Frontiers in Health Informatics
ISSN-Online: 2676-7104
www.healthinformaticsjournal.com
2024; Vol 13: Issue 3
Open Access

IoT-Based Digital Communication Networks and AI Applications for Sustainable Grocery Purchases

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Cite this paper as: N.R. Vembu, Abdul Salam Khan, Jasmeet Kaur, Gaurav Joshi, Surender, Ajay Sudhir Bale , Saurabh Mittal , Mamta B Savadatti (2024) IoT-Based Digital Communication Networks and AI Applications for Sustainable Grocery Purchases. *Frontiers in Health Informatics, 13* (3),4087-4098

Abstract: *This paper examines the integration of IoT technology with AIML application to transform the sustainable grocery purchasing online systems. To revolution is a traditional grocery shopping experience Anna and also promoting system ability the study helps in analysing how digital communication networks blockchain technology and other smart real solutions work. With the comprehensive review of the current trends in the implementations including scan and go systems AR applications and automation of the inventory management solutions this research helps uses to explore how innovations enhance the consumer experience and reducing the overall impact on the environment. The study mainly focuses on the role of IoT sensors and AI algorithms to enable real time inventory tracking reducing the overall photo wastage and facilitating inform the consumer decisions. Tera certain challenges like successful implementation consumer acceptance data privacy concern and technical interceptor requirements. The finding indicates that these technologies are offering significant potential for improving sustainability in grocery retail industry. About challenges can be met by providing systematic analysis of current implementation and future directions for IoT based grocery systems*

Keywords: *IoT, digital communication, AI, Grocery, consumer purchases*

Introduction

Industry 4.0 integrates wireless technologies, sensing, and intelligent machinery to make a fully interconnected organisation. The Industrial Internet of Things (IIoT) is a crucial element of Industry 4.0; it gathers data on procesing, item efficiency, inventory, and placing orders, and employs big data to consolidate data from suppling , makers, and users. It is a critical issue in contemporary society [1-2]; governments must promptly develop legislation and implement steps to enhance the management of safe agricultural product production, including identification and tracking. Meat products provide significant elements of human nutrition alongside agricultural items [3-4]. The agriculture and livestock industries contribute to fulfilling the hunger needs of the swiftly growing global population. The green agricultural and livestock revolution resulted in overall gains in food yields and meat consumption. Individuals want not simply sustenance but also healthful fare [5-6]. The

World Food Program reports that malnutrition is the primary cause of mortality for 45% of children under five years old, and 2 billion individuals have shortages in vitamins and minerals [7-8]. A multitude of firms and individuals are endeavouring to enhance both the quality and quantity of food goods. Precision agriculture is a primary research emphasis in the 21st century, revolutionising the agricultural sector via the introduction of several advanced technology [9-10]. The advent of information and communications technology (ICT)-based methods is substantially influencing agricultural yields; farmers may now remotely oversee their farm conditions and manage their equipment using a smartphone [11-14]. Figure 1 illustrates a cryptographic framework for message exchanges inside a blockchain.

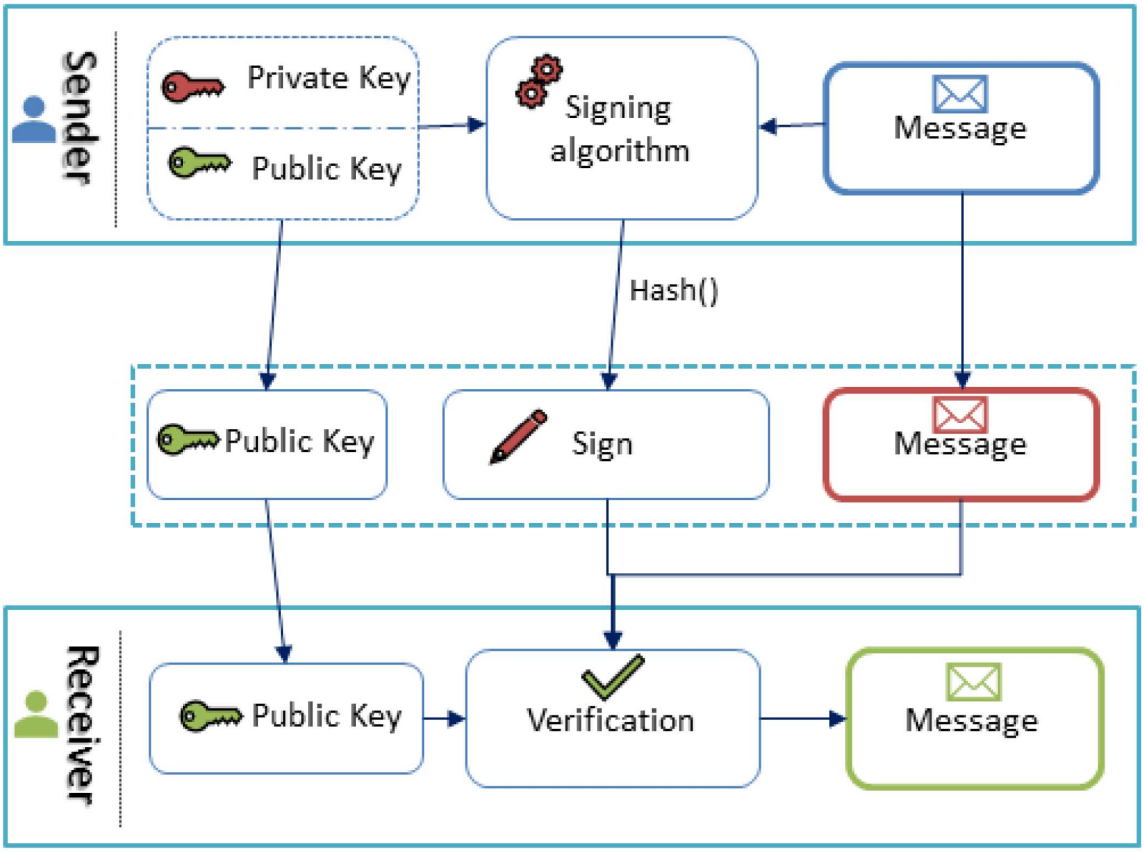

Figure 1: Cryptographic framework for operations inside a blockchain [1].

1. **Computational techniques**

Figure 2 illustrates the key aspects of the digital transformation of supermarket in-store buying within the framework of technology advancement. The authors indicate that the ensuing portions of the study offer the first part of the review, focussing on in-store purchasing [22].

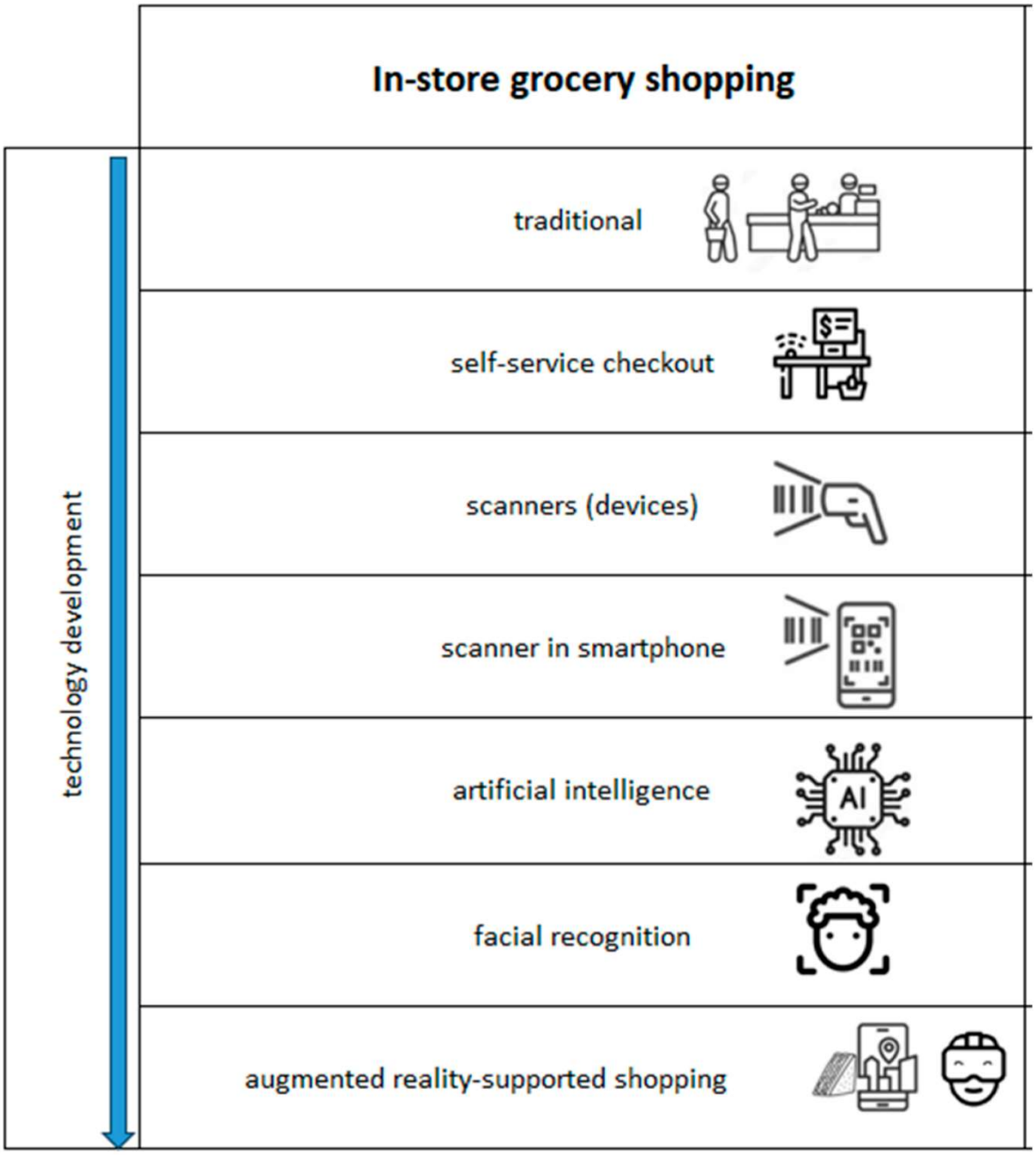

Figure 2: Outline of the key aspects of digital transformation in groceries in-store buying within the framework of technology advancement. [22]

Scan&Go technology signifies an advancement in self-service retail. Customers use portable scanners (devices supplied by the retailer) [15-18] or their own cellphones to scan merchandise while shopping, immediately inserting items into their bags. This technique may be referred to by several names based on the establishment [19-22]. A consumer may get a customised scanner (Figure 2) at no cost from the designated grocery shop. Subsequently, the goods may be scanned, allowing the consumer to generate their own buying list. Additionally,

goods may be eliminated from the gadget if the client opts not to acquire a certain item. Customers may use their own cellphones [23-25]; however, they must first download a specific application associated with each business or supermarket. This approach offers a fluid and customised buying experience, allowing consumers to monitor expenditures in real-time and use digital discounts or promotions. Figure 3 illustrates the framework of Scan&Go innovation using a smartphone.

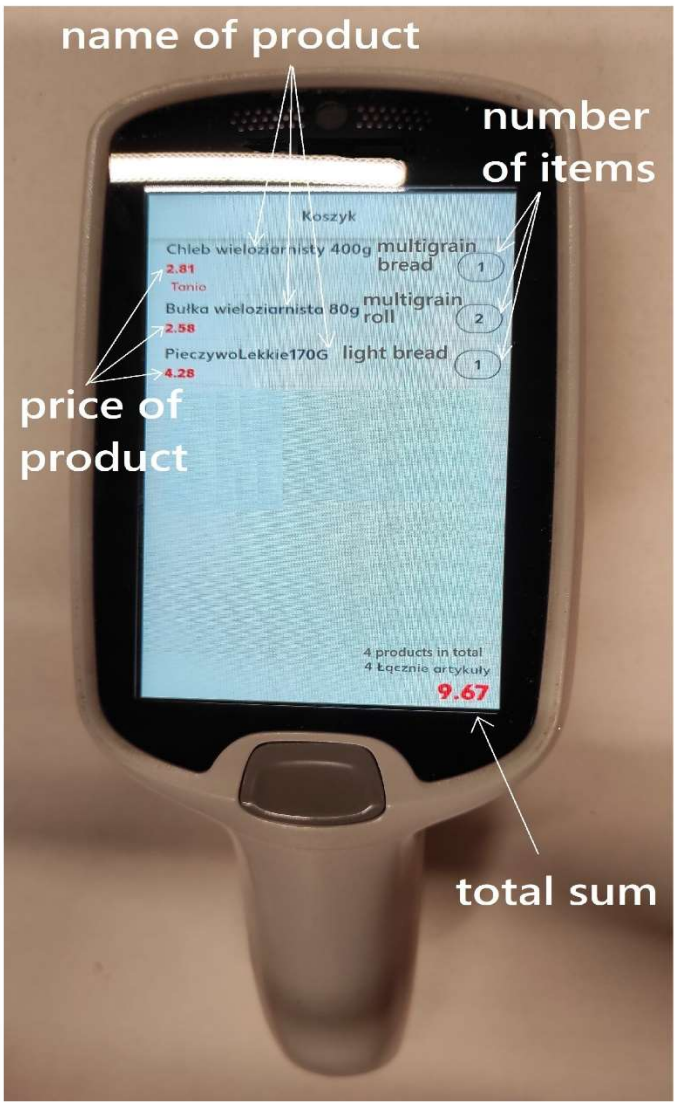

Figure 3: The overall perspective of the scanner and digital components [22]

The method of food shopping is continually shifting due to the emergence of new technology. Augmented reality (AR) emerges as a significant transformational invention. This technology provides realistic and interactive retail experiences that connect actual businesses with internet buying [26-28]. Augmented Reality superimposes digital information onto the physical environment, therefore enriching the purchasing experience. Consumers may use their smartphones or augmented reality glasses to get supplementary information about goods, locate things inside a shop, or see products in their domestic setting. Marks & Spencer (M&S) has started a public trial of their augmented reality navigation application, List&Go, at its store. The application enables

consumers to enter a product list and navigate an on-screen route to their corresponding shelf placements. The application, using the store's Wi-Fi network and digital planograms for navigation, is the first of its sort in the UK [29-32]. NISA has collaborated with technology firm Jisp to implement Scan&Save, an augmented reality vouchering system, at its UK retail outlets. This method enables users to scan product barcodes to access promotions and redeem discount coupons straight from their mobile devices. The test run of Scan&Save achieved remarkable outcomes, including over 82,000 scans, 40,000 taps, and 32,000 coupon redemptions. Participating retailers indicated substantial consumer involvement, with 81% of customers use the system again. The augmented reality technology seeks to mitigate carbon emissions and minimise food waste. Retailers get remuneration for each scan and redemption, motivating them to use the system. Due to restricted space on product labels, businesses are using augmented reality packaging [33-35]. Customers may scan a QR code on a product label to get more information about the item. Figure 4 illustrates a schematic representation of a potential use of augmented reality inside a retail environment. This exemplifies the process of scanning a product to get more information on it. The Italian sauce business Francesco Rinaldi used augmented reality packaging, enabling consumers to scan a jar with their smartphones to get comprehensive information about their sauces. Supermarkets may use augmented reality packaging to convey additional information on their private-label items, including nutritional facts and sustainability policies. Augmented reality packaging provides the opportunity for narrative to engage consumers. For example, Jack Daniels used WebAR to immerse viewers in their distillery located in Lynchburg, Tennessee.

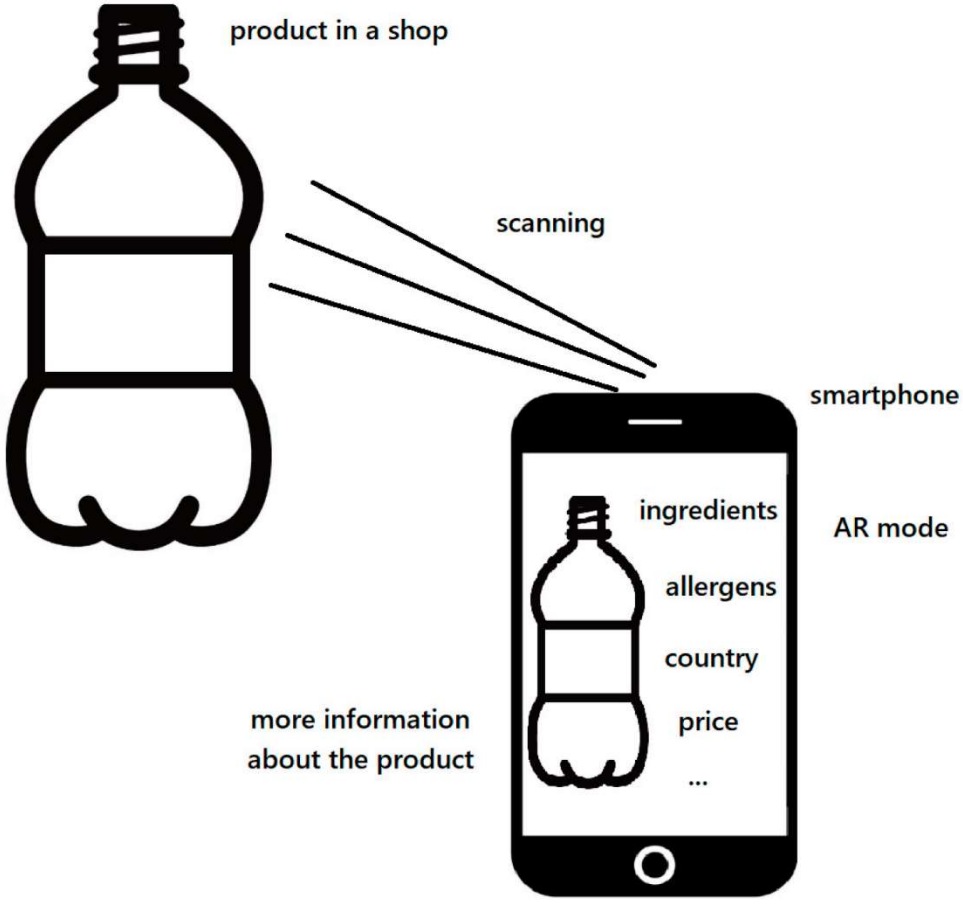

Figure 4: The scheme of an example use of augmented reality in a store [22]

The article provides a comprehensive examination of the notable technology innovations that are revolutionising the conventional supermarket shopping experience. Although SSTs and AI-driven solutions may provide significant advantages, their final efficacy is contingent upon customer perceptions of their value and usability [36-38]. Technologies seen as challenging to use or that do not effectively illustrate their benefits are less likely to be adopted by customers, irrespective of their possible benefits. The article emphasises the extensive ramifications of the digital revolution in food purchasing, indicating that these advances in technology may result in a fundamental alteration of customer behaviour and expectations. Retailers must evaluate both the operational benefits offered by these technologies and their effects on client experience and happiness as they embrace and develop them. The article posits that a balanced strategy, merging the advantages of technology innovation with a profound comprehension of customer requirements and preferences, is crucial for the effective incorporation of these novel instruments into the food purchasing landscape. The paper's academic role is twofold: it presents a comprehensive review of existing methods, highlighting their advantages and drawbacks in grocery purchasing goods; it also establishes a framework for comprehending the determinants of technological use and achievement, automatically referencing theories like the model of technology acceptance [39-41].

2. IoT integration in Sustainable Grocery Purchases

The retail sector has been using technology advancements throughout its product chain to minimise expenses and enhance customer experience, since raising profit margins and recruiting clientele are the fundamental objectives of every entrepreneur [23]. In the retail sector, the automated identification and recognition of items has facilitated a more effective allocation of resources and transformed the purchasing experience for consumers. They seek a streamlined and expeditious purchasing transaction; hence, they prioritise efficient payment methods and solutions that facilitate item discovery, ascertain product availability, and circumvent payment lines. Automated self-checkout systems address the last need. Real-time inventory management, namely automated shelf monitoring, is achievable with computer vision techniques that identify out-of-stock shelves by taking photographs of racks in real-time. Similarly, there exists a chance to ascertain if the product displays and shop layout adhere to the established planogram. Self-service technology is used to establish autonomous shops and provide a self-directed shopping experience, while product identification devices enhance the consumer experience by aiding in the accurate selection of products [42-44].
In a supermarket setting, food and nutrition labels is crucial, as it enables customers to make informed food choices that align with their requirements and tastes, hence facilitating proper storage, preparation, and consumption of food. Interpreting supermarket labels may be challenging, either owing to customers' insufficient food literacy to comprehend the information provided or due to other restrictions, such as visual clutter. This drives the creation of supplementary technologies, facilitating equitable information availability and fostering inclusive tactics; notably, those with visual impairments have significant challenges in performing everyday tasks, including autonomous food shopping. Numerous studies have examined this topic, concentrating on the identification or acknowledgement of certain goods, often under distinct situations. The computerised recognition and identification of grocery products in real-world settings presents numerous challenges, particularly when images are captured by sighted individuals, as their disability hinders their ability to ascertain whether the image contains the product or if it is clear and legible. The items may be presented in random poses and angles, cropped, partially obscured, under varying lighting conditions, reflecting from glossy packaging, at different the distance from the camera, against a chaotic beginning, or in blurry form due to camera movement, among other factors. The quality of the picture will significantly affect the effectiveness of the deployed solution, since it is fundamental for effective product identification. When capturing images or videos of grocery products, several methodologies use image- or frame-processing procedures to enhance or optimise picture quality, including multi-frame super-resolution approaches. Other frameworks use an auditory signal to

alert the user upon the detection of a product or label. In addition to the issue of picture quality, distinguishing between similar logos and other items with comparable looks is a significant challenge. Recognising nuanced characteristics is essential for precise product categorisation, since minor discrepancies in packaging often occur across items within the same category. Distinguishing between a product's subcategories may be challenging, even for humans, for as when differentiating various cereal flavours, varying quantities of shower gel, or the types of hair products within the same shampoo brand. Intraclass product identification systems must distinguish subtle differences in an uncontrolled setting. Moreover, new products are regularly introduced, and their design may evolve over time to capture consumer interest; additionally, marketing strategies may result in minor alterations in packaging (e.g., during promotional campaigns) or the bundling of items for joint sale. Figures 5 illustrate these prevalent issues in fine-grained categorisation.

Figure 5: Depiction of distinctions created by techniques for marketing, namely changes in tastes among identical parent brands (a), and minor alterations in the package of the same item (b). [23]

Deep learning and Convolutional Neural Networks (CNN) have shown efficacy in object recognition, similar to their success in several other application contexts. Various tiers of automatically acquired features have shown superior accuracy and discrimination compared to manually derived features. Despite the widespread use of deep learning techniques, two primary limitations exist: (1) performance is compromised by limited training datasets, and (2) when the model is adapted to acquire new classes or tasks, the retention of previously learnt classes or tasks is not ensured. In the grocery setting, it may be impractical to retrain the whole network with all classes upon the introduction of a new product, since even the smallest shop offers thousands of items. The extensive range of publications, however, poses a limitation in the formation of a suitable dataset. Deep neural networks surpass conventional detection and identification methods; nonetheless, they often encounter limitations due to insufficient datasets. The quantity of tagged data is as crucial as its quality. The photographs of each product should ideally be captured in authentic environments, from various angles and under varying lighting circumstances, across many retail locations. Manually marking the object's position and meticulously detailing the qualities of each product (e.g., brand, taste, kind, size, etc.) are costly endeavours. The task gets

very burdensome when all the textual information about the box must be included. Consequently, databases are constrained and inadequately represented. Certain researchers endeavour to propose flexible frameworks, while various systems incorporate data augmentation during training. For instance, models generate synthetic contexts using generative adversarial networks (GAN), some utilise transfer learning, and others employ a reference database containing images of products captured under controlled conditions from multiple perspectives during the training phase to address this disparity. The match categorisation method is also effective for managing new food items. Despite the mitigation of this problem, obstacles persist in the detection and identification of the item due to domain shift, complicated backgrounds, picture quality, intra-class similarity, and constraints of computing resources. Visual cues are no longer the exclusive method for identifying supermarket goods [43-44]. Currently, textual information, or a synthesis of both, is ubiquitous.

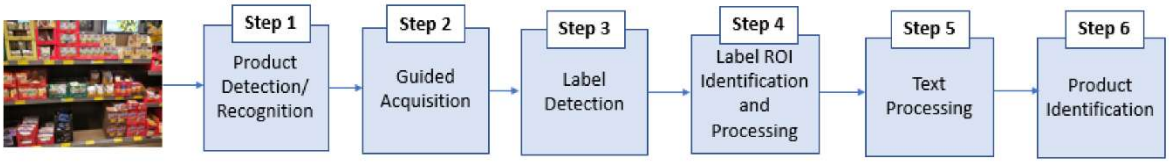

Figure 6: A theoretical framework for the examination of aided retail product labelling [23]

Irrespective of the strategies used by each method to address various difficulties, the system must support the customer throughout the selection and acquisition process of the product. It should identify and distinguish the items shown on the shelves, use photographs or videos shot by the user, and assist him in obtaining the relevant item. Upon selecting the product category, the customer should get more information on subcategories, including sub-brands, flavours, kinds, and quantities. All pertinent information is accessible on the label, if sometimes presented ineffectively. Consequently, in the subsequent phase, the system must recognise the label and delineate the regions of interest (RoI), which may include logos, alphanumeric characters, words, and symbols. The extracted Region of Interest (RoI) is to be processed to convert valuable information. Ultimately, the classifier determines the product based on textual qualities or recognised text. Figure 6 illustrates a notional pipeline that summarises these processes.

Retail shop managers often engage in manual assessments to understand consumer behaviour. This method requires a significant time commitment. Conversely, the use of technological tools enhances management efficiency, expediting the method of making decisions. Recent improvements in consumer behaviour analysis have emerged from the integration of RFID technology and ML algorithms. This research demonstrated that the MLP model, together with iForest and ADASYN, proficiently identified client actions using RFID sensors. Time-domain characteristics were derived from RFID tag RSS data, while ML models forecasted client involvement with certain tagged goods, differentiating between browsing and indifference. This trained model, incorporated into a web-based system, might use RFID reader-derived RSS data to predict client behaviour, providing significant insights for managerial decision-making, optimising store layout, and enhancing the overall shopping experience. Future study should explore more intricate real-world situations using a bigger and more diversified dataset of consumer purchase behaviours. Moreover, future research should examine the integration of diverse time series feature-extraction techniques, feature selection methodologies, and a broader range of classification models [30].

3. Discussions

The integration of IoT and AIML and technology in grocery retail presents significant opportunities research ideas and challenges for achieving sustainability. The implementation of IoT best systems demonstrate various substantial potential for reducing the wastage of water through improved inventory management and tracking systems. The research also shows real time monitoring capability enabled by making use of IoT sensors and block technology, helping retailers to maintain optimal stock levels and quickly identifying of the products

which are approaching expiry dates. The above technological integration helps in reducing waste and also generates considerable cost saving ideas for retailers which contributes to the overall sustainability of the environment. Secondly by using AI powered shopping assistant systems like augmented reality applications and smart shopping cards that has shown the promising results in enhancing consumer experience while promoting sustainable shopping behaviours

The systems provide consumers with the detail product information like sustainability Matrix environmental impact data which enable more detailed information on purchasing decisions. The study here reveals the effectiveness of the systems depending on consumer acceptance and technology literacy particularly among various older demographic groups. Thirdly investigation highlights the importance of data security and privacy in implementing IoT based retail systems. Comprehensive data protection frameworks and transparent policies are in highlight because blockchain technology offers robust security features and large-scale collection and processing of the consumer data. Lastly the study identifies several technical challenges in implementing systems made using IoT in this field of grocery retail

Fourthly the need for reliable connectivity interest structure interoperability between various technology solutions and complexity of integrating new systems with an older version in the retail. The research suggest that successful implementation requires a face-by-face approach allowing gradual technological adoption and optimisation of the system. Economic implication of implementing IoT waste sustainable retail system is significant beside maintaining and implementing cost substantial long-term benefits in terms of wastage include operation efficiency and enhance to customer satisfaction suggesting positive feedback on the overall investment. But small retailer still faces challenges in accessing the required capital because of the technology transformation

This research highlights the importance of consumer education and engaging in maximizing the benefits of sustainability through IIT based systems. The success of this technology depends not only on the technical capability what also on meaningfully engage in the consumers and promoting sustainability through their shopping behaviours. There is a need for comprehensive consumer education programs along with a technology cal implementation. Have important implications for retailer technology developers and policy makers. Careful planning and strategic implementation of the IoT technologies can help the retailers to overcome the challenges discussed., focusing on creating more institute and user-friendly solutions that can accumulated different types of consumer groups. Policy makers can also consider developing new frameworks at encourage technology innovation besides adequate protection of consumer privacy and data security.

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