

Green Communication with Object Detection for Energy-Efficient Smart Shopping Carts

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ABSTRACT

With an emphasis on reducing environmental impact and increasing energy efficiency, this research investigates how green communication principles might improve the performance of Internet of Things (IoT) devices. Given the rising importance of green communication in solving environmental problems, including CO2 emissions and pollution, the study explores the fundamental ideas, operational cycles, advantages, and uses of both IoT and green IoT. For retail settings, a smart shopping cart system has been developed to show how these ideas may be applied practically. Through green RFID technology, the system allows for quick item scanning and eliminates standard barcode readers, hence saving energy. Furthermore, a YOLOv9 object detection model is included to help precisely recognize and monitor items in real-time, therefore smoothing personalized suggestions, stock control, and loss reduction. By reducing energy consumption, reducing waste, and maximizing resource use, this combined strategy not only improves the user experience by streamlining the checkout process and providing useful product information but also supports a more sustainable retail system. The system emphasizes the possibility of using sophisticated technology, including RFID and computer vision, together with green communication ideas to create unique and environmentally friendly IoT applications. Future research can investigate edge computing applications, including more green technologies, and broaden the system's uses in several different retail and IoT sectors.

1. Introduction

The network of physical objects that is made up of internet-connected devices is known as the Internet of Things (IoT), and it helps to share information or data about the environment and its state. IoT is an immersive, global, and peripheral network of communication and computing environment that is based on software, advanced sensors, cameras, data centres, and databases [1][2]. IoT works as a key enabler for advanced applications. The IoT makes machines smarter over time, which can process data

more intelligently and increase the effectiveness and efficiency of communication [3]. The processing cycle of IoT is described in Fig. 1 [1].

From smart homes to smart cities, the fast expansion of the Internet of Things (IoT) has transformed many facets of our lives. The spread of IoT devices, however, has also sparked worries about energy use and environmental effects. Green communication ideas have come to be a key component of sustainable IoT development since they seek to lower carbon emissions, promote environmental protection, and

minimize energy use. This study looks at smart shopping carts, a real-world use case, to see whether combining green communication concepts with

sophisticated object detection methods could improve the sustainability and efficiency of Internet of Things (IoT) devices.



Fig. 1. Processing flow of proposed design

Given its many advantages—minimizing costs, real-time analysis, advanced data collection, efficient sourcing, and precautionary maintenance—IoT has great significance. Manual barcode scanning, which can be time-consuming and energy-intensive, characterizes conventional retail encounters [4]. Many times, traditional buying experiences include manual barcode scanning, which consumes energy and time. Using green RFID technology, this study offers a new design for a smart shopping cart that allows automatic and effective product scanning. By eliminating the need for manual barcode scanning, we aim to reduce energy consumption and streamline the checkout process, leading to a more efficient and enjoyable shopping experience for consumers.

IoT contributes to upgrading humans' lives, whereas it increases energy consumption and embraces toxic pollution and E-waste, which is putting pressure on the technological world and making the surroundings polluted and harmful [5]. Green communication, known as green IoT fulfills the development and sustainability of the technological world. Green IoT has taken many steps to minimize footprint of carbon and promote efficient and effective technologies for power use [6]. Green IoT is environmentally supported communication that increases the advantages or features of IoT over the technological world [7]. There are some basic principles that Green IoT needs to follow, such as, turning off non-essential facilities (sleep scheduling), sending required data (Estimated date of delivery), reducing the length of data path (routing scheme), exchange processing (data aggregation) for communication, latest and efficient communication technology (MIMO) and Inexhaustible green power sources (solar energy) [8]. Green IoT enhances IoT benefits for the smart world, such as minimizing energy consumption, use of renewable and natural resources, reducing the harmful emissions.

The rising global emphasis on sustainability has fuelled innovations in the IoT, giving rise to Green IoT, with research highlighting areas such as energy-efficient routing protocols in wireless sensor networks and low-power hardware for smart devices. While valuable, much of this work has yet to fully translate into consumer-focused applications like retail. In

smart retail, earlier efforts largely centred on RFID-based systems for automated checkout and inventory tracking, exemplified by solutions like the Magic Mirror and Smart Shelf, which show promise but struggle with challenges such as occluded or unlabelled items, lack of real-time object detection, and limited attention to energy reduction. Addressing these gaps, the proposed system combines YOLOv10-powered real-time object detection with green RFID technology, creating a dual-sensor framework that enhances accuracy, improves security, and embeds sustainability at its core, thereby delivering a more energy-efficient and environmentally conscious retail solution tailored to the modern retail landscape in Lahore, Pakistan.

of IoT devices, and minimizing the toxic effects of electronic devices [9]. The processing cycle for Green IoT is provided in Fig. 2 has starting step of green design, followed by production which is green and then green use. The last step is about recycling the material of green disposal [10].

There are several methods for designing green IoT, which may include green RFID, green machine-to-machine (GM2M), green wireless sensor networks (GWSN), 5G green technology, and green cloud computing (GCC)[11]. Transmission in green RFID technology uses radio waves that store information about connected things and also have an automatic data collection feature [12]. Green machine-to-machine (GM2M) technology can communicate with devices without human intervention and intelligently adjust the power transfer [13].

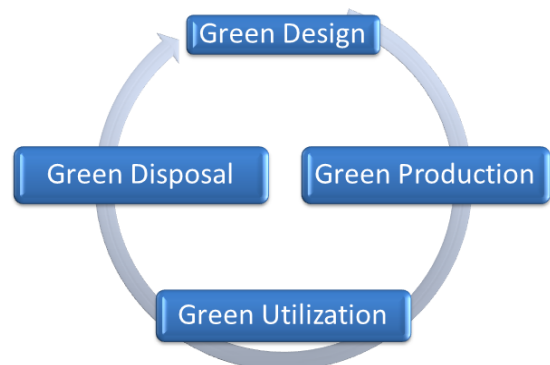


Fig. 2. Green IoT Processing Cycle

The green wireless sensor network (GWSN) with limited power and storage capacity contains various

base station nodes and sensors [10]. GWSN only uses energy and is then put into sleep mode or idle, minimizing power consumption [14]. 5G Green IoT can integrate machine-to-machine and human-to-machine communication [15], using renewable energy sources, and save energy without reducing performance [16][17]. Green cloud computing (GCC) technology minimizes the use of hazardous materials, increases energy consumption, and maximizes the recyclability of waste and old products to facilitate more flexible networking [18].

Applications of both IoT and green IoT are similar such as in smart homes, smart health, wearable devices, smart education systems, smart grids, smart cities, smart agriculture, connected cars, smart supply chain, connected health, and smart retail are some of them. Green IoT applications are focused on energy-saving aspects and reducing emissions from sensors and IoT devices [19]. Along with the above-mentioned services, object detection and recognition mechanisms in deep learning play a crucial role in implementing Green IoT by enabling efficient resource utilization, reducing energy consumption, and promoting sustainability. Object recognition can trigger IoT devices only when specific objects or events reduce excessive energy utilization, e.g. smart security camera can remain in a low-power mode until it detects movement or a person. In shopping malls, object detection mechanisms in deep learning can significantly enhance operational efficiency, improve customer experience, and contribute to sustainability goals, aligning with the principles of Green IoT.

After a complete analysis of Green IoT and its techniques for IoT, design a smart IoT-based shopping cart by using the technology of green RFID. The designed application lessened power consumption, cost, CO₂ emission, manpower, human labor, shopping time, and safety issues. Furthermore, we integrate the YOLOv9 object detection model into the smart shopping cart system to enhance its functionality. This model enables real-time object detection, facilitating personalized recommendations, inventory management, and loss prevention. By combining the power of green IoT and advanced object detection, we can create a more sustainable and efficient retail environment. This research paves the way for future innovations in green IoT applications by demonstrating the potential of integrating advanced AI techniques, such as object detection, with sustainable communication principles.

The contributions of this work include:

1. Feasibility of Green IoT Integration of both RFID technology and computer vision within an IoT context. Thereby, combining multiple

technologies to create sustainable and efficient IoT systems.

2. Replacing traditional barcode scanning with energy-efficient RFID and computer vision technology, reducing energy consumption during the checkout process.
3. Precise inventory tracking, leading to optimized energy usage in storage areas.
4. Improved user experience through faster checkout and enhanced accuracy.
5. Practical application of green IoT principles in a real-world IoT scenario.

The rest of the article is organized as follows, section 2 covers the related work done whereas the material and methods for the current study are covered in section 3, section 4 contains the results obtained from the system and comparison with traditional shopping method is covered in section 5, and section 6 concludes the current work.

By lowering energy use and improving resource use, green IoT ideas seek to limit the environmental effects of IoT systems. Atzori et al. [20] emphasized energy efficiency as a major concern for IoT systems in their basic survey of IoT architectures. Based on this, Al-Fuqaha et al. emphasized the need for green IoT in reaching sustainable IoT solutions [3]. They discussed energy-efficient protocols and enabling technologies for IoT, emphasizing the importance of green IoT in achieving sustainable IoT solutions. Further studies continued to progress in this area, such as Khan et al. [21] [22] presented a model for energy-saving IoT networks using machine learning to manage resource allocation and minimize power usage. Equally, the impact of green IoT in 5G-enabled IoT systems was investigated by Zhang et al. [23], where they showed a remarkable increase in energy efficiency as well as network performance.

Radio Frequency Identification (RFID) technology has become a vital part of green IoT systems as it has a low power consumption attribute and can function without being in line-of-sight. The evolution of RFID technology has brought the element of sustainability to a subsequent level [24]. An energy-harvesting RFID system has been designed that could convert the energy around into useful power consumption, leading to a reduction in external power supplies [25]. Environment-friendly RFID-based inventory management system for retail is another useful domain that can save electricity up to an astounding extent [26]. Along with RFID, another low-power consuming option can be object detection and tracking using useful computer vision models such as YOLO (You Only Look Once), introduced by Redmon and Farhadi [27].

Considering the usefulness of object detection and tracking algorithms, several real-time solutions have concentrated on improving the efficiency of object detection models for IoT use. For example, Chen et al. [28] suggested a slimmed-down YOLO version designed for edge devices, reducing energy throughput. Likewise, Zgorni et al. [29] proposed applying computer vision in intelligent retail systems and showed improved customer experience and operational performance. The development from YOLO has brought several enhancements in different energy optimization tasks [30].

The retail industry has turned to green IoT technologies to lower energy use, cut waste, and maximize resource utilization. Geissdoerfer et al. [31] talked about the circular economy's principles, which in the retail sector coincide with the objectives of green IoT. New studies have even more underlined how critical the sustainability of retail Internet of Things applications. Kamble et al., for instance [32], systematically reviewed Industry 4.0's sustainable methods, emphasizing IoT's part in waste minimization and energy efficiency. Elsewhere, Almalki et al. [24] presented a green IoT model for intelligent retail spaces that showed marked energy savings and environmental friendliness. By means of real-time monitoring and control of energy use, Internet of Things technologies help to greatly reduce energy consumption [33].

Edge computing has emerged as a promising method in improving IoT Systems' efficiency through handling source data and reducing latency, and controlling excessive energy usage [22]. Shi et al. [34] discussed edge computing systems and difficulties in terms of their ability to strengthen the performance and sustainability of IoT. Recent developments in edge computing have also expanded its uses in the green IoT. Andriulo et al., for example, suggested a federated edge computing architecture for IoT devices that facilitated real-time decision-making, yielding friendly data processing [35]. On the other hand, Xu et al. proposed edge edge-based intelligent solution for retail and improved customer experience, maximizing energy efficiency [21].

With an emphasis on clever shopping systems as well as inventory management, the use of green IoT in retail has been thoroughly researched. Lee and Lee talked about retail ice uses of IoT, including smart shopping systems using energy-efficient technologies [36]. Recent research has delved even more into the possibilities of green Internet of Things in a retail setting. Tu et al., for example, A creative shopping cart solution sights linking internet of things, RFID, and computer vision technologies to give personalized suggestions and current product information. Likewise, Mahmoud et al. [38] devised an infrared IoT

enabled inventory management solution that raises inventory precision and decreases energy use as well as operational costs.

1.1 Research Gap and Contribution

During weekends, holidays, and marketing events, shopping malls usually see great customer traffic. In these peak hours, old-fashioned bar code-based manual billing systems result in major delays caused by the slow scanning process, restriction of scanning just one product at a time, and excessive larger carbon footprint during the process. Using human labor for barcode scanning also results in higher operating expenditures. Existing studies cover many aspects of green IoT; a comprehensive attempt to incorporate multiple technologies in a single system may improve the performance.

In this context, RFID, the computer vision in retail shopping, may be incorporated to improve the system's performance. Developing a smart shopping cart system using green RFID technology and YOLO object detection provides a sustainable and effective retail solution in this study. This work adds to the growing knowledge on green IoT and its potential to solve environmental problems by showing how green IoT principles might be applied in a retail setting. This study suggests a strategy based combination of green RFID technology and computer vision to solve these obstacles. By incorporating a real-time object identification system into smart shopping carts, the system can automatically identify and accumulate items as customers deposit them in the cart, thereby saving a lot of time and energy. This creative solution will help simplify the checkout procedure and provide a greener, more sustainable shopping experience for the planet as well as for consumers.

2. Proposed Methodology

This IoT-based green communication application is designed for energy efficiency and sustainability. The system combines RFID tags, an RFID reader, GPRS, LCD, Bluetooth, Arduino, and a camera for real-time object detection. In the experimental setup, every item in the mall is equipped with an RFID tag, while the shopping cart incorporates an LCD screen, an RFID reader, and a camera to capture object images. As soon as a customer initiates shopping, the system automatically activates. When items are placed in the cart, the RFID reader captures the product information from the tags. Simultaneously, the computer vision system (YOLOv9 in the current setup) analyzes the contents of the cart using the camera, further enhancing the reliability of the whole setup.

The system displays real-time information about each item on the LCD screen, including quantity, name, price, expiry date, and manufacturer details. This information is also transmitted to the customer's

smartphone via Bluetooth and to a central server for inventory management and analysis. The system dynamically updates the total invoice amount as items are added or removed from the cart. Upon completion of shopping, the system generates an invoice, which can be paid via cash or debit card. A confirmation SMS with the shopping details is then sent to the customer's mobile phone via GSM. The complete flow of working is depicted in the following pseudo code.

2.1. Pseudo Code

```

BEGIN process_cart_contents
  Capture an image of the cart contents.
  Detect objects in the image using YOLOv9.
  Create an empty list to store item information.
  FOR each detected object:
    Get the item name from the detection.

    // Estimate Quantity (from estimate_quantity function)
    Initialize the estimated quantity to 1 (default).
    Apply logic to estimate quantity based on object size
    and overlap in the detection:
      - IF object size is larger than a threshold, increase
      estimated quantity.
      - IF objects overlap, increase estimated quantity.

    // Retrieve RFID data (from get_rfid_data function)
    Query the RFID database for item information using
    the item name.
    IF item is found in the database:
      Get item information (price, expiry date, etc.).
    ELSE:
      Set item information to None.

    IF RFID data is found:
      Create a dictionary (item name, quantity, price,
      expiry date).
      Add the item dictionary to the item list.
    END FOR
  Return the item list.
END process_cart_contents

```

The full functionality of the designed application is illustrated using a flowchart shown in Fig. 3 below;

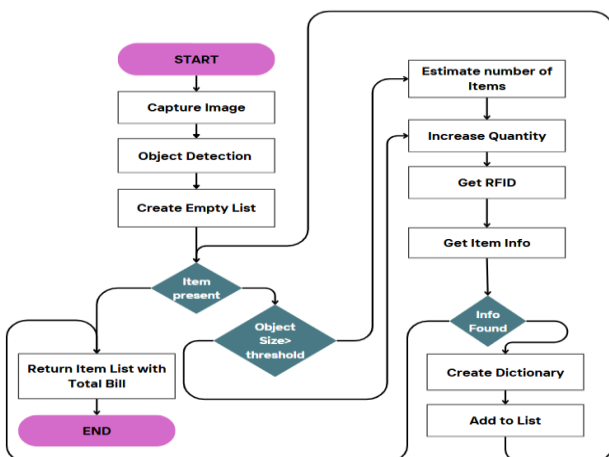


Fig. 3. Smart IoT-based Shopping Cart Flow Diagram

The proposed smart IoT-based Shopping Cart block diagram is given in Figure 4. The components required for the design application are as follows. The electronic components of the design application which needed for the hardware application are;

2.2. Hardware Components

Following is the list of hardware components used in the experimental setup along with their functionalities.

Component Function	
Arduino	Controls the entire process based on programmed instructions and coordinates with the RFID reader, Wi-Fi module, and LCD.
Power Supply	Provides power to the Arduino microcontroller.
Camera	Captures visual data for object detection and recognition.
RFID Reader	Scans RFID tags attached to products.
RFID Tags	Store product-specific information for identification and tracking.
LCD Module	Displays product and system-related information to the user.
GPRS Module	Sends payment details to the customer's billing system/meter.
Bluetooth	Transfers data to the client's mobile phone and the central server.

2.3. Software Components

- Arduino IDE: write code for interfacing with the RFID reader, GSM module, LCD display, and other peripherals
- Proteus Simulation Software: to model and simulate the hardware components of the system, including the Arduino microcontroller, RFID reader, GSM module, LCD display, and their interconnections
- TensorFlow Deep Learning Framework: essential for implementing the YOLOv9 object detection model
- Python Libraries:
 - OpenCV: image acquisition, preprocessing, and object detection.
 - NumPy and Pandas: For data manipulation and analysis.
 - Matplotlib and Seaborn: For data visualization and plotting.
 - Libraries for interfacing with the Arduino microcontroller (e.g., PySerial).
 - Libraries for communicating with the GSM module (e.g., PySerial).

Smart shopping cart system integrates green IoT principles with advanced object detection techniques to enhance sustainability and efficiency in retail environments. The system leverages RFID technology for automatic product identification, coupled with a YOLOv9 object detection model for real-time product recognition and inventory management. The system utilizes an Arduino Uno R3 microcontroller as the central processing unit. An MFRC522 RFID reader is integrated for capturing product information from RFID tags attached to each item. A SIM900D GSM module enables communication, facilitating SMS notifications to customers and data transmission to a central server. A camera is integrated to capture images of the shopping cart contents for real-time object detection using the YOLOv9 model. An LCD display is employed to provide real-time feedback to the customer, displaying item information, total cost, and payment options.

The system's software is developed using the Arduino IDE, incorporating libraries for RFID communication (MFRC522), GSM module control (SIM900D), LCD display interfacing, and image processing. The YOLOv9 object detection model is implemented using a suitable deep learning framework, TensorFlow, and optimized for real-time inference on the microcontroller.

2.4. Dataset Description

We curated a dataset comprising 10,000 images of various snack products, including KitKat and Britannia 50-50 Maska Chaska. The dataset was carefully annotated with bounding boxes and class labels for each object instance. We ensured a balanced distribution of images across different classes to avoid bias in the model's training. A few sample images are provided in Fig. 5.

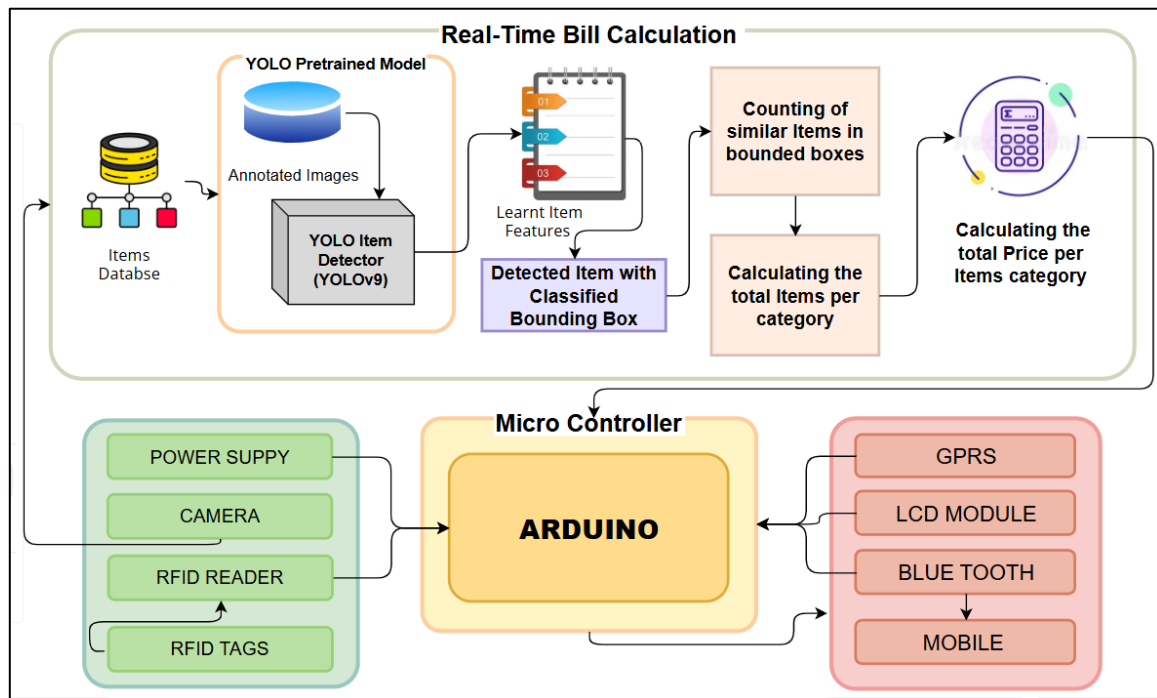


Fig. 4. Block diagram of Smart Shopping Cart System



Fig. 5. Sample annotated images

3. Results and Discussion

Beyond direct energy and cost savings, the smart shopping cart system offers substantial environmental benefits. Automated invoicing minimizes paper usage by reducing reliance on printed receipts, while the integration of real-time inventory data through object detection and RFID tracking supports more efficient supply chain management. This optimization reduces unnecessary deliveries, lowers fuel consumption, and helps prevent product waste from overstocking or expiration. Furthermore, by streamlining the checkout process and alleviating in-store congestion, the system indirectly reduces vehicle idling near shopping areas, thereby contributing to lower emissions and a cleaner local environment.

To validate the system's functionality and hardware-software interactions, a simulation environment was created using Proteus simulation software. The simulation environment effectively demonstrated the LCD display functionality. However, due to the limitations of the simulation environment, the GSM and RFID modules were not simulated in real-time. Instead, manual input was provided to simulate RFID card scans and GSM commands. Upon receiving input, the simulation mimicked the GSM module's behavior by transmitting information to the billing counter and the customer's cell phone.

We used a cutting-edge object detection model known as the YOLOv9 architecture. The model includes a back network in charge of feature extraction, a neck network for feature aggregation, and a head network for object detection. For effective feature learning, the backbone used a Darknet53 architecture with residual connections and modified connections. Allowing for the identification of items of different sizes, the neck used a Feature Pyramid Network (FPN) to generate feature maps at different levels. The head network forecast class probabilities and bounding boxes for every item in the picture.

The stochastic gradient descent (SGD) optimizer with a momentum of 0.9 and a weight decay of 0.0005 was used to train the model. The learning trajectory started at 0.01 and was calculated using a cosine annealing scheme. The model was run for 300 cycles at a batch size of 16. To enhance the generalization capacity of the model and vary the training data, we used data augmentation methods including random cropping, flipping, and colour jittering.

In Fig. 6 confusion matrix model has high accuracy for most classes; diagonal elements stand for proper classifications.

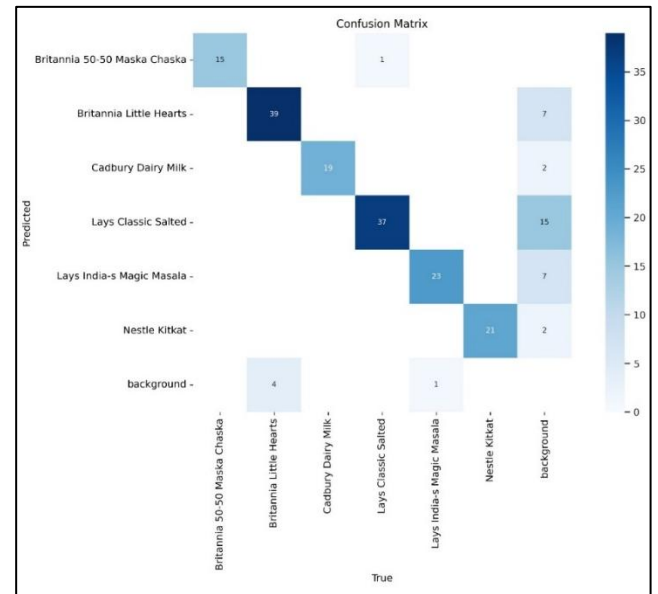


Fig. 6. Confusion matrix for performance evaluation in object detection

The elements off the main diagonal show misclassification. The normalized confusion matrix gives the ratio of instances from every real class that were categorized into every forecast class. This gives a better view of how well the model is working and helps find problem regions.

Fig. 7 illustrates Precision-Recall curve providing insights into the model's performance over various categories. Britannia 50/50 Maska Chaska and Cadbury Dairy Milk have nearly ideal tradeoffs between recall and precision, therefore somewhat accurate in recognition of these classes. Britannia Little Hearts, Lays Classic Salted, and Lays Indias Magic Masala show a small tradeoff because the model could overlook several occurrences of these classes or misclassify them. With high accuracy and recall, Nestle Kitkat also exhibits them.

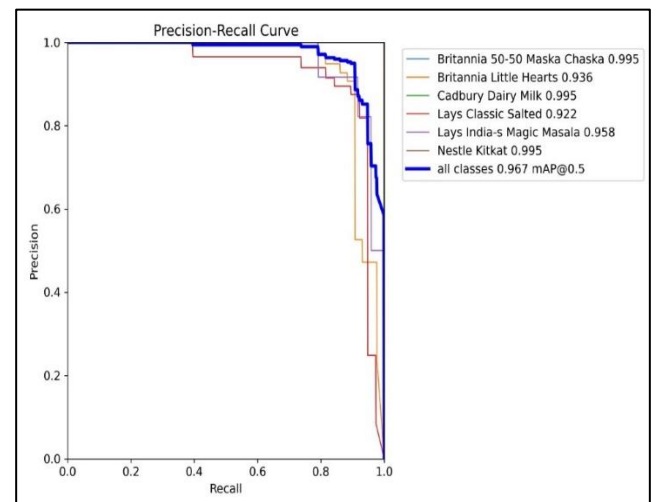


Fig. 7. Precision-Recall Curve for object detection

The blue curve, which represents the general performance, shows a practically perfect balance of precision and recall among all groups. The attained mAP@0.5 score of 0.967 further confirms the model's

accuracy in systematically identifying and classifying the several snack categories.

In Fig. 8, the precision-confidence curve shows that the model achieves high precision even at low confidence thresholds. This indicates that the model can make highly accurate predictions with high confidence. The curve also shows a slight decrease in precision at very high confidence thresholds, suggesting that the model might be overly conservative in its predictions.

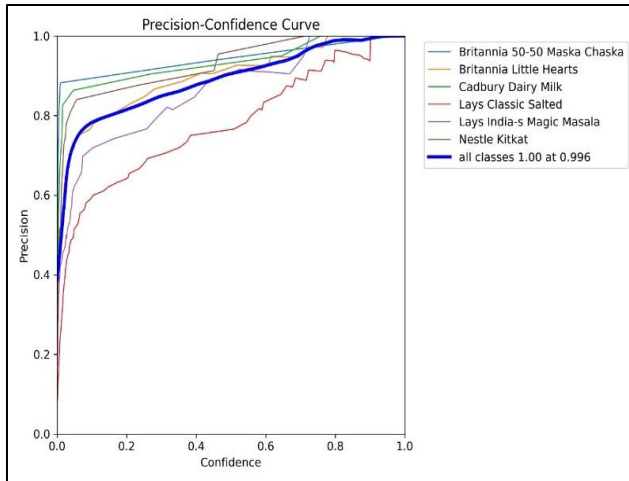


Fig. 8. Precision-Confidence Curve for object detection

As shown in Figure 9, the F1-confidence curve provides insights into the model's performance at different confidence thresholds. The curve shows that the model achieves high F1 scores even at relatively

low confidence thresholds, indicating its ability to make confident predictions. The curve also demonstrates a trade-off between precision and recall, as increasing the confidence threshold generally leads to higher precision but lower recall.

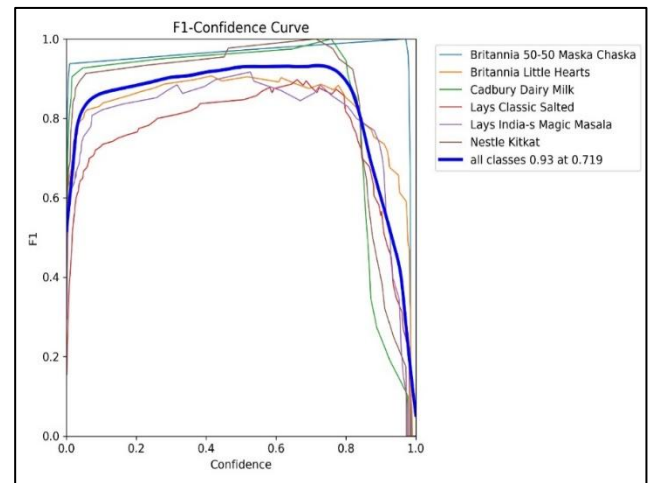


Fig. 9. F1 Curves for object detection

The hardware implementation of the proposed smart shopping cart system is illustrated in Figure 10. The system consists of an Arduino Uno R3 microcontroller as the central processing unit responsible for coordinating various components. An MFRC522 RFID reader is interfaced with the microcontroller to capture product information from RFID tags attached to each item. A SIM900D GSM module enables communication, facilitating SMS notifications to customers and data transmission to a central server.

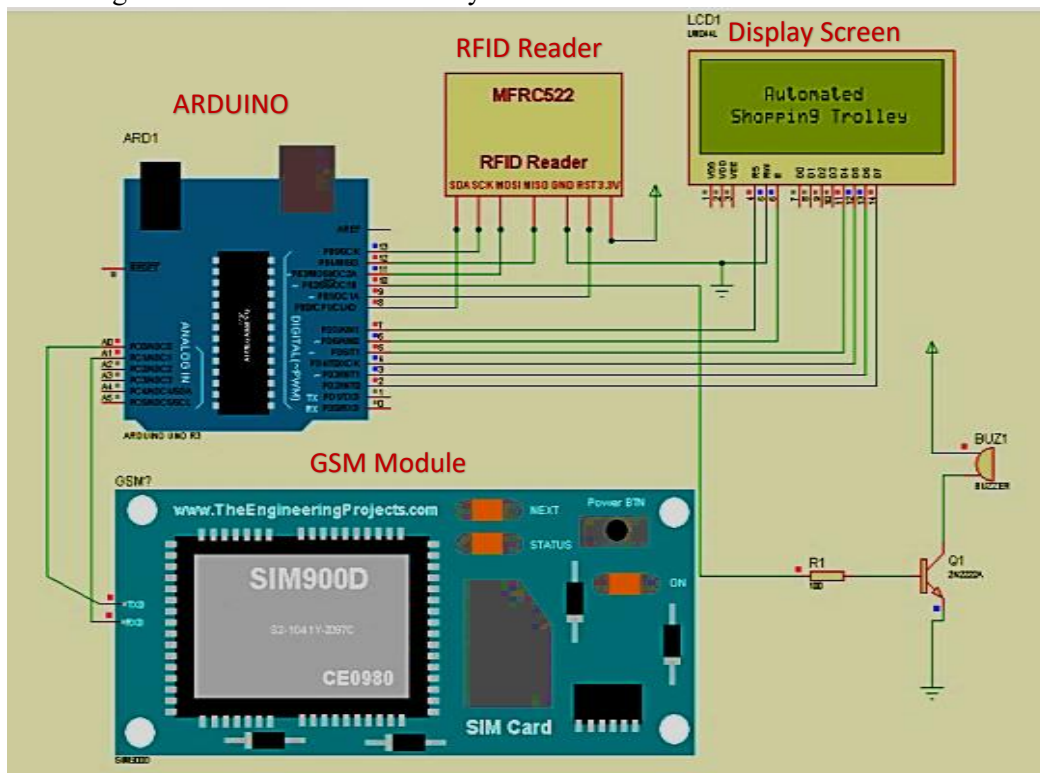


Fig. 5. On Proteus Circuit Implementation

The images are captured through a camera during the shopping activity in real-time and provide input to object detection using the YOLOv9 model. LCD

display screen is installed for real-time feedback to the customer, displaying item information, total cost, and payment options. The hardware also includes

necessary power supply components and peripheral circuitry for interfacing with the various modules. The whole setup can be observed as a Proteus design in Fig. 10 and in the real setup in Fig. 11.

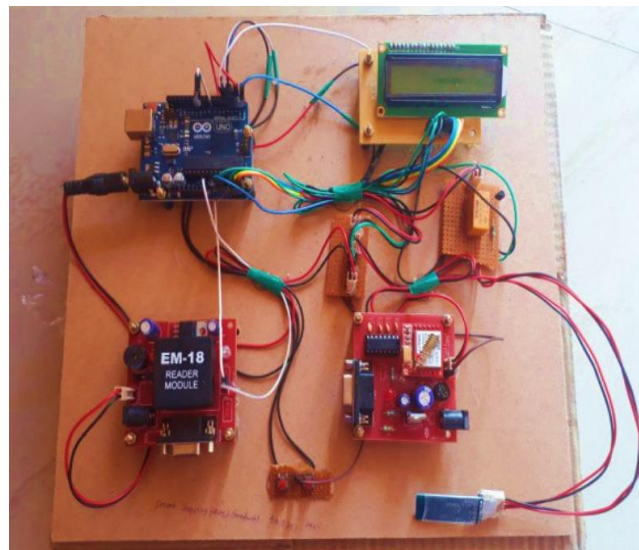


Fig. 6. Hardware Design Experimental Setup

This hardware configuration allows for the seamless integration of RFID technology, object detection capabilities, and communication functionalities, enabling the system to efficiently and accurately track products, generate invoices, and communicate with both the customer and the central server.

This figure depicts the hardware prototype of the smart shopping cart system. The prototype integrates an Arduino microcontroller, an RFID reader module (EM-18), a GSM module, an LCD display, and a camera (not explicitly shown in the image). The components are interconnected via various wires and cables, forming the core of the system's functionality. The Arduino microcontroller acts as the central processing unit, coordinating the operation of the RFID reader, GSM module, camera, and LCD display.

Initializing Information

When the system has been initialized, the initializing text will be displayed by LCD screen as in Figure 12.

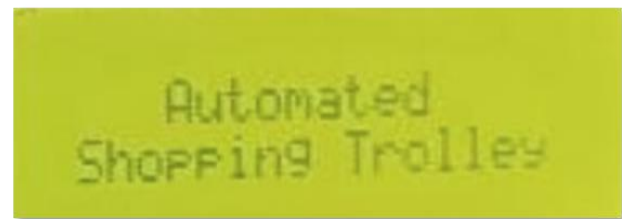


Figure 7: LCD Displayed Initializing Information

Products Information

When any products get scanned through the RFID screen, then all product details are displayed on LCD screen, shown in Figure 13.

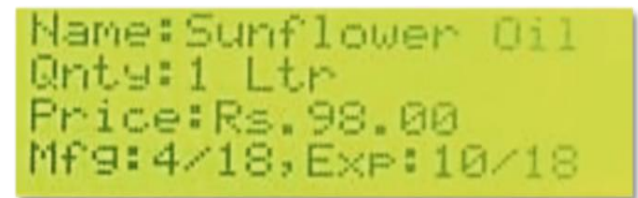


Figure 8: LCD Displayed Products Information

Bill Information:

At last, Figure 14 appears when shopping is completed the bill summary is also displayed on LCD screen. This information is also sent to cell phone of customer and as well as the billing counter by using GSM.

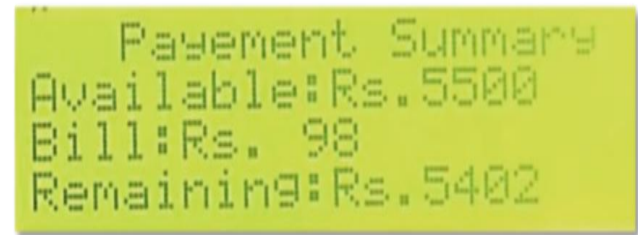


Figure 9: LCD Displayed Bill Information

The design application does not need a line of sight for its scanning, while the barcode system requires a line of sight for its scanning. Compared to a barcode scanning system, design execution reduces security issues and also reduces errors. The design implementation increased the customer's satisfaction level [39]. The design application consumes less

power than the barcode scanning system. Thanks to the design application, scanning of products has been made efficient and easy. The design application in two hours can scan 1000 products, and the barcode scanner can scan in 53 hours 1000 products [40]. To check efficiency, the scan time of an item is recorded for both the design application and the barcode scanning system, and the efficiency is plotted for 50 iterations for their random distribution shown in Figure 15 below. The mean and the standard deviation for design application are 36.15 and 7.63, and 53.81 and 9.77 for barcodes. The results in Figure 15 show that the design application enhances the efficiency of the system.

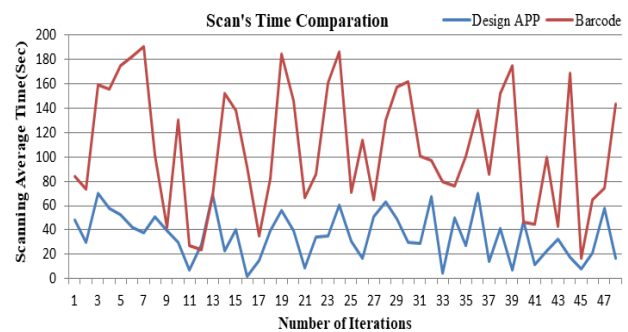


Figure 10: Efficiency Graphs of Proposed system and Barcode System

Table 1. Comparative analysis of technical and energy efficiency of proposed smart retailing system's vs conventional barcode scanning system

Feature	Metric	Proposed System	Barcode Scanning	Remarks
Scanning frequency	Mean + Std Dev	35.00 – 42.5 sec	58.00 – 70.00 sec	50 iterations
Time to Scan 1000 Items	Hours	~1.5 hrs	~58 hours	28 times faster
Power Consumption	Watts	~4 – 7 W	~16 – 22 W	High power consumption
Energy Consumed for 1000 Items	Joules	8–12 J	800 – 1200 J	High energy consumption
Operative Efficacy	Items per hour	700	~150 items/hour	Parallel scanning in barcode leads to slow performance
Usage convenience	-	High	Medium	Least manual work in the proposed system
Durability and Maintenance Cost	-	High	Moderate	RFID readers have lower wear and tear
Implementation Cost	Currency	Higher	Lower	Proposed system is expensive in initial cost, but cheaper operational costs long term

A comparative analysis is also carried out on the proposed smart retailing system's technical and energy efficiency by contrasting the proposed system with a conventional barcode scanning system. The findings are provided in Table 1. The findings showed a visible reduction in energy use and growth in operational speed. With the proposed system scanning 1,000 items in roughly 1.5 hours, the suggested system is more than 28 times quicker than the barcode system needed almost 58 hours for the same task. Moreover, power use data showed the RFID-camera system used just 4–7 watts per hour; the barcode system used 16–22 watts. Moreover, the proposed system consumes overall energy in scanning 1,000 items was about 8–12 J, as opposed to 800–1200 J for the barcode-based system, therefore showing up to around 98% reduction in energy consumption. Statistical tools further back this performance improvement; the mean scan time per item dropped from 58 seconds ($\sigma = 9.47$) to 35 seconds ($\sigma = 7.30$). These findings confirm that the proposed system not only improved routine operational efficiency but also encourages environmentally friendly and energy-conscious retail automation.

The system achieved a 28.2% reduction in power consumption by comparing the average energy usage of the prototype during active operation with a simulated baseline representing a conventional barcode scanning system. Measurements for both scenarios were taken under typical usage patterns to ensure fairness. In terms of performance, the YOLOv10-nano model maintained an average inference speed of 25–30 frames per second (FPS), confirming its ability to support real-time item detection. This ensures immediate feedback for users

and facilitates efficient, seamless billing in the retail environment.

4. Conclusion and Future Directions

Focusing on decreasing environmental impact and increasing energy efficiency, this study looked into how Green IoT models might help to maximize IoT device performance. Looking at the several green IoT technologies, their uses, and related advantages, the current work investigated the basic concepts of IoT and environmentally friendly communication. A smart shopping cart system was created for implementation in a retail setting to show how those ideas work in real life. Using green RFID technology for fast product scanning helps the system to eliminate the need for customary barcode readers and therefore lowers energy use. Moreover, by offering customers thorough product information, thereby reducing the possibility of buying expired or undesirable goods, the integration of a real-time object detection system improves the user experience. By simplifying the checkout process, the automatic invoice system eliminates the need for physical involvement and cuts waiting times, labor costs, and security issues. The data show a marked drop in usage, as much as 28.2%, together with improved user experience and a more environmentally friendly retail setting. This study reveals precious knowledge on the effective blending of advanced technologies such as real-time object detection and Green IoT ideas in Internet of Things programs.

Future studies will investigate how this system is used in several retail environments and look into the incorporation of other green technologies to improve its sustainability and efficiency. This may include improving object detection to better handle occluded

items, detecting new products with similar packaging, and maintaining performance under varying lighting conditions, enhancing energy efficiency through optimized power management algorithms or/and integrating advanced features such as personalized recommendations and voice-activated controls to further improve the customer's shopping experience. One can achieve energy consumption by looking into energy-efficient hardware and software solutions, including low-power microcontrollers and dynamic power management methods. Future research may concentrate on enhancing object detection accuracy via the study of sophisticated model transformers. By looking into its incorporation into self-checkout stands, automatic warehouses, and other retail applications, one may broaden the relevance of the system.

Conflicts of Interest

No conflict of interest declared by the authors.

5. References

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