized and reliable operation of

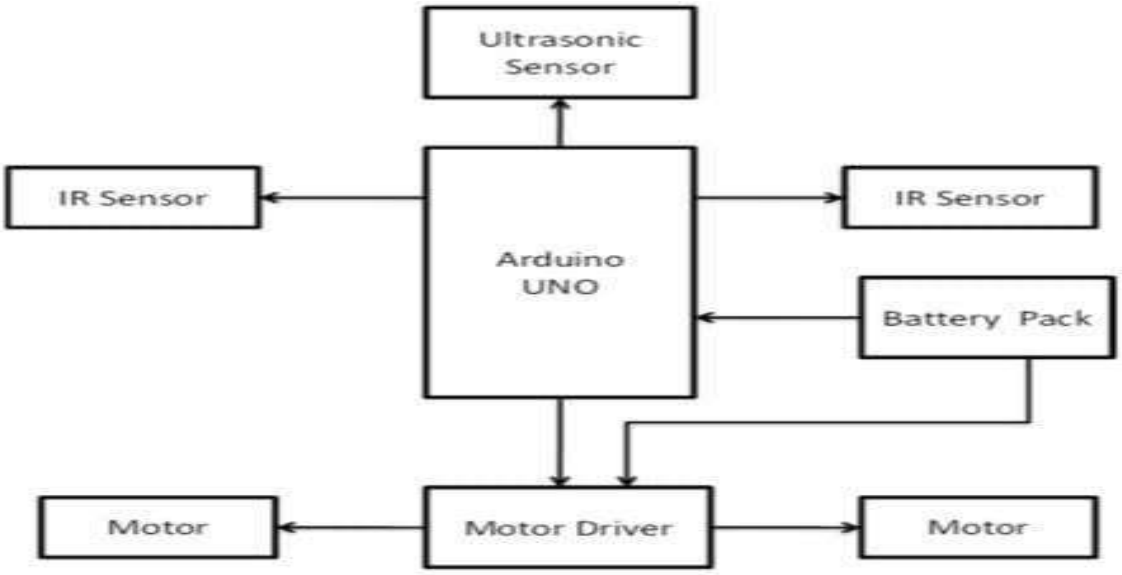


Fig 1: Block diagram of trolley control system

Customer Detection and Tracking Module:-

This module enables the trolley fig.2 to follow the customer throughout the shopping area autonomously. An ultrasonic sensor array or PIR (Passive Infrared) sensors detect the customer's position and maintain a fixed distance

by continuously measuring range values. The system fig 2 uses a servo-controlled motor driver for smooth movement and obstacle avoidance. The distance data is processed by the Arduino Uno/Nano microcontroller, which adjusts the motor speed and direction dynamically.

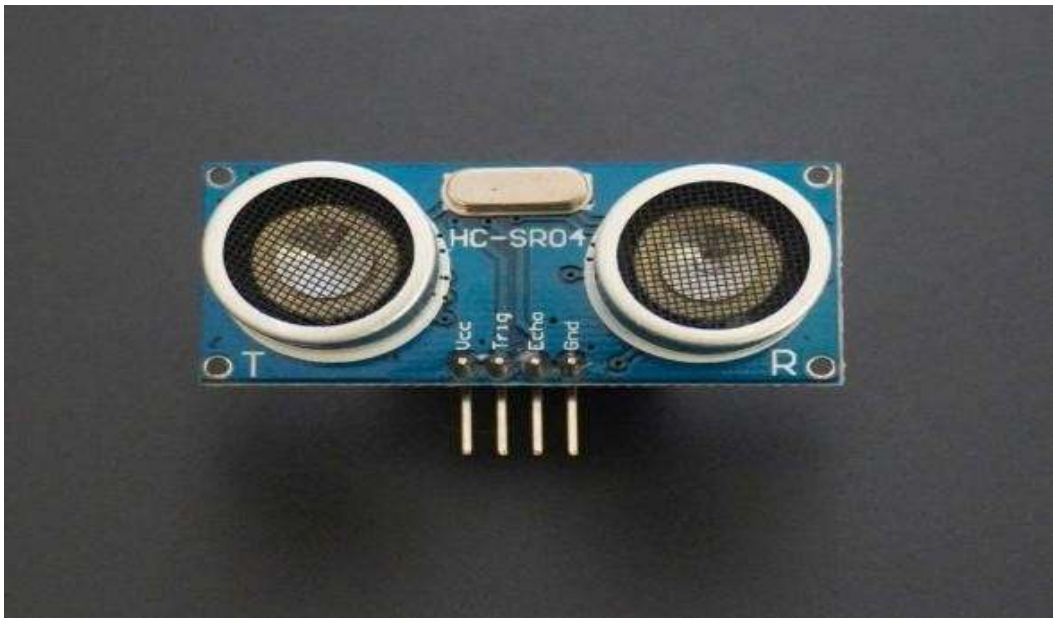


Fig 2: Ultrasonic sensor

If the trolley Fig.3 detects an obstacle within a predefined range (e.g., 30–50 cm), it automatically stops or changes direction to prevent collisions. This ensures safety and uninterrupted movement even in crowded shopping environments.

Fig 3: IR sensor

Product Identification and Billing Module:-

The billing process is fully automated using RFID technology. Each product in the store is tagged with a unique RFID label containing its identification code. The trolley is equipped with an Fig. 5 RFID reader module that scans these

tags when products are placed inside the trolley. The microcontroller retrieves the product ID and transmits it to the central database or cloud server, where the product details (name, quantity, and price) are fetched.An LCD fig.4 or OLED display mounted on the trolley continuously fig 4 shows the list of items added, their respective prices, and the total bill amount. When an item is removed, the RFID reader in Fig.5 updates the list accordingly to prevent double-billing.

Fig. 4: LCD Display

Fig 5:RFID

Control and Navigation Module:-

This module is responsible for the physical movement of the trolley. Two DC motors are used for the rear wheels, controlled through an L298N motor driver. The Arduino microcontroller receives distance data from the ultrasonic sensors and uses a simple proportional control algorithm to maintain a constant distance from the customer. To enhance stability and path accuracy, a servo steering mechanism is incorporated, allowing smooth turns and movement in narrow aisles. A rechargeable Li-ion battery pack supplies power to all modules, ensuring continuous operation for several hours.

IoT-Based Communication and Data Management:-

The smart trolley is connected to a cloud database via Wi-Fi (ESP8266/NodeMCU module). This connection enables: Real-time synchronization of product and billing data User authentication and trolley assignment at the store entrance fig.6 Automatic payment processing through a connected mobile application When shopping is complete, the customer can view the total bill and proceed to checkout digitally without manual cashier intervention. The store database is simultaneously updated for inventory and analytics purposes.

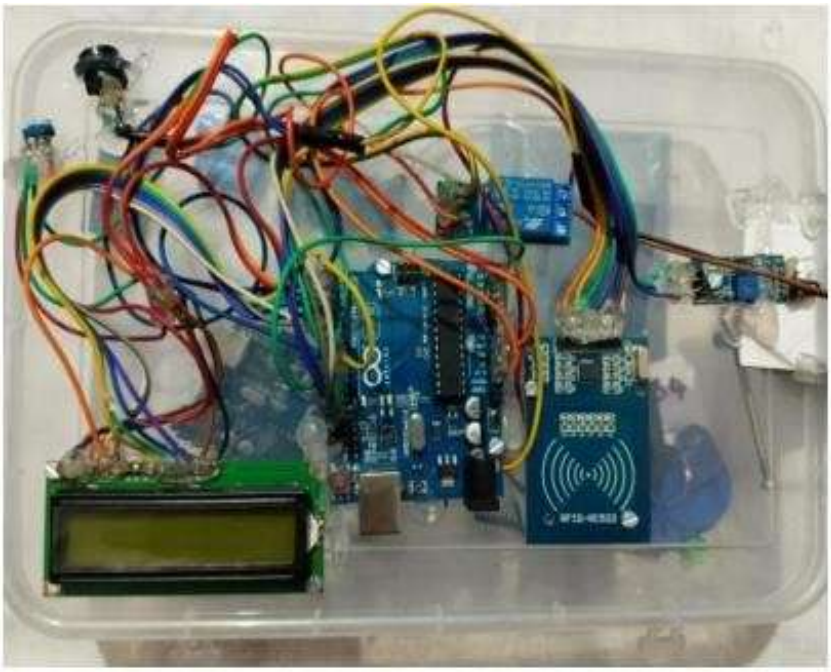


Fig.6 wired billing system

Software Implementation:-

The software design integrates embedded C/C++ programming for Arduino and cloud connectivity through IoT protocols such as MQTT or HTTP. The data collected from sensors is processed locally on the microcontroller and periodically transmitted to the cloud. A simple Android interface or web dashboard allows users to monitor shopping details and confirm payment.

A flowchart of the overall process is shown below:

1. System initialization
2. Detect customer position using sensors
3. Follow the customer, maintaining a safe distance
4. Detect items via RFID when placed in the trolley
5. Update product list and display bill
6. Transmit data to the cloud and the database
7. Complete payment automatically or at checkout

Advantages of the Proposed System:-

Hands-free movement and convenience for customers Automated billing reduces human intervention and queue times Real time data management for store inventory control Energy efficient and cost effective embedded system implementation Scalable and compatible with IoT-based retail infrastructure

Experimental Setup:-

The prototype system is implemented using Arduino Uno, HC-SR04 ultrasonic sensors, an RFID reader (RC522), an ESP8266 Wi-Fi module, an L298N motor driver, and DC gear motors. Tests are conducted in a controlled indoor environment resembling a retail aisle to evaluate tracking accuracy, response time, and billing efficiency.

Automatic Billing System Implementation:-

The Automatic Billing System's architecture fig.7 is developed to harmonize with the RFID infrastructure embedded in the Smart Trolley. A robust logic is defined for the billing process, ensuring accurate transactions in real-time.

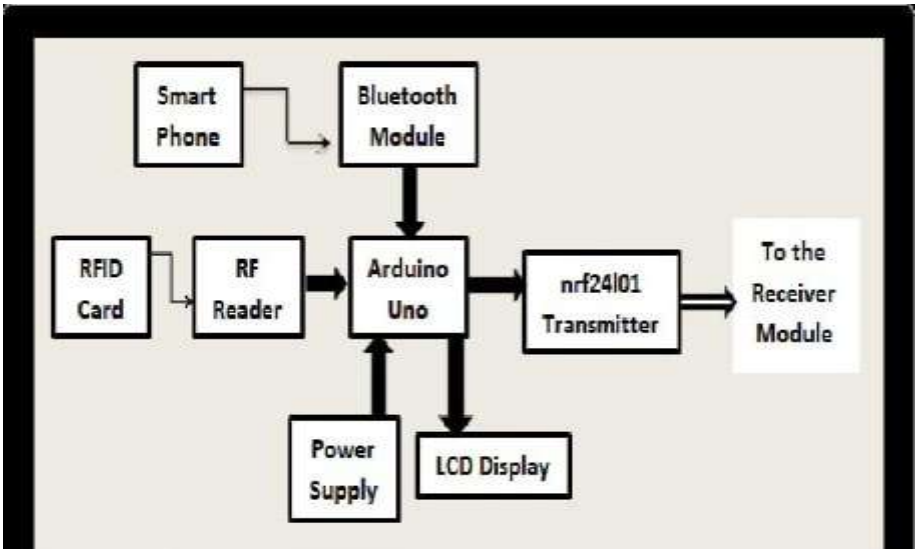


Fig 7: flow chart of working

Smart Trolley Prototype Development:
The physical design of the Smart Trolley is carefully crafted, considering user interfaces and ergonomic factors. The prototype prioritizes user comfort, ensuring an intuitive and efficient shopping experience .

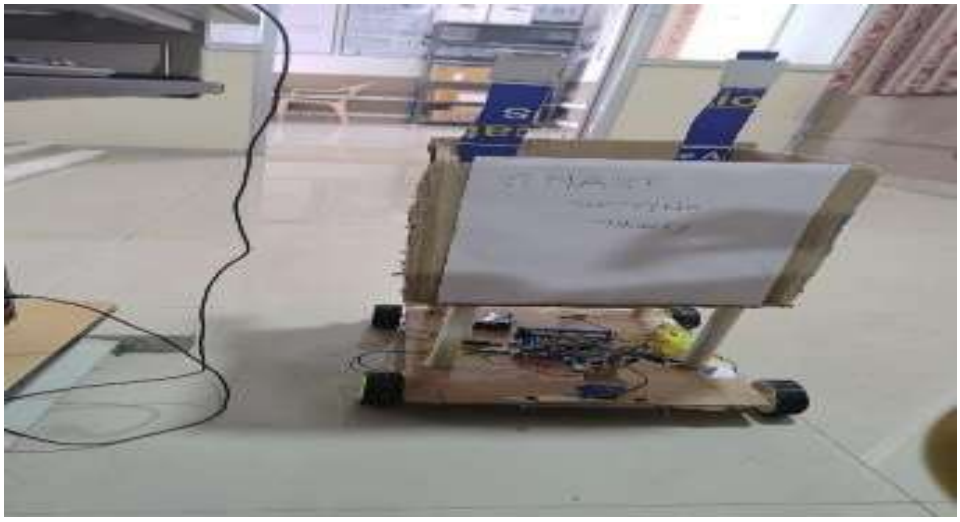
Field Testing And Evaluation:
A comprehensive field testing strategy is executed to measure the impact of the Smart Trolley on checkout times and accuracy. Customer feedback is collected and analyzed to assess the overall shopping experience, providing valuable insights for refinement.

Testing:-
The retail industry is undergoing a significant paradigm shift, driven by the relentless integration of advanced technologies aimed at elevating customer experiences and optimizing operational efficiencies. This research project embarks on a pioneering endeavor, leveraging Radio-Frequency Identification (RFID) technology to conceptualize and implement a Smart Trolley with an Automatic Billing System. Traditional retail checkout processes, marked by extended wait times and manual transactions, have become a bottleneck in the contemporary consumer landscape. This project seeks to redefine the shopping experience by introducing automation to the billing process through the incorporation of RFID technology. The exploration of RFID applications in inventory management, supply chain optimization, and customer engagement lays the foundation for the research objectives. Existing smart shopping cart systems are critically examined to identify gaps and limitations, positioning the proposed Smart Trolley system as an innovative solution to address these shortcomings.

The core objectives of this research are threefold: firstly, to design a Smart Trolley equipped with RFID technology; secondly, to implement an Automatic Billing System seamlessly integrated with the RFID infrastructure; and thirdly, to evaluate the systemic impact on both customer satisfaction and operational efficiency. Moving beyond the objectives, this introduction delves into the broader technological landscape, highlighting the principles and benefits of RFID technology, such as real- time tracking and data accuracy. The architectural intricacies of the Automatic Billing System, intricately linked with the RFID technology embedded in the Smart Trolley, are expounded upon, providing a comprehensive understanding of the technical underpinnings. As the research progresses, the subsequent sections will delve into the intricate hardware components, RFID technology principles, Automatic Billing System architecture, Smart Trolley design considerations, and the step-by-step guide to RFID integration. Field test results, customer feedback, challenges faced during implementation, proposed solutions, and avenues for future research will be rigorously examined and discussed, contributing to the burgeoning discourse on the future of retail automation. In conclusion, the significance of the Smart Trolley with Automatic Billing System in reshaping the retail landscape will be succinctly summarized, reinforcing the transformative potential of this innovative solution.

Result and Discussion:-

Fig.8 A Smart Trolley Checkout Time Analysis:



Field tests were conducted to assess the efficiency of the Smart Trolley Fig.8 in reducing checkout times compared to traditional methods. Results indicate a significant reduction in the time customers spend at the checkout counter, enhancing overall operational efficiency.

Exactness Appraisal:
The exactness of the Programmed Charging Situation was thoroughly assessed by contrasting created bills and genuine purchases. The framework showed a serious level of accuracy, limiting mistakes in exchange handling and guaranteeing exact charging for clients.

Customer Feedback:
Qualitative data from customer feedback forms and interviews shed light on the subjective experiences of users. Positive responses highlighted the convenience of the Smart Trolley, emphasizing its user-friendly design and the seamless integration of RFID technology. Constructive feedback informed potential areas for refinement.

Comparative Analysis:
A comparative analysis was conducted to benchmark the performance of the Smart Trolley against traditional shopping methods. The results underscored the system's superiority in terms of checkout speed, accuracy, and overall customer satisfaction.

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