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Design and Implementation of An Intelligent Vision-Based Retail Monitoring System with an Age-Driven Recommendation Engine

K Purushotham Reddy[1]
M.Tech Student
Department of Electronics and Communication Engineering (ECE)
National Institute of Technical Teachers Training and Research (NITTTR), Chennai

Dr. P. Sivasankar[2]
Professor
Department of Electronics and Communication Engineering (ECE)
National Institute of Technical Teachers Training and Research (NITTTR), Chennai

Dr. G. Kulanthaivel[3]
Professor & Head,
Department of Electronics and Communication Engineering (ECE)
National Institute of Technical Teachers Training and Research (NITTTR), Chennai

Abstract **- This paper presents a design and implementation of a vision-based retail monitoring system with an age-driven recommendation engine, aimed at improving customer behavior analysis in contemporary retail settings. Traditional surveillance solutions can only provide passive monitoring and cannot offer meaningful insights into customer preferences and interactions. The proposed system aims to overcome this limitation by integrating real-time facial recognition and behavior tracking using the Local Binary Pattern Histogram (LBPH) algorithm, implemented on a Raspberry Pi with a USB camera, to provide an efficient and reliable system capable of functioning in a variety of environmental settings. The system classifies customers in various age groups based on facial features and matches each category with specific product preferences to allow product-specific recommendations to be made. It also records customer interactions with products as well as dynamic records of activities with the aim of supporting behavior-based analysis and making informed decisions. The system also uses the LCD to display real time and a buzzer indicating an alarm is also used to enhance the usability of the system. The outcomes of experiments prove the reliable performance, effective customer segmentation, and enhanced retail analytics. All in all, the suggested solution turns the traditional monitoring system to a data-driven, intelligent platform that will support targeted marketing, personalised services, and efficient retail management.**

Keywords - Vision-Based Retail Monitoring, Age-Driven Recommendation Engine, Face Recognition, Local Binary Pattern Histogram (LBPH), Customer Behaviour Analysis.

I. INTRODUCTION

Over the past few years, the development of computer vision and embedded systems has had a great impact on the evolution of the retail industry towards automation and intelligent decision-making. The conventional retail monitoring systems are mainly based on surveillance cameras which are capable of passively observing the consumer behaviour, preferences and interaction patterns with other customers. This constraint presents a challenge to the retailers in that they are unable to know the customer needs, optimize the products placement, and adopt effective marketing strategies. With the competition in retail sector continually growing, the demand of smart systems capable of real time monitoring as well as real time analysis of customer activities in the retail sector has continued to rise. The combination of vision-based technologies and intelligent analytics has proved to be a potentially effective solution to these issues and allow retailers to achieve greater operational efficiency and enhanced customer experience. This work aims at designing and implementing an intelligent vision-based retail monitoring system and an age-driven recommendation engine to overcome the constraints of the traditional systems. The proposed system employs the Local Binary Pattern Histogram (LBPH) algorithm to achieve efficient and reliable face recognition and runs on a platform of Raspberry Pi to perform the recognition in real time. It classifies the customers into various age groups according to the facial features and associates the factors with particular product preferences to facilitate individual recommendations. The system also monitors interactions that customers have with products and activity records on behaviour-based analysis. Through a combination of real-time tracking, demographic classification, and intelligent recommendation systems, the system will offer valuable insights that can be used to support targeted marketing and improved store management. This concept will turn the conventional retailing experience into intelligent, data-driven systems that can help improve the performance of the business and customer satisfaction.

II. PROBLEM STATEMENT

Conventional customer monitoring applications in stores and open settings mostly rely on cloud-based processing and conventional surveillance techniques, which pose challenges such as high latency, increased dependence on internet connectivity, data privacy concerns, and limited real-time decision-making capability. Such systems do not provide efficient on-device intelligence for customer detection and behaviour analysis on resource-constrained embedded platforms. To overcome these limitations, a compact, low-cost, and privacy-preserving solution is required that can perform face monitoring and behaviour analysis directly at the edge. Therefore, this work focuses on the development of an Edge-AI-based intelligent customer monitoring system using a Raspberry Pi, capable of performing on-device face recognition, age-based customer classification, and

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recommendation generation with low latency, reduced cloud dependency, and enhanced data security.

A. CONTRIBUTIONS

- Design of a smart vision-based retail monitoring system linked to an age-driven recommendation engine to provide real-time customer analysis.
- Application of the Local Binary Pattern Histogram (LBPH) algorithm on a Raspberry Pi to make the face recognition process efficient and reliable.
- Introduction of an age-based customer segmentation method to enable personalized product recommendations.
- Real-time monitoring of customer interactions with products in order to analyze and collect behaviour-based data.
- Application of edge computing to guarantee low latency, reduced reliance on the cloud, and increased data privacy.
- Design of a compact, affordable, and scalable platform appropriate for the modern retail environment.

III. LITERATURE SURVEY

AR, with the application of Deep Learning (DL) and Computer Vision (CV) is changing the way retail is conducted, by establishing interactive and personalized shopping experiences. However, the existing AR systems suffer from various issues such as low recognition accuracy, low adaptability and low personalization. The proposed framework VISAR (Vision-Intelligent Smart Augmented Retail) consists of CNN based object recognition, generative models for generating realistic AR images and reinforcement learning for generating the adaptive product suggestions. It is there for you to see the product live, make offers specific to you and even see the product in 3D (like trying a product in 3D). Also, VISAR employs the analysis of customer behavior and detection of sentiments to enhance recommendations and inventory decisions. The experimental findings indicate that VISAR can be a good solution to the future of smart retail [1].

In this study, a multi-layer suggestion system for the retail based on machine learning and association rule mining (ARM) is proposed. The system first extracts association rules from transaction data, next leverages meaningful features for extraction from the data, and then synthesizes multiple synchronized ML techniques from multiple layers to generate recommendations that are customer-centric. It achieves high performance with 99.09% accuracy, 0.95 F1 score, 0.94 precision, 0.925 recall, and 0.987 AUC. Moreover, the system is tested in such conditions as noise, data drift, seasonality, and anomalies, which proves its strength and flexibility. In general, it provides a correct, dynamic and dependable solution to a contemporary retail setting [2].

For embedded vision devices, a smart retail analytics framework has been developed to analyze customer movement, shelf interactions and shopping behavior. This system helps to lower latency and keep customers' data private, but also provides valuable data for store optimization. The study shows that using edge-based analytics can help cut down bandwidth requirements without compromising customer behaviour analysis [3].

An intelligent smart shopping assistant integrating computer vision and recommendation algorithms has been introduced for modern retail environments. The system identifies customers using facial recognition, monitors product selection, and recommends similar or complementary products based on customer preferences. The proposed solution enhances shopping convenience while improving sales opportunities through personalized recommendations [4]. A computer vision and computer-aided recommendation based smart shopping assistant is introduced to the smart retail scene. The system can recognise the user by face, can control the selection of product and can recommend similar or complementary product based on user's choice. The proposed solution will not only offer an enhanced shopping convenience but also better sales opportunities due to the generation of personalised recommendations [4].

The vision based customer behaviours analysis system based on artificial intelligence was designed to identify the movement pattern, product interaction time and browsing behaviour of the customers in supermarkets. The gathered behavioural data helps retailers optimize the products, design the store and enhance customer satisfaction by making the decisions based on data [5].

An edge-based facial recognition system optimized for Raspberry Pi has been suggested to implement surveillance and customer identification system. The system adopts efficient feature extraction strategy to attain fast face recognition and with less computational overhead. The embedded implementation has been proved to be appropriate for implementation of the low cost intelligent retail monitoring system [6].

Great need for intelligent systems to support the elderly in order to live safely and independently has emerged in the context of the ageing population. The elementary elderly activity monitoring system, easy and user friendly graphical user interface (GUI) and artificial intelligence (AI) are employed. This would be a system that would monitor the activities in real time, identify any unusual patterns, and notify caregivers/family members accordingly. The AI algorithms interpret the data gathered by the sensors to identify normal patterns and notify for abnormalities, such as inactivity, falls and abnormal movements. The GUI provides real time visualization of data for activity, system status and alert notifications, essential to ensure that non-technical users can access this data. Simplicity, scalability, reliability are all emphasized, with the system being applicable in the actual world and suitable for home. Experimental tests demonstrate the capability of the system to track the activities and respond to abnormal events, which help to improve safety, health monitoring and quality of life for elderly people [7].

An innovative platform that has the potential to simplify grocery shopping and solve problems like too many product options available in the market, socio-political and economic effects of the pandemic. It helps customers to quickly compare products from various online platforms, provides personalised suggestions and renders the products more accessible, convenient and affordable. Highlights include search by images, a user-specific coupon manager and a recommendation engine. To achieve more customisation, preferences are stored in user profiles, so that product

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discovery processes with different options can be more efficient and effective [8].

For people with longer lives, physical, mental, cognitive and social well-being is an important way to address the health challenges of aging. This paper will review the role of recommendation systems, in particular, the ones that utilize artificial intelligence and machine learning, in promoting healthy behaviours and active ageing. Based on the guidelines of systematic review, the 34 research articles related to the systematic review were analysed. The results emphasise that AI-based recommendation systems have the potential to effectively individualise health suggestions to enhance lifestyles and decrease health risks. But there are some difficulties, such as limited application of simple models and no reliable and traceable systems in place. More generally, it is crucial to have solution-oriented and short-term decision making processes that might be available later to help people age healthily [9].

In order to estimate customer age and gender, from facial pictures taken inside retail stores, a deep learning based customer demographic analysis system is proposed. The framework is used in conjunction with convolutional neural networks (CNNs) to identify the demographic segments; and the retailer can then deliver personalized ads and product suggestions. Experimental research has proven that demographical marketing plans can result in more customer engagement [10].

IV. RESEARCH GAP

Although a number of recent works propose the application of recommendation systems in the field of retail, there are analysis platforms of customer behavior, augmented reality shopping, and edge-based retail analytics, most of the existing proposals focus exclusively on the recommendation or the monitoring independently. Few systems come with both real-time face recognition and age-based classification of the customer, behavior analysis, and then personalized product recommendation in a single embedded platform. Furthermore, several of the methods are based on cloud computing which causes latency and privacy concerns. Therefore, an intelligent customer monitoring system based on edge has to be developed to detect customers and analyze the demographic information, provide recommendations and record the customers' situation locally with limited computation load on the Raspberry Pi.

V. EXISTING SYSTEMS

The current retail and grocery shopping systems are mainly based on traditional e-commerce and simple recommendation engines, which provide little personalisation and interaction. The platforms used, however, rely on manual search and fixed filters and therefore are time-consuming and ineffective for the process. Even when certain systems have recommendation capabilities, these systems tend to be grounded on previous purchase history or general trends other than the real-time behaviour or visual data. Search features of a product based on images are either limited or do not provide highly accurate search results. Moreover, the old fashioned retail surveillance systems rely on cameras to provide security services and do not analyze customer behaviour or preference. Management of coupons is frequently done via discrete applications, is not well integrated with shopping platforms. This means that the current systems are not unified to provide intelligent, real-time and personalized shopping experiences and therefore it is necessary to have more advanced and integrated solutions.

Therefore, an integrated edge-based intelligent retail monitoring system is required to overcome these limitations.

VI. PROPOSED METHODOLOGY

The proposed system deploys an age-based intelligent vision retail monitoring system, which uses a Raspberry Pi and a USB camera to acquire and process real-time data. The system captures the live video stream and face detecting and recognizing with the Local Binary Pattern Histogram (LBPH) algorithm, which guarantees satisfactory performance through different conditions. The identified faces are processed in order to make age group estimates, and customers are divided into predetermined segments, which correspond to particular product preferences, so that the customers could be offered individual recommendations. Moreover, the system monitors the interactions of customers with the products to measure the behavioural tendencies and keep a record of activity to gain additional insights. All processing is done locally on the Raspberry Pi, which ensures low latency, less reliance on cloud services, and privacy of data. A LCD provides real-time information of the system, and a buzzer is used to provide a notification of a certain event. The combination of these measures allows effective customer tracking, behaviour analysis and smart recommendation and enhances retail management and customer experience.

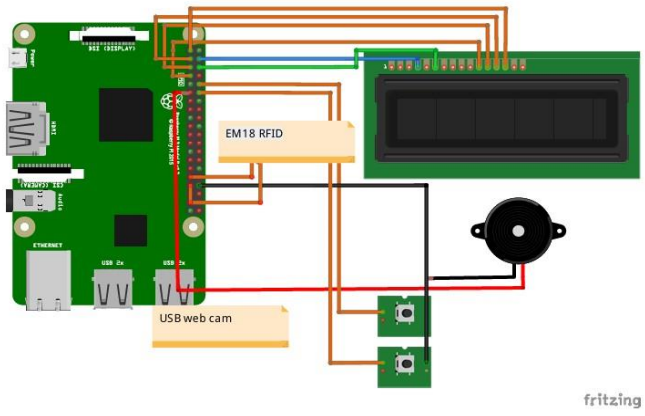

Fig. 1. Circuit diagram of the proposed intelligent retail monitoring system.

Fig. 1. proposed system uses a Raspberry Pi–based camera module to capture live video, which is processed through face detection and age/gender estimation to build a customer profile. This profile drives a recommendation engine that displays relevant product suggestions on an LCD/monitor, while detection events are simultaneously logged for footfall and demographic analytics.

a) Face Detection and Recognition using LBPH

The system captures live video using a USB camera interfaced with the Raspberry Pi. Each frame is processed to detect faces, followed by recognition using the Local Binary Pattern Histogram (LBPH) algorithm, which encodes local texture patterns of the facial region into a histogram representation. This approach is computationally lightweight,

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well suited to the limited resources of the Raspberry Pi, and remains robust to moderate changes in lighting conditions.

b) Age and Gender Classification

Once a face is detected, the system estimates the customer's age range and gender using a pre-trained classification model. Based on the estimated age bracket, the customer is placed into a predefined category (e.g., youth, adult, senior), which forms the basis for personalized recommendations.

c) Recommendation Engine and Product Mapping

A set of product preferences are associated with each age category as are, if relevant, a suggested store floor or section. The system will list all the recommended floors/sections for a customer, along with other product suggestions, and then present the customer with an option to make an itemized list of the items purchased.

d) Real-Time Feedback, Logging and Billing

The interactions that customers have with products that have been recommended are captured to be analysed based on behaviour. The system takes a set of selected items, calculates an itemised bill of the items selected and prints the customer's name and the total amount of the bill on the LCD screen. A buzzer is used to indicate the completion of the transactions and/or occurrence of a particular event in the system which enhances interactivity and usefulness of the system.

VII. ADVANTAGES OF PROPOSED SYSTEM

The proposed system has several benefits, such as offering an efficient and privacy-preserving solution for monitoring and analyzing retail customers. Using a Raspberry Pi for edge processing, the system ensures customer facial information is processed locally, giving edge users greater privacy over their data while reducing communication latency and dependence on cloud services. Because the LBPH algorithm is easily implemented on low-power embedded system and can be applied to the embedded system with limited computing power with good face recognition accuracy, it is used in the system, which is light and computational efficiency.

Moreover, the suggested system provides personalized customer interaction based on analysis of information related to age and suggesting suitable age-related information based on customer profile. This Raspberry Pi implementation is fast, frugal and mobile, enabling the system to be deployed and moved to any retail environment such as shops, supermarket outlets or smart stores. This means that there is no need to purchase expensive computer systems, have a continuous cloud connection and provides a practical, scalable and simple solution to monitor an intelligent retail store.

VIII.BLOCK DIAGRAM

Fig. 2 shows the block diagram of the proposed system. A USB camera continuously captures the retail floor and customer faces, streaming frames to the Raspberry Pi. The Raspberry Pi runs the LBPH-based face detection and recognition pipeline, followed by an age and gender classification stage. The classification result is passed to the recommendation engine, which maps the customer's age category to relevant products and a suggested floor or section. Customer interactions and generated bills are logged for behavior analysis, while the LCD displays real-time status and output, and the buzzer provides an audible alert for completed transactions or system events.

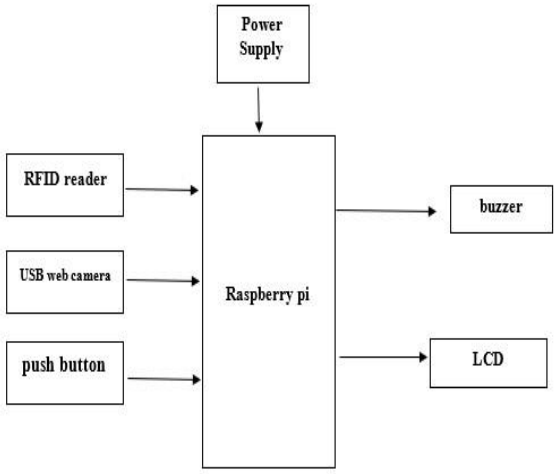

Fig. 2. The proposed proposed intelligent retail monitoring system has been presented in Block diagram.

IX. COMPARISON OF EXISTING SYSTEMS AND PROPOSED SYSTEM

Feature / Parameter	Existing Systems	Proposed Retail Monitoring System (LBPH-based)
Monitoring Capability	Existing retail monitoring and customer behaviour analysis systems provide domain-specific monitoring with limited integration and personalization.	Real-time integrated customer monitoring using a USB camera and LBPH-based face recognition for continuous customer awareness.
Prediction / Decision Ability	Existing AI-based recommendation systems provide predictive decisions based on customer preferences or historical data but have limited real-time adaptability.	Adaptive age-driven decision-making using LBPH-based classification for personalized product recommendations.
Personalization	Personalization is generally based on customer profiles, purchase history, or demographic information with limited behaviour analysis.	Advanced personalization based on customer age category, product interaction, and real-time behaviour data
Accuracy	Existing AI and computer vision models provide moderate to high recognition performance depending on the algorithm and dataset used.	High accuracy achieved through LBPH-based face recognition and age/gender classification
Real-Time Processing	Several systems support near real-time processing, while others depend on cloud computing or higher computational resources.	Fast real-time processing with efficient on-device LBPH algorithm execution on the Raspberry Pi

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Feature / Parameter	Existing Systems	Proposed Retail Monitoring System (LBPH-based)
Scalability	Existing systems are scalable but often require cloud infrastructure and greater computational resources.	Highly scalable due to modular, camera-based architecture and efficient resource management
System Efficiency	System efficiency depends on the complexity of AI models and available computing resources.	Improved efficiency with optimized resource utilization and lightweight LBPH processing suited to embedded hardware
Security / Reliability	Existing solutions provide reliable monitoring but may raise privacy concerns due to cloud dependency.	Enhanced reliability and data privacy through edge-based processing with no dependency on cloud services

X. RESULTS

The proposed system was implemented and tested with a raspberry pi interfaced with a USB camera, LCD display and buzzer to check its face recognition and age classification capabilities with the proposed system in real time and also to verify the recommendation functionality.

The physical prototype of the system is shown in figure 3 with the addition of the power supply module and a 16x2 LCD. The LCD displays the name of the customer that the customer entered, along with the total amount of the bill (the amount calculated by the system), indicating that the system was able to correctly collect the customer's name and calculate the bill.

Fig. 3. It's a prototype of the hardware, with the completed customer transaction being displayed on the LCD.

Fig. 4 the age driven recommendation engine is tested in real time in a test run, which is printed on the console, and is displayed .The system has been accurate in detecting the gender and age range of the customer, classified the customer in an appropriate age group and suggested a corresponding floor/product to the customer. The system could be able to calculate the prices of the items based on the customer classification and then give an integrated bill to demonstrate the entire process from classification based on face to personalised recommendation/billing.

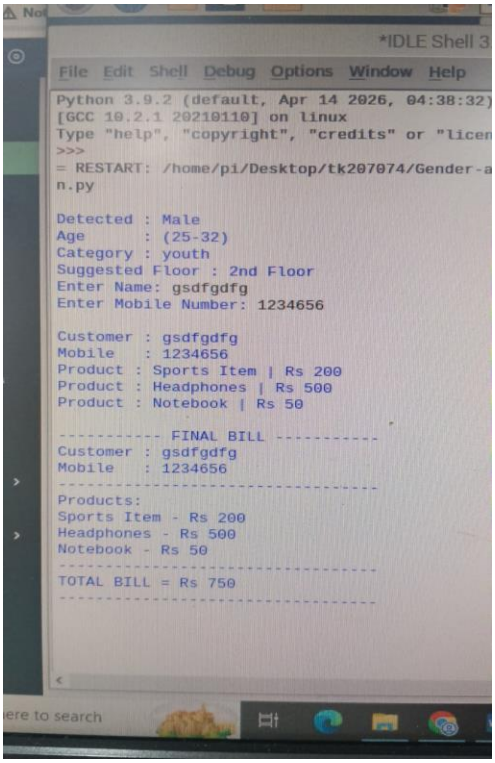

Fig. 4. Console Output of Age/gender detection, category classification, Product recommendation and generated Bill.

The validation of the results have demonstrated that the system is capable of providing accurate age group classification of customers, age dependent suggestions about products/locations can be generated in the system and the output generated by the system for billing is accurate, which validate the effectiveness of the age based recommendation approach in a real retail environment.

The results of the experiments validate the success of embedded hardware-based customer detection, age estimation and recommendation generation, and billing without leaving the device. In the smart retail space, face recognition and recommendation modules are combined to provide an efficient solution, which is simple to operate and guarantees privacy of customers.

XI. CONCLUSION

The proposed system is a successful example of smart retail monitoring using embedded system-based vision-based face recognition and age-based recommendation system. The system can recognize the users and categorize them into age bands and it can also determine how many times the users interact with the product by implementing the LBPH algorithm and real-time processing on a Raspberry pi. This allows for personalized suggestions and analysis based on behavior, providing additional customer insight and facilitating marketing decisions. Implementation ensures low latency, minimisation of cloud dependency, and boosts data privacy with edge computing. In summary, the system is a smart and data-driven solution that enhances retail decision-making, customer experience, and efficiency in the modern

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retail landscape, moving beyond traditional surveillance methods.

XII. FUTURE SCOPE

- Incorporation of state-of-the-art deep learning algorithms to enhance the accuracy of face recognition and age estimation.
- Introduction of emotion detection and gender classification features to create more personalized recommendations.
- Cloud integration for big data storage, analytics, and remote monitoring across multiple store locations.
- Creation of mobile or web-based dashboards for real-time monitoring and system control.
- Multi-camera expansion and IoT-enabled smart shelves to better track products and manage inventory.
- Integration of Large Language Models (LLMs) to generate personalized conversational shopping recommendations.

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