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Design of an ArUco Marker-Guided Smart Trolley with Integrated Billing Estimation

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Abstract

The growing adoption of automation in retail environments has increased the need for intelligent systems that improve user convenience and reduce manual effort. This paper presents the design and development of a human-following smart shopping trolley with an integrated automatic billing system based on computer vision. The proposed system employs ArUco marker–based human tracking to achieve reliable and real-time following behaviour. A Raspberry Pi serves as the central processing unit, acquiring visual data from a USB camera and controlling DC motors to enable autonomous movement of the trolley. Human-following functionality is achieved by detecting ArUco markers and estimating the relative position of the user with respect to the trolley. Based on the detected marker position within the camera frame, the system generates appropriate control signals to drive the motors in forward, left, or right directions. To ensure safe navigation, an ultrasonic sensor is incorporated for real-time obstacle detection, allowing the trolley to stop automatically when an obstacle is detected within a predefined threshold distance. In addition to navigation, the system integrates an automatic billing mechanism using barcode recognition. The onboard camera captures product barcodes, which are decoded using image processing techniques. The extracted barcode data are mapped to a predefined product database containing item names and prices. The system updates the total bill dynamically and displays the information on an LCD interface. A delay-based filtering mechanism is implemented to prevent duplicate scanning of the same product within a short time interval, thereby improving billing accuracy. The proposed system operates in dual modes, namely follow mode and billing mode, controlled through a user interface switch. Experimental results demonstrate that the system performs efficiently in real- time conditions, providing a cost-effective and practical solution for smart retail automation.

Keywords: Human-following robot, smart shopping trolley, ArUco marker, computer vision, raspberry Pi, barcode detection, automatic billing system, autonomous navigation.

INTRODUCTION

In recent years, the rapid advancement of Internet of Things (IoT), embedded systems, and computer vision technologies has significantly transformed modern retail systems [1–5]. Traditional shopping methods often involve manual product selection and long billing queues, leading to inefficiencies and poor customer experience [5–10]. To overcome these limitations, smart shopping solutions have been proposed that automate billing and improve user convenience using IoT-enabled devices and intelligent systems [3, 8, 11].

Smart shopping carts have emerged as an effective solution to reduce checkout time and enhance operational efficiency in retail environments.

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These systems integrate sensors, microcontrollers, and communication technologies to enable automatic product identification and billing. Several studies have demonstrated the effectiveness of IoT-based smart carts in minimizing human intervention and improving accuracy in billing systems [4, 5, 10].

Computer vision plays a crucial role in enabling intelligent navigation and tracking in modern automation systems. Techniques such as real- time object detection and marker-based tracking have been widely used for autonomous systems. ArUco markers provide a reliable and efficient method for object tracking and localization in real-time applications [1]. Similarly, advanced object detection algorithms such as YOLO have demonstrated high performance in detecting and tracking objects in dynamic environments [2].

Embedded platforms such as Raspberry Pi and Arduino are widely used in smart systems due to their low cost, flexibility, and ability to interface with multiple hardware components. These platforms support the integration of sensors, cameras, and actuators, making them suitable for developing smart trolley systems with autonomous navigation and billing capabilities [6, 7].

Computer vision plays a crucial role in enabling intelligent navigation and tracking in modern automation systems. Techniques such as real-time object detection and marker-based tracking have been widely used for autonomous systems [12–14]. ArUco markers provide a reliable and efficient method for object tracking and localization in real-time applications [1, 13]. Similarly, real-time object tracking and following systems based on computer vision have demonstrated effective performance in dynamic environments [15].

Advanced object detection algorithms such as YOLO further enhance detection accuracy and system responsiveness [2].

However, despite these advancements, several research gaps still exist in current smart shopping systems. Most existing solutions primarily focus on either automated billing or navigation independently, lacking a unified system that integrates both functionalities. System based on RFID increase implementation cost, while barcode-based solutions are often not combined with intelligent navigation techniques. Additionally, many proposed models do not address real-time challenges such as obstacle detection, repeated scanning errors, and system reliability in practical environments. Therefore, there is a need for a cost-effective and integrated smart trolley system that combines computer vision-based user tracking, obstacle detection, and automated billing into a single platform. The proposed system aims to address these limitations and provide a seamless and efficient shopping experience [3, 7]

LITERATURE REVIEW

Several research works have been carried out in the domain of smart shopping systems, focusing on automation, billing efficiency, and user convenience. Early studies primarily emphasized the use of IoT-based smart shopping carts to reduce manual effort and improve the retail experience. For instance, IoT-enabled smart carts integrated with payment gateways allow seamless billing and reduce checkout time [3]. Similarly, hardware-based implementations of smart shopping carts using IoT technologies demonstrate improved efficiency in retail environments [4, 5].

Many researchers have also explored automated billing systems using barcode and RFID technologies. Barcode-based systems provide a cost-effective solution for product identification and billing, while RFID-based systems enable faster scanning but increase overall system cost. Studies such as [9] and [12] highlight the use of Arduino-based billing systems for automation, whereas [6, 10], and [11] present IoT-based approaches to improve billing accuracy and reduce human intervention.

In addition to billing, computer vision techniques have been widely used for object detection and trackingin autonomous systems. The work presented in [1] introduces ArUco markers, which provide a reliable method for real-time marker detection and localization. Further improvements in fiducial marker generation and detection are discussed in [13], enhancing tracking accuracy in dynamic environments.

Moreover, real-time object detection algorithms such as YOLO have demonstrated high efficiency in detecting and tracking objects in real-time applications [2]. Vision-based tracking and following systems have also been explored, where systems can autonomously follow a target using camera input [15].

Embedded systems play a crucial role in integrating various hardware components required for smart trolley systems. Platforms such as Raspberry Pi and Arduino are widely used due to their flexibility and ability to interface with sensors, cameras, and actuators. Research in [14] demonstrates the implementation of vision-based autonomous navigation using Raspberry Pi, highlighting its capability for real-time processing. Additionally, smart trolley systems integrating embedded platforms with IoT technologies have been proposed to improve both navigation and billing functionalities [7, 8].

Although significant progress has been made in developing smart shopping systems, most existing works focus on individual aspects such as billing, navigation, or IoT integration. There is limited research that combines computer vision-based user tracking, real-time obstacle detection, and automated billing into a single system. The proposed system addresses this gap by integrating ArUco-based tracking, barcode- based billing, ultrasonic obstacle detection, and embedded system control into a unified smart trolley solution.

OBJECTIVES

The primary objective of the proposed Smart Trolley system is to develop an intelligent and automated solution that enhances the overall shopping experience by reducing manual effort and checkout time. The system aims to implement a computer vision-based user tracking mechanism

using ArUco marker detection to enable the trolley to autonomously follow the user.

Additionally, the project focuses on integrating a real-time automated billing system using barcode scanning for efficient and accurate product identification. To ensure safe navigation, an ultrasonic sensor-based obstacle detection system is incorporated to prevent collisions during movement. The system also utilizes a Raspberry Pi-based embedded platform for real-time processing and control of various hardware components, including motors, sensors, and display modules. Furthermore, the objective is to provide dynamic billing information to the user through an LCD interface while maintaining a cost-effective and practical design suitable for real-world retail environments.

PROPOSED SYSTEM

The proposed system is a Smart Trolley designed to enhance the shopping experience by integrating computer vision, embedded systems, and automated billing into a single platform. The system operates in two primary modes, namely Follow Mode and Billing Mode, which are controlled using a mode selection button.

In the Follow Mode, the trolley autonomously follows the user using a computer vision-based tracking mechanism. A camera continuously captures video frames, which are processed using OpenCV to detect ArUco markers. Based on the position of the detected marker relative to the centre of the frame, the system determines the direction of movement. The trolley moves forward, left, or right accordingly using motor control through GPIO pins of the Raspberry Pi. Additionally, an ultrasonic sensor is used to measure the distance from obstacles, and the trolley stops automatically if an object is detected within a predefined threshold to ensure safe navigation.

In the Billing Mode, the system performs automated product identification and billing using barcode scanning. The camera captures images of product barcodes, which are decoded using the pyzbar library. Each product is mapped to its corresponding name and price stored in the system database. Upon scanning, the product details are displayed on an LCD screen, and the total bill is updated dynamically. A delay mechanism is implemented to prevent multiple scans of the same product within a short time interval.

The entire system is controlled by a Raspberry Pi, which acts as the central processing unit, handling image processing, sensor input, and hardware control. Additional components such as:

DC motors, motor drivers, an LCD display, and a buzzer are integrated to enable movement, user interaction, and alert mechanisms. The proposed system provides a cost-effective and efficient solution by combining autonomous navigation, obstacle detection, and real-time billing in a unified smart trolley system.

HARDWARE USED

Raspberry Pi (4B)

The Raspberry Pi acts as the central processing unit of the system, responsible for handling image processing, sensor inputs, and motor control. It executes computer vision algorithms and manages communication between all hardware components. It ensures real-time operation of both follow mode and billing mode.

Camera Module

The camera is used to capture real-time video input for both ArUco marker detection and barcode scanning. It enables the system to track the user's position and identify products efficiently. The captured frames are processed using OpenCV for decision-making.

Ultrasonic Sensor (HC-SR04)

The ultrasonic sensor is used for obstacle detection by measuring the distance between the trolley and nearby objects. It ensures safe navigation by stopping the trolley when an obstacle is detected within a threshold distance 30cm. This improves system reliability and prevents collisions.

Motor Driver

The motor driver acts as an interface between the Raspberry Pi and the DC motors. It receives control signals from the controller and drives the motors accordingly. It enables directional movement such as forward, left, and right.

DC Motors (M1, M2, M3, M4)

A 12 V, 30RPM DC geared motor is used. The DC motors are responsible for the physical movement of the trolley. They are controlled through the motor driver to achieve directional motion. The coordinated operation of multiple motors ensures smooth and stable movement.

LCD Display (16x2 with I2C)

The LCD display is used to show product details and the total billing amount to the user. It provides real-time feedback during barcode scanning. The I2C interface reduces wiring complexity and enables efficient communication with the Raspberry Pi.

Battery (12V)

The 12 volts- 8 AH battery provides the primary power supply to the entire system. It ensures portability and enables the trolley to operate without external power sources. A stable power supply is essential for consistent system performance.

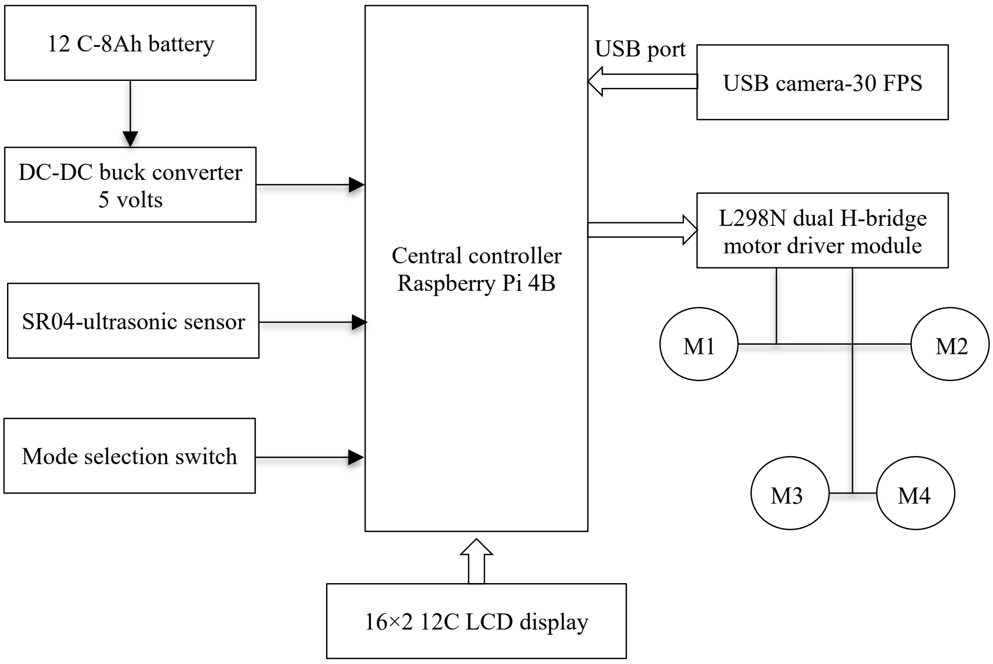


Figure 1. Block diagram of the ArUco marker guided smart trolley with integrated billing estimation.

DC to DC Converter (5V)

The DC-DC converter steps down the 12V battery voltage to 5V required by the Raspberry Pi and other components. It ensures safe and regulated power distribution. This prevents damage to sensitive electronic components.

Mode Selection Button (Switch)

The push button is used to switch between follow mode and billing mode. It allows the user to control the operation of the trolley easily. The input from the button is read by the Raspberry Pi through GPIO pins.

BLOCK DIAGRAM AND WORKING

The proposed smart trolley system operates through the integration of computer vision, embedded control, and sensor-based automation to provide both user-following and automated billing functionalities. The Raspberry Pi 4B serves as the central controller, managing all input and output operations in real time (Figure 1).

Initially, the system is powered using a 12V battery, which is stepped down to 5V using a DC- DC buck converter to safely power the Raspberry Pi and other low-voltage components. Once the system is powered on, it continuously captures video input through a USB camera operating at 30 frames per second. The system operation is divided into two modes: follow mode and billing mode, which are selected using a hardware switch connected to the GPIO pins.

In the follow mode, the camera feed is processed using OpenCV to detect ArUco markers. The system identifies the position of the marker relative to the center of the camera frame and accordingly determines the direction of movement. If the marker is detected towards the left or right side, the trolley adjusts its direction by controlling the motors through the L298N motor driver. When the marker is aligned with the center, the trolley moves forward. If no marker is detected, the trolley stops automatically. Additionally, an ultrasonic sensor (HC-SR04) continuously measures the distance to nearby obstacles. If any object is detected within a predefined safe distance, the system immediately stops the motors to avoid collision.

In the billing mode, the system switches from navigation to product scanning. The camera is used to scan product barcodes, which are decoded using the pyzbar library. Each detected barcode is matched with predefined product data stored in the system, including product name and price. Once a product is scanned, its details are displayed on the 16x2 I2C LCD, and the total bill is updated dynamically. A time delay mechanism is implemented to prevent repeated scanning of the same product within a short duration. A buzzer is also triggered to indicate successful scanning of a product.

The L298N motor driver controls four DC motors arranged in pairs, where the left-side motors (M1, M2) and right-side motors (M3, M4) operate together to achieve directional movement. The Raspberry Pi sends appropriate control signals to the motor driver based on the processing of visual and sensor data. All components work in synchronization to ensure smooth operation of the trolley.

METHODOLOGY

The methodology of the proposed smart trolley system describes the step-by-step working process based on two operational modes: follow mode and billing mode. The system continuously monitors the mode selection switch and executes the corresponding logic. The overall working is divided into three stages: system initialization, billing mode operation, and follow mode operation.

System Initialization and Mode Selection

The system begins with initialization, where all hardware components such as the camera, GPIO pins, LCD display, ultrasonic sensor, and motor driver are configured. Once initialized, the system continuously reads input from the mode selection button. Based on the button state, the system decides whether to operate in follow mode or billing mode (Figure 2).

If the button state is LOW, the system enters follow mode and executes the navigation logic. If the button state is HIGH, the system switches to billing mode and performs product scanning and billing operations. This continuous monitoring ensures real-time switching between both modes without restarting the system

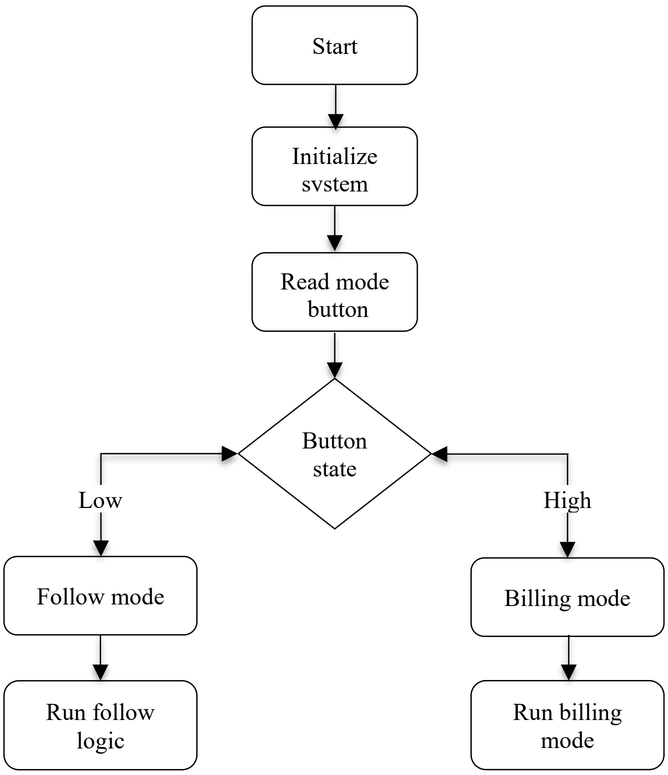


Figure 2. Methodology of proposed system.

Billing Mode Operation

In billing mode, the system captures frames continuously from the camera to scan product barcodes. The system first checks the mode button and confirms entry into billing mode. Once activated, it starts scanning for barcodes using image processing techniques.

If no barcode is detected, the system displays a message such as “Scan Product” along with the current total on the LCD. When a barcode is detected, it is decoded, and the system checks whether the scanned code is the same as the previous one within a short time interval to avoid duplicate entries.

If the barcode is valid and not repeated, the system verifies the product in the predefined database. Upon successful validation, the product name and price are retrieved, and the price is added to the total bill. The updated product details and total amount are displayed on the LCD. A short delay is introduced after each successful scan to ensure proper processing before scanning the next item.

This process continues in a loop, allowing multiple products to be scanned efficiently in real time.

Follow Mode Operation

In follow mode, the system enables autonomous navigation of the trolley using computer vision and sensor data. The camera continuously captures frames, and the system checks the mode button to confirm follow mode operation. Once activated, the system displays the follow mode status on the LCD.

The ultrasonic sensor first measures the distance between the trolley and nearby objects. If the detected distance is less than a predefined threshold (e.g., 30 cm), the system immediately stops the motors to prevent collision. If no obstacle is detected, the system proceeds with ArUco marker detection.

When an ArUco marker is detected, the system calculates the center position of the marker within the camera frame. Based on the position of the marker, the system determines the movement direction. If the marker is on the left side, the trolley turns left; if it is on the right side, it turns right; and if it is near the center, the trolley moves forward (Figures 2 and 3).

If no marker is detected, the system stops the motors to avoid unintended movement.

RESULTS AND DISCUSSION

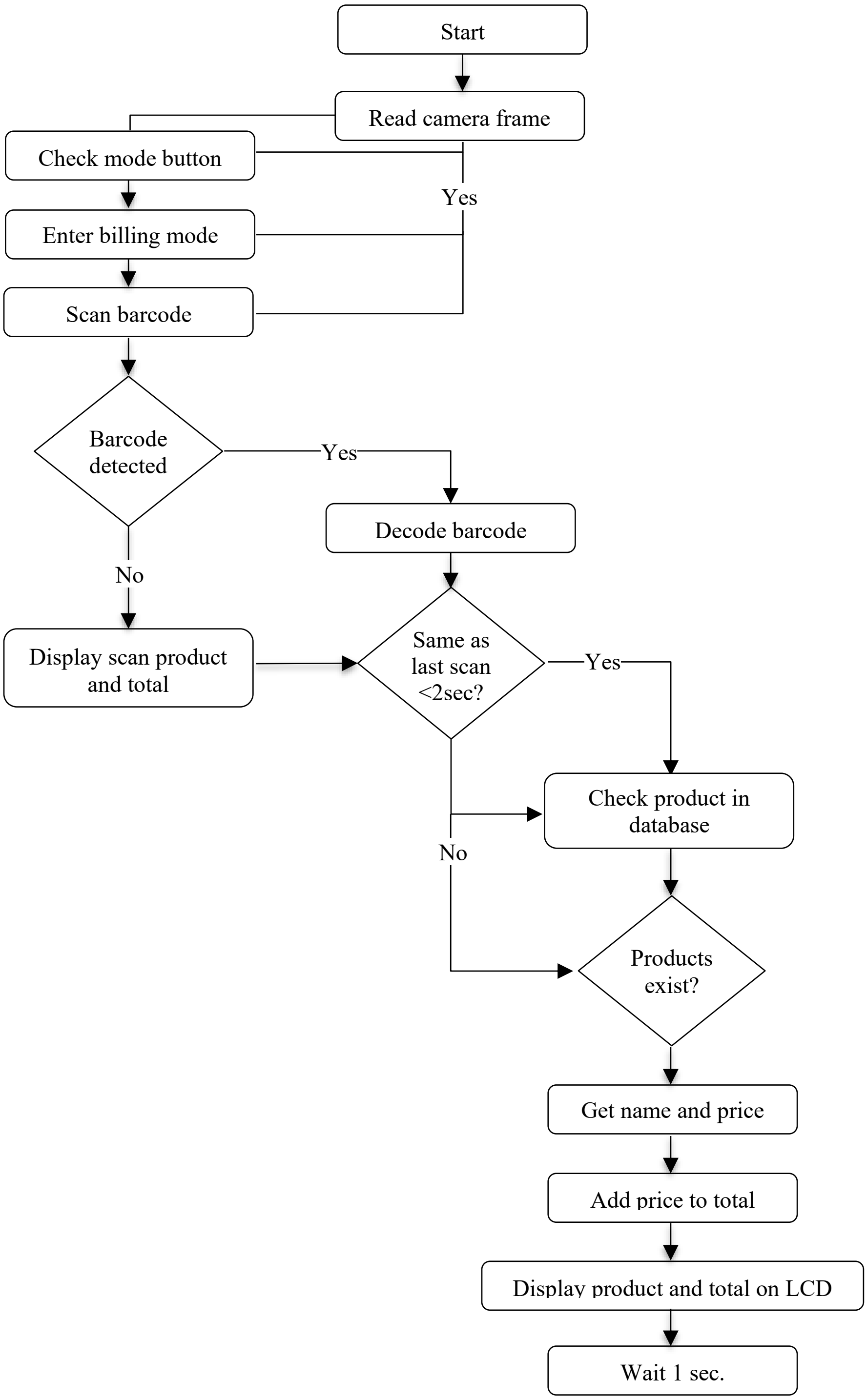
The proposed smart trolley system was successfully implemented using a Raspberry Pi 4B, integrating computer vision, embedded control, and sensor-based automation. The system was tested under real-time conditions to evaluate its performance in both follow mode and billing mode.

In the follow mode, the system demonstrated effective user tracking using ArUco marker detection. The trolley was able to accurately detect the marker and adjust its movement based on the relative position of the marker in the camera frame. The directional control (left, right, and forward movement) was achieved smoothly using the motor driver and DC motors. The inclusion of a dead zone in the center region helped in reducing unnecessary oscillations, resulting in stable movement. Additionally, the ultrasonic sensor effectively detected obstacles within a threshold distance of approximately 30 cm, ensuring safe navigation by stopping the trolley when required.

In the billing mode, the system successfully performed real-time barcode scanning using the camera and pyzbar library. Products were accurately identified, and their corresponding details were retrieved from the predefined database. The system displayed the product name and price on the 16×2 LCD, while dynamically updating the total bill. A delay mechanism was implemented to prevent repeated scanning of the same barcode within a short interval, which improved billing accuracy. The buzzer provided immediate feedback upon successful scanning, enhancing user interaction.

The integration of both modes within a single system allowed seamless switching between navigation and billing using a hardware button. The Raspberry Pi efficiently handled image processing, sensor inputs, and motor control without noticeable delay, demonstrating the feasibility of real-time operation.

However, certain limitations were observed during testing. The performance of ArUco detection was influenced by lighting conditions and camera positioning. Similarly, barcode scanning accuracy depended on proper alignment and visibility of the barcode. Despite these limitations, the overall system performed reliably and achieved the intended objectives.



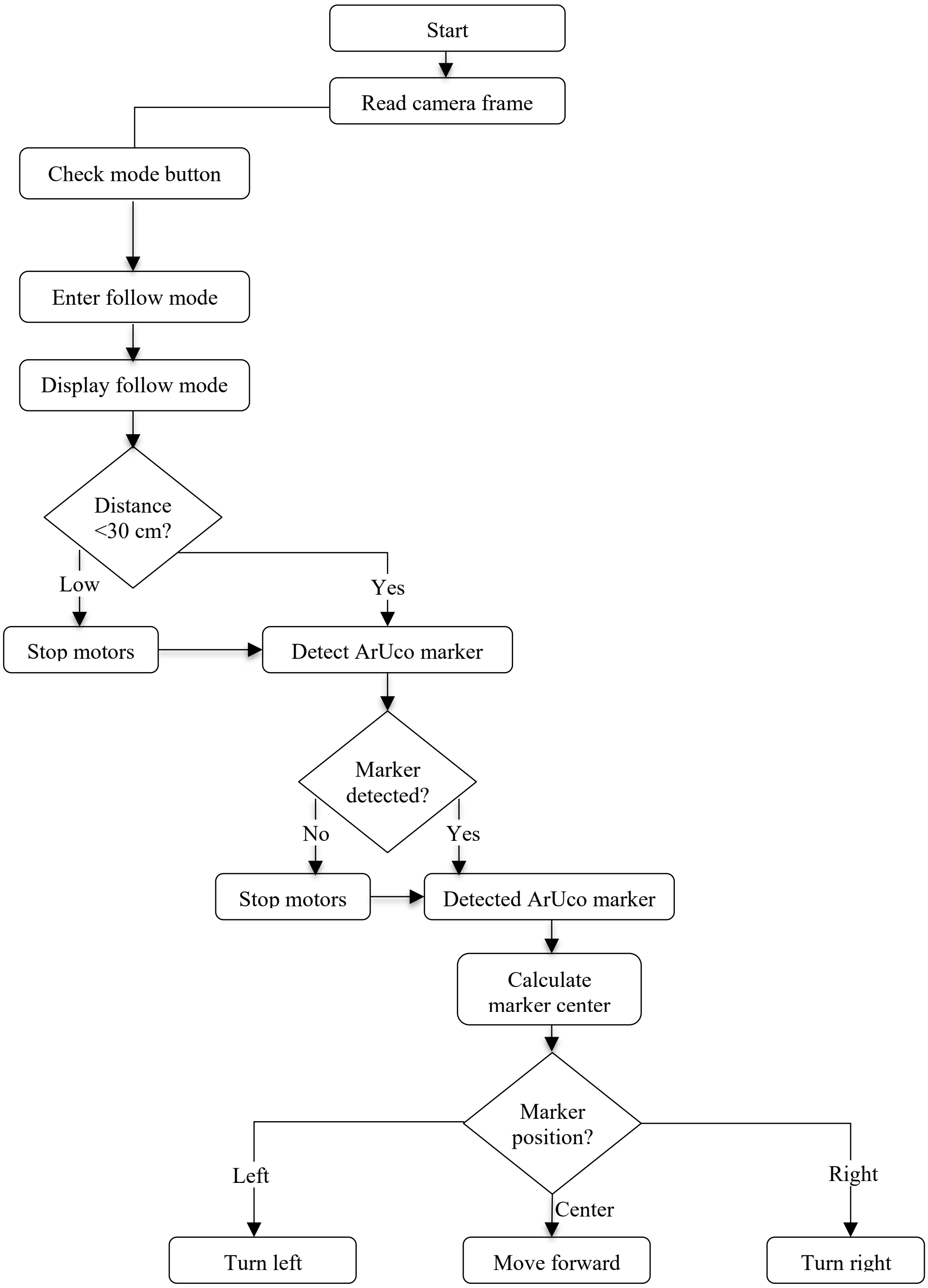


Figure 3. Follow mode operation.

The results indicate that the proposed system provides a cost-effective and practical solution for smart retail environments by combining autonomous navigation, obstacle detection, and automated billing into a unified platform.

FUTURE SCOPE

The proposed smart trolley system demonstrates a functional integration of computer vision, automated billing, and embedded control; however, there is significant scope for further enhancement. One potential improvement is the incorporation of advanced object detection algorithms, such as deep learning-based models, to eliminate the dependency on ArUco markers and enable direct human or object tracking. This would make the system more robust and user- friendly in real-world retail environments.

The billing system can be further enhanced by integrating wireless communication technologies such as mobile applications or cloud-based databases. This would allow real-time synchronization of billing data, digital payment integration, and inventory management. Additionally, the use of RFID technology alongside barcode scanning can improve scanning speed and reduce dependency on camera alignment.

Further improvements can also be made in navigation by incorporating additional sensors such as infrared or LiDAR to enhance obstacle detection and path planning. This would enable smoother and more reliable movement in crowded environments. Power management can be optimized by using efficient battery systems and energy-saving techniques to increase operational time.

Moreover, the system can be extended to include features such as voice assistance, multilingual support, and personalized user interaction to enhance usability. With these advancements, the proposed smart trolley system can be developed into a fully autonomous and intelligent retail solution suitable for large-scale deployment**.**

CONCLUSION

In this work, a smart trolley system was designed and implemented to simplify the shopping process by combining user-following and automated billing in a single platform. The system makes use of a Raspberry Pi along with computer vision techniques to detect ArUco markers for tracking, while barcode scanning is used for product billing. The integration of an ultrasonic sensor ensures safe movement by preventing collisions during operation.

During testing, the trolley was able to follow the user smoothly and perform billing operations accurately in real time. The switching between follow mode and billing mode using a simple button made the system easy to operate. The use of commonly available components also keeps the system cost-effective and practical for small-scale implementation.

Although some challenges such as lighting conditions and barcode alignment were observed, the overall performance of the system was satisfactory. The project demonstrates that it is possible to combine navigation and billing features effectively in a single system. This work can serve as a foundation for developing more advanced smart shopping solutions in the future

Declarations

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Data Availability

The experimental data generated and analyzed during this study are available from the corresponding author upon reasonable request.

Authors' Contribution

All group members' contributions help find information.

Conflict of Interest

There is no conflict of interest regarding the publication of this paper.

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