Development of Shopping Bot

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B.Tech. in Mechanical Engineering

Faculty of ENGINEERING AND TECHNOLOGY

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Certificate

This is to certify that the Project titled "Development of Shopping Bot" is a bonafide work carried out in the Department of Mechanical and Manufacturing Engineering by Ms. Lalitha Sri C S bearing Reg. No. 20ETRE409012, Mr. Pavan M J bearing Reg. No. 20ETRE409014, Mr. Suhan R bearing Reg. No. 20ETRE409026 and Mr. Toushif Ahammad bearing Reg. No. 20ETRE409029 in partial fulfilment of requirements for the award of B. Tech. Degree in Robotics Engineering of M.S. Ramaiah University of Applied Sciences.

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Declaration

Development of Shopping Bot

The project work is submitted in partial fulfilment of academic requirements for the award of B. Tech. Degree in the Department of Mechanical Engineering of the Faculty of Engineering and Technology of M. S. Ramaiah University of Applied Sciences. The project report submitted herewith is a result of our own work and in conformance to the guidelines on plagiarism as laid out in the University Student Handbook. All sections of the text and results which have been obtained from other sources are fully referenced. We understand that cheating and plagiarism constitute a breach of University regulations, hence, this project report has been passed through plagiarism check and the report has been submitted to the supervisor.

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Summary

In today's fast-paced world, convenience reigns supreme. Traditional in-store shopping, however, often falls short, plagued by long checkout lines and the tedious search for products. This project tackles these challenges head-on by introducing the shopping bot – an innovative solution designed to revolutionize the in-store experience.

The shopping bot is an intelligent assistant that leverages robotics and web technologies to streamline the shopping process. At its heart lies the Raspberry Pi Model 4B, a powerful microcomputer responsible for controlling the bot's operations. An Arduino board acts as the intermediary, facilitating communication between the Raspberry Pi and the motors driving the bot. The bot boasts a four-wheeled design with rear-wheel drive, offering optimal maneuverability within store aisles. Line following sensors strategically placed at the front enable it to navigate designated paths with accuracy. An additional IR sensor on the side ensures collision avoidance and smooth navigation by detecting obstacles and stoppers placed at checkpoints. Customer interaction is facilitated by a user-friendly web interface developed using Flask. Accessible through any web browser on a mobile phone or laptop within the store's network, the interface allows customers to log in, browse product catalogs, add desired items to their shopping cart, and initiate the shopping process. Once the order is placed, the Raspberry Pi receives the list of products, prompting the bot to navigate the aisles and retrieve the items autonomously.

The project successfully developed a functional prototype, demonstrating the feasibility of this innovative concept. During testing within a controlled environment (e.g., simulated store aisle), the bot exhibited promising performance. The line following sensors effectively steered the bot along the designated path, and the camera, coupled with robust QR code scanning algorithms, ensured accurate product identification. While these results are encouraging, further development is necessary to optimize the bot's capabilities for real-world application in a retail setting.

Table of Contents

Acknowledgement **3**

Summary **4**

Table of Contents **5**

List of Tables **7**

List of Figures **8**

Nomenclature **8**

Abbreviation and Acronyms **10**

1. Introduction **11**

1.1 The Inefficiencies of Traditional Shopping: A Call for Innovation 11

1.2 The Rise of Customer-Centric Solutions in Retail 13

1.3 The Need for a Hybrid Approach: Introducing the Shopping Bot 13

2. Background Theory **15**

2.1 Robotics and Automation 15

2.2 Web Technologies and User Interaction 16

2.3 Integration and System Design 17

3. Aim and Objectives **18**

3.1 Title : 18

3.2 Aim: 18

3.3 Objectives 18

3.4 Methods and Methodology/Approach to attain each objective 19

3.4.1 Objective 1 20

3.4.2 Objective 2 26

3.4.3 Objective 3 38

4.Prototype Designing **44**

4.1 Objective 4 44

4.1.1 Workflow 44

4.1.2 Functionalities..46

4.1.3 Integration of the Circuit 50

4.2 Bill of Material..54

5.1 Objective 5 55

5.1.1 Fabrication of the Shopping Bot 55

5.1.2 Test the prototype functionality...58

5.1.3 Demonstration of the Prototype 61

5. Results 65

6. Project Costing 67

7. Conclusions and Suggestions for Future Work.............................. 68

References... 70

Appendix 72

List of Tables

Table 1: Methods And Methodology 19
Table 2: Literature Review 20
Table 3: Components Used 30
Table 4: Comparison b/w the different concepts 43

List of Figures

Figure 1: Traditional Supermarket Aisle 12
Figure 2: Assistive Shopping Bot 14
Figure 3: Field Visit 25
Figure 4: Shop floor Layout with Path 27
Figure 5: Shop floor Layout 27
Figure 6: Loads acting on chassis and wheels 34
Figure 7: Wheel parameters 35
Figure 8: Modular Shopping Assistant Platform 38
Figure 9: Interactive Shopping Assistant Bot 39
Figure 10: Basic Line Following & QR Scanning Bot 41
Figure 11: Flowchart detailing integration of different electronics part 44
Figure 12: Raspberry Pi Circuit Diagram 50
Figure 13: Arduino Uno Circuit Diagram 51
Figure 14: Assembly of the product 58
Figure 15: Customer interactive webpage 62
Figure 16: Sensor Placement in the Bot 62
Figure 17: Gripper for item retrieval 63
Figure 18: Project Group Photo 66

Nomenclature

A	Acceleration	m/s^2	Rate of change of velocity
θ	Angle	°	Measure of rotational displacement
I	Current	A	Flow of electrical charge
F	Force	N	Push or pull acting on an object
H	Height	m	Vertical distance from a reference point
L	Length	m	Horizontal distance from one end to another
mm	Millimetre	mm	One thousandth of a metre
P	Power	W	Rate of doing work
N	Speed (RPM)	RPM	Rotations per minute
K	Temperature (K)	K	Absolute temperature scale
t	Temperature (°C)	°C	Celsius temperature scale
T	Torque	Nm	Twisting force applied to an object
W	Track Width	m	Distance between the inner edges of two tracks
V	Voltage	V	Electrical potential difference
w	Weight	kg	Force exerted on an object by gravity

Abbreviation and Acronyms

AI	Artificial Intelligence
CPU	Central Processing Unit
CMOS	Complementary Metal-Oxide Semiconductor
DC	Direct Current
FRC	Flat Ribbon Cable
GPIO	General Purpose Input/Output
GPU	Graphics Processing Unit
HTTP	Hypertext Transfer Protocol
IR	Infrared sensor
LCD	Liquid-Crystal Display
LIDAR	Light Detection and Ranging
LED	Light-Emitting Diode
PID	Proportional-Integral-Derivative
PWM	Pulse Width Modulation
QR	Quick Response code
RFID	Radio Frequency Identification
RAM	Random-Access Memory
RWD	Rear Wheel Drive
RPM	Revolutions Per Minute
SQL	Structured Query Language
USB	Universal Serial Bus
UART	Universal Asynchronous Receiver/Transmitter

1. Introduction

Preamble:

The contemporary retail environment necessitates a focus on customer convenience and efficiency. However, traditional brick-and-mortar stores often encounter challenges in meeting these demands. Lengthy waits in checkout lines and the time-consuming task of locating desired products can significantly hinder customer satisfaction[2]. This project presents the development of a shopping bot, a pioneering solution designed to revolutionize the in-store shopping experience. By strategically leveraging advancements in robotics and web technologies, the shopping bot automates product retrieval and streamlines the checkout process, thereby enhancing convenience and expediting the shopping journey for customers.

1.1 The Inefficiencies of Traditional Shopping: A Call for Innovation

The familiar in-store shopping experience, while holding a certain appeal for the ability to browse products physically and assess quality first-hand, faces limitations due to inherent inefficiencies. These inefficiencies can significantly impact customer satisfaction and act as deterrents to repeat visits. Let's delve deeper into some of the key challenges:

- **Time-Consuming Tasks:** Navigating crowded aisles in search of specific items and waiting in checkout lines are significant pain points that contribute to a sense of inefficiency. This is particularly true for busy individuals with limited time, those with young children, or people with limited mobility [2]. Extensive product selection can be overwhelming, and store layouts may not always be intuitive, leading to frustration and wasted time searching for desired items. Long checkout lines, especially during peak hours or when unexpected delays occur, further exacerbate the feeling of inefficiency and can significantly impact customer satisfaction [1].

- **Limited Online Solutions:** Existing online shopping options, while offering a degree of convenience by allowing purchases from the comfort of home and avoiding physical store visits, often lack the efficiency and ease of a physical store visit. Challenges associated with online shopping include:
    - Limited product selection: Online stores may not carry all the same products as a physical store, and selection can vary depending on location and availability.
    - Difficulties in accurately assessing freshness (particularly for groceries): It can be difficult to assess the quality and freshness of perishable items, such as fruits, vegetables, and meat, based solely on online pictures and descriptions.
    - The added cost of delivery fees: Online shopping often incurs additional delivery fees, which can negate the perceived cost savings of avoiding travel to a physical store.

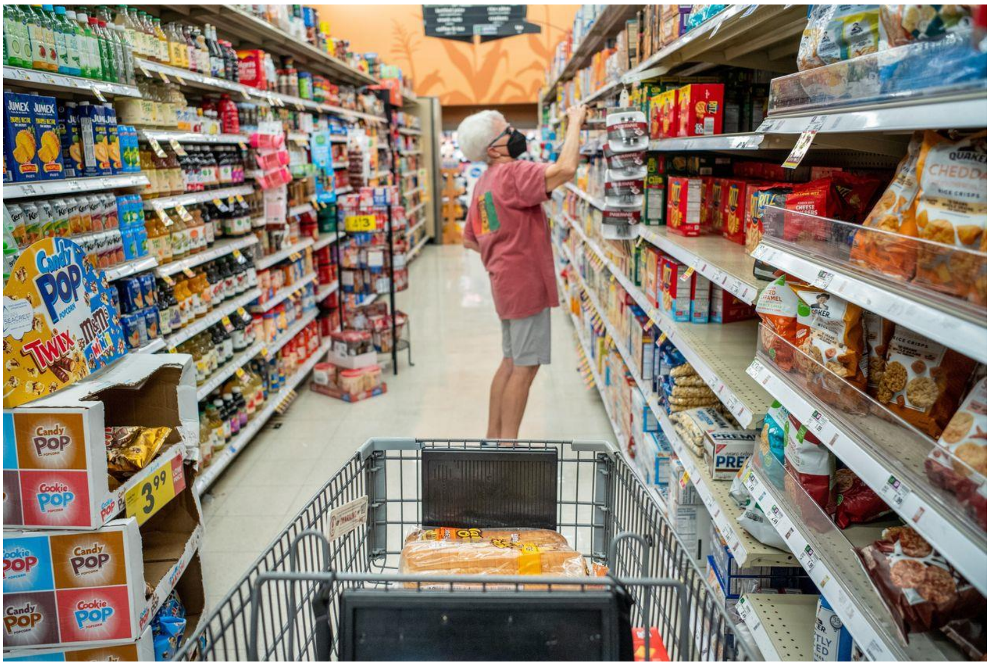

Figure 1: Traditional Supermarket Aisle
Source: New York Times

1.2 The Rise of Customer-Centric Solutions in Retail

The growing emphasis on customer experience has spurred innovation within the retail industry. Consumers are increasingly seeking shopping experiences that prioritize convenience and cater to their time constraints. Consequently, retailers are exploring solutions that can address the challenges discussed above.

The development of online shopping platforms and mobile app integrations are examples of advancements facilitating a more streamlined customer journey. These solutions allow customers to browse product selections, compare prices, and even place orders online for in-store pickup or home delivery. However, these solutions often necessitate a shift away from the physical in-store experience that some customers still value, such as the ability to browse products physically, assess quality first-hand, and enjoy the social aspect of shopping.

1.3 The Need for a Hybrid Approach: Introducing the Shopping Bot

The ideal solution would bridge the gap between the convenience of online shopping and the tangible experience of a physical store. This project addresses this need by introducing the shopping bot, a novel approach to in-store retail. The shopping bot leverages advancements in robotics and web technologies to automate product retrieval and streamline the checkout process, ultimately aiming to provide customers with a more efficient and enjoyable shopping experience. The shopping bot offers the following potential benefits:

- Increased Efficiency: By automating product retrieval and streamlining the checkout process, the shopping bot can significantly reduce the time customers spend shopping. This is particularly beneficial for busy individuals or those with limited mobility.

- Improved Customer Satisfaction: By addressing the inefficiencies of traditional shopping, the shopping bot has the potential to improve customer satisfaction and encourage repeat visits.
- Enhanced Personalization: The shopping bot can be integrated with existing loyalty programs and customer data to personalize the shopping experience. For example, the bot could recommend products based on past purchases or suggest complementary items.

Figure 2: Assistive Shopping Bot

Source: Wikimedia

2. Background Theory

The development of the shopping bot draws upon a rich tapestry of established theories and concepts from various fields. Understanding these underlying principles is crucial for appreciating the functionality and potential impact of this innovative project.

2.1 Robotics and Automation

Robotics plays a central role in the shopping bot's design. This sub-field of engineering deals with the design, construction, operation, and application of robots. The shopping bot, in essence, is a mobile robot equipped with various sensors and actuators that enable it to navigate autonomously within a store environment [1].

- **Line Following Algorithms:** Line following algorithms are fundamental to the shopping bot's navigation capabilities [4]. These algorithms allow the bot to detect and follow designated paths marked on the store floor, typically using line sensors or cameras. Common line following algorithms include the bang-bang control algorithm, which is a simple yet effective approach that steers the bot based on the deviation from the detected line, and the proportional-integral-derivative (PID) control algorithm, a more sophisticated method that considers the history of errors to provide smoother and more precise line following.
- **Object Recognition and Path Planning:** While line following is sufficient for basic navigation in controlled environments with well-defined paths, advanced shopping bots may incorporate object recognition and path planning techniques for more dynamic and adaptable operation in real-world stores [4]. Object recognition algorithms, leveraging computer vision and machine learning, enable the bot to identify obstacles such as shopping carts, abandoned items, or unexpected spills on the floor. This allows the bot to dynamically adjust its path for safe and efficient movement, avoiding collisions and ensuring a smooth shopping experience for both customers and other store patrons. Path planning algorithms, on the other hand, allow the bot to determine the most optimal route

to reach a specific destination within the store, considering factors such as distance, potential obstacles, and even store traffic patterns [5]. By incorporating these advanced techniques, shopping bots can navigate more complex environments and adapt to unforeseen situations, enhancing their reliability and effectiveness in real-world retail settings.

2.2 Web Technologies and User Interaction

The human-computer interaction aspect of the shopping bot relies heavily on web technologies. This subheading delves into the key components that facilitate user interaction:

- **Web Development Frameworks:** Frameworks like Flask (used in this project) provide a foundation for developing user-friendly web interfaces. These interfaces are designed to be intuitive and accessible through a web browser on any smartphone or laptop connected to the store's network. Customers can use this interface to log in, browse product catalogs, add desired items to their shopping cart, and initiate the shopping process.
- **Communication Protocols:** Communication protocols establish a reliable connection between the user interface and the shopping bot, enabling the seamless exchange of information. Common protocols include Wi-Fi and Bluetooth. Wi-Fi offers a wider range and faster data transfer speeds, making it suitable for transmitting product information, user commands, and real-time sensor data. Bluetooth, on the other hand, is a lower-power option that can be sufficient for basic communication needs, especially when dealing with smaller data packets. The choice of protocol depends on factors such as the required data transfer rate, range, and power consumption considerations.
- **Security Considerations:** Security is paramount when dealing with user data and online transactions. The web interface and communication protocols should be designed with robust security measures in place to protect sensitive customer

information. This may involve encryption of data transmission, secure user authentication protocols, and adherence to relevant data privacy regulations.

2.3 Integration and System Design

The successful operation of the shopping bot hinges on the effective integration of various hardware and software components. This subheading explores the importance of system design principles:

- **Modular Design:** A modular design approach decomposes the system into smaller, self-contained modules with well-defined interfaces. This allows for independent development and testing of individual components, such as the sensor modules (e.g., line sensors, cameras), the robotic arm control system, and the web interface. Modular design facilitates easier maintenance, upgrades, and future enhancements. For instance, if a new sensor type needs to be integrated for improved obstacle detection, the modular design allows for modifications to be made to the sensor module without affecting other parts of the system [12].
- **Real-Time Processing:** Real-time processing of sensor data is crucial for the bot's responsiveness. The system needs to analyze sensor data (e.g., line sensor readings, camera images) and translate it into appropriate motor commands in real-time to ensure smooth and accurate navigation. This necessitates the use of low-latency communication protocols and efficient algorithms for sensor data processing [14]. Additionally, the control system software should be optimized for real-time performance, minimizing processing delays and ensuring timely responses to sensor inputs.

3. Aim and Objectives

3.1 Title :

“ Development of Shopping Bot”

3.2 Aim:

“To Develop a smart shopping assistant robot with path following and QR code reading capabilities for efficient product information retrieval”

3.3 Objectives

Objective 1:

“To study literature related to mobile robot, end effectors, object handling and user interface”

Objective 2:

“To arrive at the prototype specification for the shopping bot”

Objective 3:

“To conceptualize various designs on shopping bot and select the best design concept”

Objective 4:

“To fabricate, Incorporate electronics and develop web app”

Objective 5:

“To test and demonstrate the working of the prototype”

3.4 Methods and Methodology/Approach to attain each objective

Table 1: Methods And Methodology

Sl No.	Statement of the Objective	Method/ Methodology	Resources Utilized
1	To study related literatures	• Refer Journals, books, articles and magazines. • Approach field experts and relevant places	• Journals, articles, Books • University Library
2	To arrive at Prototype specifications	• Survey & observe users to understand their needs, translating them into specific functionalities • Brainstorm diverse designs, gather feedback, and refine based on feasibility, cost, and potential risks	• Surveys • Literature review • Catia
3	To Conceptualize various designs and select a feasible design	• Explore varied design concepts considering user feedback and technical feasibility • Select the most promising design based on functionality, cost, and ease of implementation	• Catia • Ansys Software
4	To Incorporate electronics and develop web app	• Utilize readily available hardware & software components for cost-effectiveness and efficiency • Develop both electronics and web app in iterative cycles, allowing for ongoing testing and improvement	• Electronic Components • Web App development network
5	Fabrication, Testing and Demonstration of prototype	• Make use of workshop facility to build the product and iterate the process if necessary • Perform test runs on the prototype and gathering feedback for a user-friendly demonstration	• Workshop • User testing

3.4.1 Objective 1

To carry out literature review on existing rehabilitation devices and technologies, analysing their actuation mechanisms and design principles.

Table 2: Literature Review

Sl. No	Title	Year of publication	Authors	Methods and Methodologies used	Research Findings	Conclusion drawn by authors	Limitations of study
1	System, Platform and Method for Personalized Shopping Using a Virtual Shopping Assistant	2019	David , Bleicher, Tamir, LOUSKY	Development of a personalized shopping system utilizing virtual shopping assistants.	The system provides personalized product fitting based on user history, preferences, and anatomical data, enhancing the online shopping experience.	Personalized shopping systems offer tailored recommendations, improving user satisfaction and engagement in online shopping.	Lack of empirical validation or real-world implementation.
2	Shopping Market Assistant Robot	2015	Herrera, Viviana; Villa Medina, Juan; Porta-Gándara, Miguel; Gutierrez , Joaquin	Implementation of a scaled four wheeled differential vehicle robot a prototype used for shopping assistance by using microcontrollers,	The autonomous robot proved to be a reliable tool for a shopping assistance in convenience stores.	The implementation demonstrated the feasibility and effectiveness of the robot in assisting shoppers.	Limited to small-scale stores

				ultrasonic sensors, ZigBee communication and RFID tags.			
3	A System for Aiding Consumers with Grocery Market Shopping	2015	Hmood Al-Dossari, Maha Al-Yahya, Khaled Al-Quraini, Yahya Al-Qahtni, Sultan Al-Barrag	Development of Price Points system to assist consumers in selecting the best groceries.	Price Points system compares items in various grocery stores based on multiple criteria to guide consumers in making informed choices.	Price Points system offers justified recommendations for consumers, aiding in selecting preferred groceries.	The study may lack scalability testing in real-world grocery shopping scenarios.
4	Smart Shopping Cart with Automatic Billing System using RFID & Arduino	2014	How 2 electronics	Building a smart shopping cart with an Automatic Biling system utilizing EM-18 RFID Module and Arduino.	Automatic billing system integrated into shopping carts using RFID technology. LCD display shows item names and prices.	The system offers convenience by automating the billing process, reducing waiting time for customers.	Lacks functionalities like product recommendations
5	Shopbots and Pricebots	2012	Amy R. Greenwald & Jeffrey O. Kephart	Analyzing the impact of shopbots and pricebots on consumer	Shopbots gather information from online vendors, aiding buyers in minimizing expenditure.	The proliferation of shopbots and pricebots can lead to game-	Requires advanced user knowledge and may lead to price wars

				shopping behavior.	Pricebots, on the other hand, use price-setting algorithms to maximize profits.	theoretic equilibria, affecting market dynamics.	
6	Progress in developing an interactive mobile shopping assistant for everyday use	2008	H. -M. Gross; H. -J. Boehme; C. Schroeter; S. Mueller; A. Koenig; C. Martin; M. Merten; A. Bley	Development progress of an intelligent and interactive mobile shopping assistant.	Successful implementation of mapping and user detection/tracking methods in robotic shopping assistants.	The ShopBot project demonstrates the feasibility and reliability of mobile shopping assistants in real-world scenarios	May lack recent advancements in technology and user interaction. Requires complex infrastructure and may not be suitable for all stores
7	Shopping robots and e-commerce	2007	Antonella Reitano	Analysis of shopbots' features, roles, and functions in e-commerce.	Shopbots automate product search and comparison, providing users with extensive product information quickly.	Shopbots are considered essential for electronic business, offering efficient access to product information.	Published in 2007, may not cover recent advancements in shopping robot technology.
8	Shopbots: A Syntactic Present, A Semantic Future	2006	M.Fasil	Exploration of semantic technologies to enhance shopbots'	Semantic Web and Web services technologies can overcome current	Semantic technologies hold the key to realizing shopbots' significant	Limited discussion on empirical validation or practical

				capabilities.	limitations of shopbots, enriching the online shopping experience.	potential in enhancing online shopping.	implementation.
9	Designing a Better Shopbot	2004	Alan L. Montgomery; Kartik Hosanagar; Ramayya Krishnan; Karen B. Clay	Developing an improved shopbot design based on a utility model of consumer behavior.	Improved shopbot designs can increase consumer utility by intelligently searching and presenting offers	A utility-based approach can enhance shopbots' efficiency and effectiveness in aiding consumers.	Relies on accurate data about user preferences and store response times
10	Product Searching with Shopping Bots	2000	Jennifer Rowley	Review of search facilities offered by shopping bots.	Effectiveness of shopping bots depends on search facilities, product coverage, and added value features such as reviews.	Shopping bots play a crucial role in supporting consumers with product search and identification in e-shopping.	The study may lack coverage of recent advancements in shopping bot technology.

3.4.1.1 Summary of Literature review:

After going through number of journals and reviewing the designs, assumptions, trials, concepts and mechanisms involved, the literature review can be summarised into these following points:

- Research explores the development and implementation of various shopping assistance technologies like robots, smart carts, and virtual assistants in retail settings.

- Service robots, RFID-based systems, and AI-powered assistants are emerging technological solutions offering advanced functionalities.
- These technologies benefit consumers by promoting convenience, saving time, providing extensive product information, generating personalized recommendations, and enabling secure payments.
- Studies examine the impact of shopping bots and price bots on consumer behavior, highlighting their potential to minimize expenditure, maximize satisfaction, and support informed purchase decisions.
- The focus lies on enhancing the user experience through personalized assistance, task automation, and reduced search and payment times.
- Challenges include scalability issues, lack of real-world validation, and the need for continuous advancements.
- The literature emphasizes further research on semantic technologies, adaptive assistants, and personalized systems.
- Shopping assistance technologies play a crucial role in modern retail, holding the potential to reshape the shopping experience for increased convenience and efficiency. Sustained innovation is vital to meet evolving consumer needs and remain competitive within the retail landscape.

3.4.1.2 Field Visit

Field visit was carried out at a supermarket “Fresh Mart”

Mr. Ranjith, the owner of Fresh Mart, graciously offered his time and perspective.A discussion was carried out with Mr. Ranjith and several customers to understand their challenges and identify potential areas where the shopping bot project could provide solutions. Measurements of the shop floor and rack dimensions were noted down to aid in the robot's design and navigation

Figure 3: Field Visit

Customer Pain Points:

- Difficulty in Finding Specific Items: This could be due to poor store layout, lack of proper signage, or insufficient staff assistance. A shopping bot with navigation capabilities and the ability to access product location data can address this.
- Lack of Product Information: Customers might struggle to find detailed information about products, leading to indecisiveness or frustration. QR codes on products linked to a product information database accessible through the shopping bot can solve this.
- Long Checkout Lines: This can significantly impact customer satisfaction. While a shopping bot might not directly address checkout lines, it can help customers find items faster, potentially reducing overall shopping time.
- Limited Assistance: Finding a staff member for assistance can be time-consuming. A shopping bot with voice recognition or a touch screen interface can offer basic product information and answer frequently asked questions, reducing the burden on staff.

Mr. Ranjith's Concerns:

- Inventory Management: Knowing what's in stock and keeping shelves filled is crucial. A shopping bot with shelf scanning capabilities can transmit real-time inventory data, facilitating timely restocking.

- Labor Costs: Staffing costs are a significant expense. Shopping bots can handle basic tasks like product information retrieval and navigation, potentially freeing up staff for higher-value interactions with customers.
- Product Promotion: Mr. Ranjith likely wants to promote specific products or highlight special offers. The shopping bot's display or voice interaction can be used to showcase targeted promotions based on customer location or purchase history.
- Data Collection: Customer behavior data can be used to optimize store layout, product placement, and promotional strategies, ultimately improving the customer experience

3.4.2 Objective 2

This objective focuses on arriving at a detailed specification for the shopping bot prototype. This specification will outline the hardware components, software functionalities, and overall system design necessary to achieve the desired level of functionality and performance. By achieving this objective, the groundwork for the physical construction and programming of the shopping bot is laid, ultimately leading to the creation of a tangible prototype.

3.4.2.1 Defining Prototype Requirements

The initial step in achieving Objective 2 involved defining the specific requirements for the shopping bot prototype. This included considering the following factors:

- **Target Environment:** The prototype's operational environment was a key consideration. The necessary measurements of the shop floor were taken during the field visit and the conclusions drawn from it are as follows:

Shop floor Layout

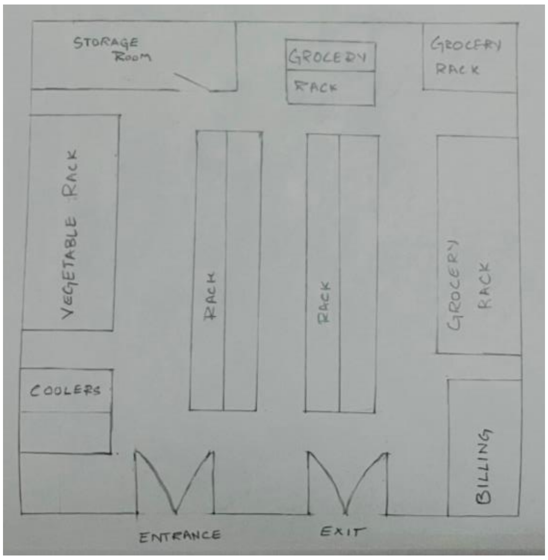

Figure 5: Shop floor Layout

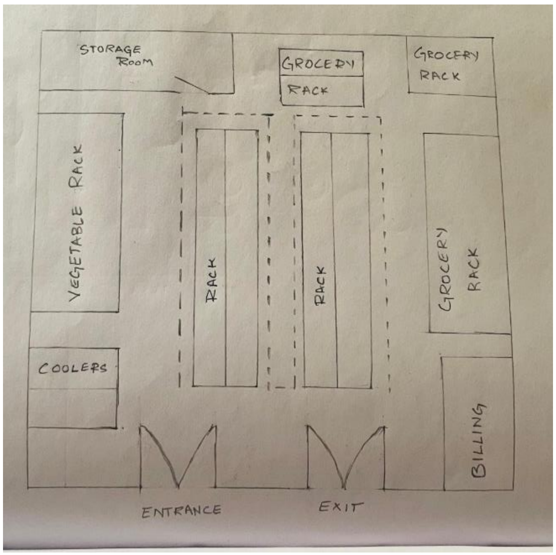

Figure 4: Shop floor Layout with Path

- During the field visit, shop floor was measured to be approximately 900 sqft, which will serve as the reference layout for the shopping bot project
- The shelves are 10 meters long, offering plenty of space for displaying a variety of products.
- The shelves are 1 meter deep, and there's a half-meter gap between them.
- A regularly shaped shop floor with wide aisles like this could be well-suited for a line following shopping bot
- The distance between two aisles is 1.5m
- The clear path between shelves would allow the bot to follow a defined line for navigation
- The shopping bot will navigate the shop floor by following the designated path marked by the dotted line. This line should be clearly visible and uninterrupted throughout the planned route

- Considering the narrow aisles (2 meters total width, 1m depth of the shelves and 0.5m gap), the shopping bot's design should be compact to ensure smooth maneuvering within the limited space
- Hence the length and the width of the robot is to be less than a meter.
- The line following sensors on the shopping bot requires calibration into account for the specific distance between the dotted line and the shelves. This ensures the bot stays on track and avoids collisions

- **Functionality Scope:** The bot utilizes line following mechanism along with Rear Wheel Drive(RWD) transmission system to traverse through the store aisles while searching for the products. QR scanning feature is made possible by using a web cam and image processing algorithms/libraries. A simple robotic arm with two-jaw gripper is interfaced with the bot for function of product retrieval. Features like Path Recognition and Obstacle Avoidance can be included in the future versions of the bot.
- **Performance Considerations:** The prototype should be capable of supporting a weight of 10kg(including its body weight) and perform its functions optimally for at least a runtime of 15 mins.

3.4.2.2 Hardware Component Selection

Based on the defined prototype requirements, the next step involved selecting suitable hardware components. These components form the building blocks of the shopping bot, enabling its movement, sensor data collection, and interaction with the environment.

Some key hardware components typically considered for a robot prototype are:

- **Microcontroller:** This acts as the brain of the bot, processing sensor data and issuing control commands to the motors. Popular options include Raspberry Pi or Arduino boards.
- **Motor System:** Motors are responsible for propelling the bot and enabling movement. The choice depends on factors like the desired speed, payload

capacity, and maneuverability requirements. Options include DC motors, stepper motors, or servo motors.

- **Sensors:** Sensors provide essential information about the bot's surroundings. Line following sensors are crucial for basic navigation. Additional sensors could include cameras for object recognition, IR sensors for obstacle detection, or ultrasonic sensors for measuring distance.
- **Robotic Arm:** This component allows the bot to manipulate products. The complexity of the arm depends on the desired functionality. A simple gripper mechanism might suffice for basic pick-and-place operations, while more sophisticated articulated arms could offer greater dexterity.

Table 3: Components Used

Name	Specification	Functionality	Application
IR Sensors	Board Size -3.2 x 1.4cm Working voltage-3.3to5V DC Operating voltage-3.3V:~23 mA, to 5V: ~43 mA Detection range2cm – 30cm	IR sensor is an electronic device, It has an LED emitting infrared light invisible to us and a photo-diode to detect it. An IR sensor detects the motion. Usually, in the infrared spectrum, all the objects radiate some form of thermal radiation.	The sensor reads reflected light. Bouncing back from a white surface (surface other than the black path line) tells the robot it's on track. By sensing reflections, the robot can tell the difference between the line (no reflection) and its surroundings, allowing it to follow the line.
DC-Gearbox Motors(Johnson)	Size (70 x 22 x 18mm) Torque (0.8 kg.cm at stall) Speed (roughly 90 to 200 RPM) Voltage- 3V and 6V	Converts electrical energy to mechanical motion Affordable, easy to control	The Johnson DC motors are connected to the wheels of the robot, providing the necessary torque to the rear wheel drive of the robot and make turns based on the signals received from the line detection sensors. It is used for robot arm moment.

Raspberry Pi 4 Model B (Pi4B)	Operating system- Raspberry Pi OS System on a chip- Broadcom BCM2711 CPU Quad-core ARM Cortex-A72 @ 1.5 GHz (B0 Revision) / 1.8 GHz (C0 Revision) Memory-(LPDDR4 @ 3200 MHz)	Functions as a powerful single-board computer capable of handling general computing tasks, multimedia playback, and dual 4K monitor output. It also offers extensive connectivity options with dual-band Wi-Fi, Bluetooth 5.0, Gigabit Ethernet, and a 40-pin GPIO header for hardware interfacing.	It can run the line following algorithm, process data from the web cam, and communicate with the web app and rear wheel motor drive.
Web Cam	Image Sensor - Colour CMOS image sensor Video Format - 24bit RGB Interface - USB Frame Rate - 320×240 up to 30 frames/sec, 640×480 up to 15 frame/sec Sensor Size - 4.38×3.64mm	A webcam is a digital camera that captures video and audio data and transmits it in real-time over the internet.	Webcam is used QR scanning purpose
LCD Display	Min logic voltage:4.5 V Max logic voltage:5.5 V Typical LED backlight voltage drop: 4.2 V Typical LED backlight current:120 mA Supply current:2 mA	Uses the light-modulating properties of liquid crystals combined with polarizers.	To visually display information in the form of text, numbers, or graphics.
Motor Drivers (L293/D)	Power Supply : Over FRC connector 5V DC. External Power 9V to 24V DC. Dimensional Size : 44mm x 37mm x 14mm (l x b x h) Temperature Range : 0°C to +70 °C.	Amplifying electrical signals to power and control the motor Drive a DC motor in either direction and also control the speed of the motor.	The Pi will send control signals to the L293/D, which will then amplify these signals and provide the necessary power to drive the motors based on the commands from the line following algorithm

12V Battery	Capacity:1.3 Ah Rechargeable lead acid battery	Store energy for you to use later. The power that 12V batteries produce is classified as direct current (DC) power.	Battery are used to run the rear drive motors.
Arduino UNO	Micro controller ATmega38P – 8 bit AVR family micro controller Digital I/O Pins 14 Flash Memory 32 KB (0.5 KB is used for Bootloader)	The Arduino Uno is a micro controller board used for building digital devices and interactive objects, capable of reading inputs (such as sensors) and controlling outputs (like motors and LED's).	Due to lack of pins in the Raspberry Pi board, It is used for controlling vertical and horizontal movement of robot arm and gripper.
Cardboard	Thickness – 5.5 mm Height – 50 mm Length and Width- 50mm x 33mm	Cardboard is commonly utilized as a construction material for building the body of low-cost robots due to its affordability, ease of manipulation, and lightweight nature, making it an ideal choice for prototyping and experimentation in robotics projects.	Cardboard is employed to construct the structural frame and chassis of a robot body, providing a lightweight yet sturdy foundation for mounting electronic components and facilitating movement.
12mm Wheels	12 mm diameter, durable plastic or rubber construction, and a hub designed to fit 3 mm or 4 mm motor shafts	12 mm wheels are typically used in small-scale robotics and model applications to provide mobility and maneuverability. They are designed to fit onto small motor shafts, enabling precise movement and control in compact robotic systems	The two back wheels are attached to Johnson DC motors, which provide forward movement, while the other two wheels are driven by the back wheel motors.

Screw and nut	Screw Dia - 5mm Screw Head Dia - 8.28, 8.72mm Nut Dia - 5mm Socket Size-8mm Nut Thickness - 4mm	Engage with the internal threads of the nut, creating a secure connection. This mechanism enables adjustable and reversible assembly, allowing for efficient joining of components in various applications,	Screws and nuts are employed to firmly secure objects together and to tightly fit materials, providing a robust and adjustable fastening solution for a wide range of applications.
L-shaped metal support	Material- Aluminium Thickness - 3mm Angle-90°	L-shaped metal supports are often used to mount components securely within the robot's frame, providing structural integrity and support for various modules such as motors, sensors, and control boards.	L-shaped metal supports are utilized to provide structural reinforcement and stability to the frame and chassis of a robot, ensuring reliable support for components and maintaining the overall integrity of the robot's construction.

3.4.2.3 Software Development Framework

This step involves all the coding for the functioning of the bot. A suitable web hosting framework is to be selected and using python programming language the website is hosted in the local server. Raspberry Pi board is used to run these program. Also it is interfaced with Motor driver and Aurdino Uno board as the pins on the Pi board is already used up for controlling RWD motor, LCD. So By using Aurdino the control of the gripper is done.

3.4.2.4 Calculations

1) Calculation for selection of motor

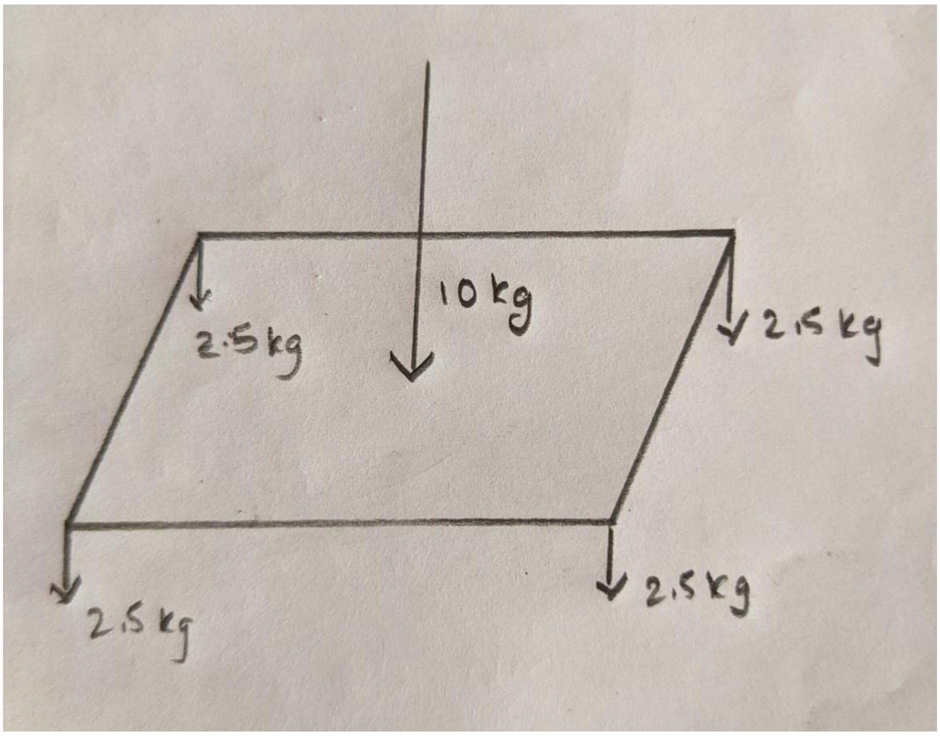

Figure 6: Loads acting on chassis and wheels

As shown in the figure 6, let us consider that the total weight on the chassis of the model to be **3 kg**, also including the weight of the products/items to be **7kg** max. Now the total load acting on the chassis (inclusive of its weight) is **10kg** as shown in the figure.

The four wheels provide support for the structure, therefore assuming that the load is acting equally among the wheels,

Load on wheel, P = 2.5kg

The wheel used for the project is easily available in the market, which has a diameter of 6.5cm I,e. radius of wheel, r = 3.25 cm

The objective of the project is to develop a shopping bot which can navigate the aisles using line following mechanism with an average speed of **50 cm/s. (acceleration a= 0.5 m/s²)**

The formula to find the angular velocity(ω) of the wheel is,

V= r x ω , V is linear velocity and r is radius of wheel

50 = 3.25 x ω

ω = 50/3.25

ω = 15.38 rad/s

Now converting it into RPM

2.55 rev/s = <u>153 RPM</u>

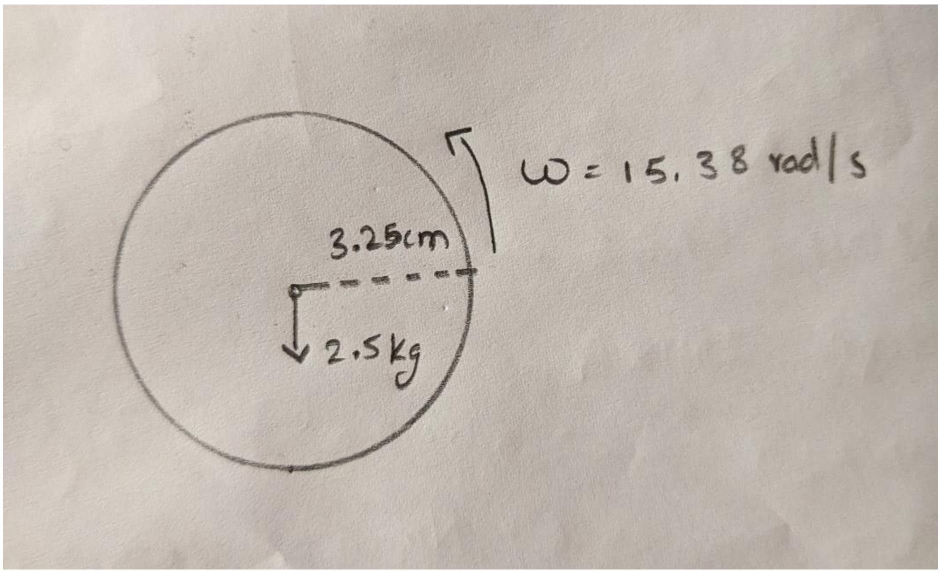

Figure 7: Wheel parameters

Now to find force(F) and torque(τ) acting on the wheel,

<u>Force under gravity</u>

Fg = mass/load (m) × gravity (g)

Fg = 2.5 × 10 , ($g=9.81 m/s^2$ approximated to $10 m/s^2$)

Fg = 25 N

Force under acceleration

Fa = m × a , acceleration a = 0.31 m/s^2

Fa = 2.5 × 0.31

Fa = 0.775 N

Total force acting, F = Fg +Fa = 25.775 , approximated to **25.8 N.**

Torque (τ) = F × d , d is perpendicular distance i.e. radius r in this case

τ = 25.8 × 3.25

τ = 83.85 N-cm

From the above calculation it is derived that the motor must have torque capacity greater than 83.85 N-cm in order for the bot to work smoothly under a payload of 7kg. **Therefore a center shaft geared DC Motor with torque of 117.67 N-cm has been selected.**

2) Calculation for power consumption

To calculate the power required to run a four-wheeled robot with RWD, Raspberry Pi 4 as the microcontroller, and L298 motor driver for controlling gear DC motors on a flat surface:

Given:

Weight of the robot: 10 kg

Acceleration: 0.31 m/s^2

Wheel radius: 3.25 cm = 0.0325 m

Battery voltage: 12V

Calculations are as follows:

- Frictional forces: For a flat surface, the rolling friction force is negligible.
- Acceleration Forces: The force required to accelerate the robot is:

  F=m x a

  $F_{acceleration} = M_{robot} \times a$ = 10kg × 0.31m/s² = 3.1N
- Torque : The torque required to overcome the acceleration force is:

$\tau = F_{acceleration} \times r$ = 3.1N × 0.0325m =0.10075Nm

- The angular velocity of the motor is:

  $\omega = v/r$ = 0.31m/s 0.0325m 9.54 rad/s

- The power required is:

  $P = \tau\omega$ = 0.10075m ×9.54rad/s =0.96W

- Motor Efficiency: Assuming a motor efficiency of 80%, the motor electrical input power is:

  $P_{motor} = P/ N_{motor}$=0.96W/ 0.8= 1.2W

- Current Draw: The current draw from the 12V battery is:

  $I = P_{motor}$ = 1.2W/ 12V=0.1A

To run the shopping bot on a flat surface, with a weight of 10 kg and an acceleration of 0.31 m/s^2, a 12V battery capable of providing at least 0.1A of current to each motor is needed. The total power required for all six motors is approximately 6.6W . Considering loss of energy during transmission and due to heat the power consumed is taken as 7W

3) Calculation for total runtime on battery

To determine how long the 12V 1.3 Ah battery can support power comsumption of 7W.

To calculate the battery runtime use the formula:

Run Time =Battery Capacity Ah / Load Current A

To calculate the load current:

Load Current = Power (W)/Voltage (V)= 7W/12V = 0.583 A

Now, calculating the run time:

Run Time = 1.3 Ah/0.583 ~ 2 hours

Therefore, the 12V 1.3Ah battery can run all the motor continuously for approximately two hours.

3.4.3 Objective 3

Concept 1: Modular Shopping Assistant Platform

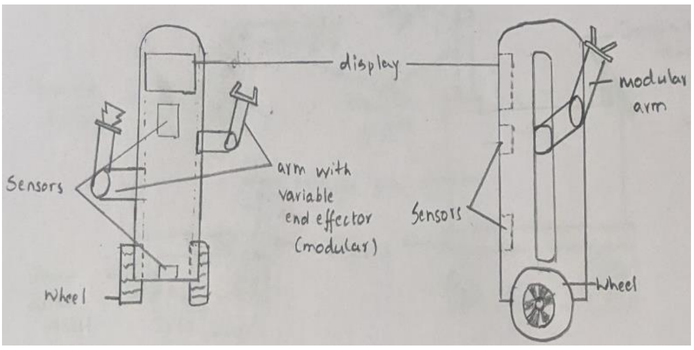

Figure 8: Modular Shopping Assistant Platform

Core Functionality:

- Base Unit: The foundation of the shopping bot is a base unit equipped with two key functionalities.
- Line Following: This allows the bot to navigate autonomously within the store by following designated paths marked on the floor.
- QR Code Scanning: The bot can scan QR codes placed on shelves or products, potentially providing customers with additional information, product reviews, or triggering targeted promotions.

Modular Design:

- The modularity aspect elevates the bot's capabilities. Attachable modules can be added to the base unit, expanding its functionalities to cater to specific store needs:
- Shelf Scanning Module: This module allows the bot to scan shelves and track inventory levels. This data can be fed into the store's inventory management system, providing real-time stock information and facilitating timely restocking.
- Interactive Display Module: This module incorporates a screen that can display targeted promotions or product information. As the bot navigates the store,

customers can easily view these promotions, potentially leading to increased sales. The display can also be interactive, allowing customers to access product details or reviews

Benefits of a Modular Approach

- Customization: Stores of various sizes and layouts can benefit from this modular design. A small convenience store might only require the base unit with line following and QR scanning, while a larger supermarket might utilize all three modules for comprehensive functionality.
- Scalability: As technology advances, additional modules with new functionalities can be developed and integrated with the base unit, future-proofing the system.
- Cost-Effectiveness: Stores can choose the modules they need, optimizing costs and functionality. Upgrading with additional modules becomes easier in the future.
- Improved Customer Experience: The modular bot offers features that can enhance the customer experience. Easy access to product information, automated inventory management, and targeted promotions can all contribute to a more streamlined and enjoyable shopping experience

Concept 2: Interactive Shopping Assistant Bot

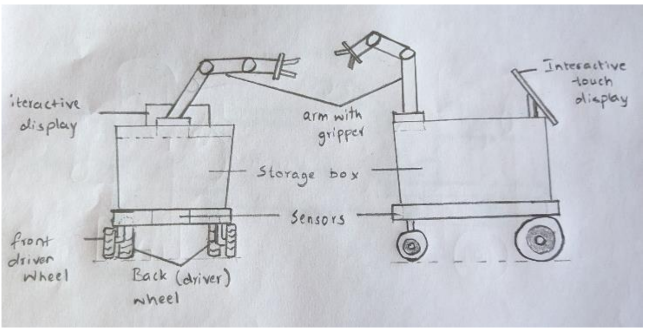

Figure 9: Interactive Shopping Assistant Bot

Enhanced Navigation and Obstacle Avoidance:

- Advanced Sensor Suite: This robot goes beyond basic line following. It utilizes a comprehensive sensor suite including LiDAR, stereo cameras, and ultrasonic sensors. LiDAR provides high-precision 3D mapping of the environment, allowing for precise line following even on complex routes. Stereo cameras enhance depth perception and object recognition, while ultrasonic sensors detect unexpected obstacles like abandoned carts or displays.

- Advanced Algorithms: The robot leverages powerful algorithms to process sensor data and plan its path efficiently. These algorithms account for dynamic obstacles and optimize navigation for smooth movement and efficient customer service.

User Interaction and Information Access:

- Touchscreen Display: A large, user-friendly touchscreen display becomes the centerpiece for user interaction. Customers can access product information, browse store layouts, and check their shopping lists directly on the robot's screen.
- Voice Recognition: Incorporating voice recognition technology allows for natural language interaction. Customers can ask questions about products, request assistance, or add items to their shopping lists through voice commands.

Personalized Shopping Experience:

- Mobile App Integration: The robot can connect seamlessly with a dedicated mobile app. This app allows customers to create and manage shopping lists, receive personalized recommendations based on their purchase history and preferences, and locate specific products within the store using the robot's navigation capabilities.
- Benefits of an Advanced Shopping Assistant Robot:
- Improved Efficiency: Advanced navigation reduces travel time and optimizes the robot's route, leading to faster customer service. Obstacle avoidance ensures smooth operation and reduces the risk of collisions.
- Enhanced Customer Experience: The touchscreen display and voice recognition features facilitate easy access to information and a more interactive shopping

experience. The mobile app integration adds a layer of personalization and convenience.

- Increased Sales: Personalized recommendations can influence customer purchase decisions and potentially lead to increased sales. The robot can also highlight promotions and new arrivals, further contributing to sales growth.

Concept 3: Basic Line Following & QR Scanning Bot

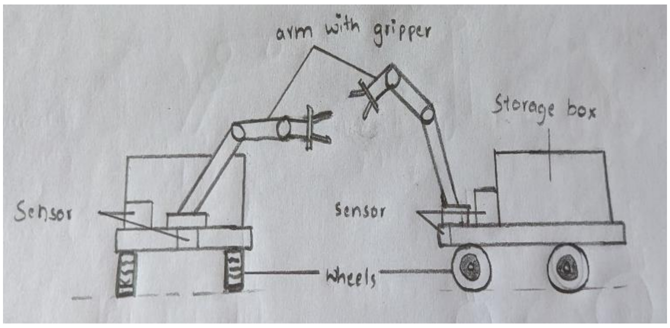

Figure 10: Basic Line Following & QR Scanning Bot

Core Functionalities:

- Basic Navigation: This bot prioritizes simplicity and affordability. It utilizes line sensors or a camera to follow designated paths marked on the store floor. This allows for autonomous navigation within the store, freeing up staff from basic wayfinding tasks.
- QR Code Scanning: A camera equipped on the bot allows for QR code scanning. This enables customers to access additional product information, reviews, or promotional offers by simply scanning a code placed on the product or shelf.
- Onboard Display (Optional): For enhanced user interaction, the bot can optionally include a small onboard display. This display can show basic product details accessed through QR code scanning, offering a quick and convenient way for customers to learn about products without needing a separate device.

Benefits of a Compact Shopping Assistant:

- Cost-Effectiveness: Due to its smaller size and simpler functionalities, this bot is more affordable than its feature-rich counterparts. This makes it accessible to a wider range of stores, especially smaller businesses.
- Easy Deployment: The bot's compact design and basic navigation make it easier to deploy and maintain. Additionally, the use of line sensors or a camera for navigation minimizes the need for complex infrastructure changes within the store.
- Improved Customer Experience: Even with its basic functionalities, the bot can significantly enhance the customer experience. Autonomous navigation frees up staff to offer more personalized assistance, while QR code scanning provides instant access to product information, leading to more informed purchase decisions.

Target Audience:

- Smaller Retail Stores: This bot is ideal for smaller stores with limited budgets and less complex layouts. The simplicity and cost-effectiveness make it a viable option to introduce basic automation and enhance customer service.
- Seasonal or Pop-Up Stores: These stores often require flexible and easily deployable solutions. The compact size and minimal setup needs make this bot a suitable choice for temporary retail environments.
- Night store: These stores usually have less number of work personnel, having a robot can increase the store’s order deployment efficiency.

Comparison between the different concepts:

Table 4: Comparison b/w the different concepts

Parameters	**Modular Shopping Assistant Platform**	**Interactive Shopping Assistant Bot**	**Basic Line Following & QR Scanning Bot**
Focus	Customizable features for diverse needs	User interaction & personalized experience	Navigation & basic product information
Complexity	Medium	High	Low
Cost	Medium	High	Low
Scalability	High	High	Limited
User Interaction	Varies depending on modules	High	Minimal

From Table 4 it is clear that Concept 3, the compact and lightweight shopping bot, is identified as the ideal design for the project. This choice aligns perfectly with the goals due to its focus on simplicity and cost-effectiveness. Concept 3 prioritizes core functionalities like basic navigation and QR code scanning, enabling efficient development within the scope of the project. Furthermore, its manageable size and clear objectives make it a perfect starting point. This approach allows us to achieve tangible results while laying the foundation for potential future expansion with additional features.

4.1 Objective 4

To Incorporate electronics and Develop web app

4.1.1 Workflow

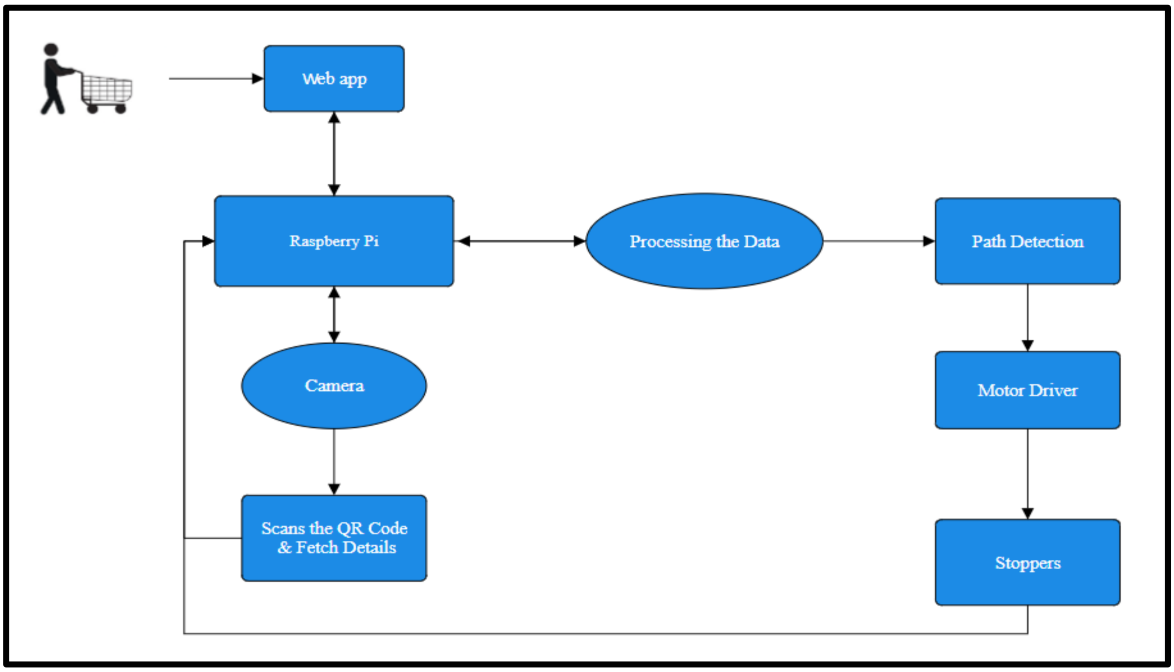

Figure 11: Flowchart detailing integration of different electronics part

1. <u>Web App</u>

As shown in figure 11, the process starts with a web app, The web app acts as the bridge between the customer and the shopping bot. Customers interact with the bot through a user-friendly interface on the web app, selecting desired items. This web app runs on the Raspberry Pi, acting as a server. The Raspberry Pi communicates with the web app using a protocol like HTTP. When a customer finalizes their selections, the web app transmits this information to the Raspberry Pi , then it processes this data and translates it into control signals for the robot, effectively turning customer choices into actions for the shopping bot.

2. Raspberry Pi Processing the Data

The Raspberry Pi receives instructions or data from the web app.

The Raspberry Pi serves as the brain and central server for the shopping bot. It runs the web application that customers interact with to choose their desired items. This web app can be accessed through any web browser on a phone, tablet, or computer. The Raspberry Pi communicates with the web app using a protocol like HTTP, allowing it to receive customer selections and send instructions. Once it has this information, the Raspberry Pi processes it and translates it into control signals for the robot. The Raspberry Pi as a translator, taking customer choices from the web app and turning them into a language the robot understands. It then transmits these signals, which controls the bot's movements and actions.

3. Motor Drivers

The Raspberry Pi doesn't directly control the motors. It processes information like user selections and sensor data. Based on this, it generates control signals for the motor drivers. These drivers act as translators, interpreting the Raspberry Pi's instructions and converting them into electrical signals suitable for the DC Gear Motors. The motor drivers then regulate the power and direction of the motors, propelling the bot along its designated path or initiating specific movements for item selection.

4. Path Detection And Stoppers

The Raspberry Pi sends signals to the IR sensors, Two infrared (IR) sensors are strategically positioned on the bot's undercarriage. These sensors detect the presence or absence of a dark line on the ground. By following this designated line, the bot remains on track. This line-following approach ensures the bot travels efficiently and reaches the designated item racks. When the bot encounters an stopper in the third IR sensor, it interprets this as a potential stopping point, likely an item rack. This triggers the bot's item identification and selection process.

5. Camera Scans the QR Code & Fetches Details

The camera is used to scan QR codes. When a QR code is detected in the image, the Raspberry Pi can decode the QR code data and fetch the information and matches with the QR code data. This fetched information is used for various purposes, such as controlling the motor driver or displaying product information on the web app.

4.1.2 Functionalities

Key functionalities of the electronics and software integration are:

Web Application

- A web application serves as the user interface for the Shopping Bot system. Accessed through a web browser on any device, the app offers the following functionalities:
- **Product Selection:** Users can browse through a digital inventory, conveniently selecting the items they wish to purchase.
- **Purchase Confirmation:** Once items are chosen, the app allows users to confirm their purchase and proceed to checkout.
- The Shopping Bot and web application operate seamlessly through the following integration methods:
- **Wi-Fi:** The Raspberry Pi utilizes Wi-Fi connectivity to establish communication with a local server.
- **Localhost Server:** A local server acts as the intermediary between the web application and the Shopping Bot. This allows for real-time data exchange and control of the bot's actions.
- Microweb framework **flask** is used to host the website.
- Flask is a microweb framework written in Python. It is classified as a micro framework because it does not require particular tools or libraries. It has no

database abstraction layer, form validation, or any other components where pre-existing third-party libraries provide common functions. Flask supports extensions that can add application features as if they were implemented in Flask itself.

Raspberry Pi 4

- The Raspberry Pi 4 Model B (Pi4B) is the first of a new generation of Raspberry Pi computers supporting more RAM and with significantly enhanced CPU, GPU and I/O performance in a similar form factor, power envelope and cost as the previous generation Raspberry Pi 3B+.
- It can run the line following algorithm, process data from the camera module, and communicate with the web app and motor drivers.
- The Raspberry Pi 4 is a significant upgrade over its predecessor, with a faster processor, more RAM, and improved I/O capabilities.
- Communicates with the Arduino Uno, motor drivers, IR sensors, webcam, and LCD display.
- Sends commands to the robot arm and motors based on the selected items and navigates the bot along the line following path.
- GPIO pins: 40

Line Following: The robot employs an infrared (IR) sensor to detect a designated line on the floor. This line serves as a guide, enabling the robot to navigate autonomously within the store environment.

IR sensor

- It has an LED emitting infrared light invisible to us and a photodiode to detect it.
- The sensor reads reflected light. Bouncing back from a white surface (the line) tells the robot it's on track. By sensing reflections, the robot can tell the difference between the line (no reflection) and its surroundings, allowing it to follow the line.
- **Product Identification:** A camera connected to a Raspberry Pi 4 Model acts as the bot's vision system. Upon reaching designated stopping points marked by

additional IR sensors, the camera activates and scans a QR code positioned near the product rack.

- **QR Code Scanning:** By reading the QR code, the bot can access information about the product's availability. This allows the bot to determine if the desired item is present on the shelf

Web Cam

- The Raspberry Pi High Quality Camera is the latest camera accessory from Raspberry Pi.
- Captures real-time video and images for scanning QR codes and identifying items on shelves.
- Captures images of QR codes on racks.
- The camera activates, scanning a QR code located near the rack. This code presumably holds information about the items stocked on the rack.
- Sends the captured images to the Raspberry Pi for processing and item identification.
- Helps verify if the scanned item matches the selected item in the order.
- Resolution: 720p to 1080p (HD)
- Frame rate: 30 to 60 frames per second
- PyZBar is a Python library for image processing. To decode a QR code from the webcam of a Raspberry Pi using PyZBar, you need to install the PyZBar library, capture frames from the webcam, and use PyZBar to detect and decode QR codes in real-time. The decoded information can then be compared with a text file of product names for validation.

DC Gearbox Motors

- It is cost-effective. Its small size (70 x 22 x 18mm) makes it ideal for building a compact shopping bot.

- It operates between 3V and 6V, the motor offers adjustable speed (roughly 90 to 200 RPM) based on voltage. It provides enough torque (0.8 kg.cm at stall) to propel shopping bot with light cargo.
- Provides torque and controlled speed to move the bot along the line following path.
- Controlled by the motor driver connected to the Raspberry Pi.
- 3 motors are used for the rotation, vertical and horizontal movements of the robot arm and one motor for the gripper movement.

Motor Drivers

- The L293/D will be connected between the Raspberry Pi and the DC motors of your shopping bot.
- The Pi will send control signals to the L293/D, which will then amplify these signals and provide the necessary power to drive the motors based on the commands from the line following algorithm
- The L293 can handle up to 1 Amp (per channel) of current, while the L293D can handle 600mA
- Dual H-bridge motor driver ICs used to control the DC motors in both the robot arm and wheels.
- Controls the direction and speed of the DC motors based on input signals from the Raspberry Pi and Arduino Uno.
- Drives the motors by providing the necessary current and voltage.

LCD Display

- Provides visual feedback to users and status information about the shopping bot's operations.
- Displays status messages, item information, and other relevant data to the user.
- Connected to the Raspberry Pi, which sends data to be displayed.
- Common type: 16x2 character LCD
- Operating voltage: 5V

Arduino Uno

- Microcontroller board used to control the robot arm's motors for rotation, horizontal, vertical movements, and gripper operation.
- Receives commands from the Raspberry Pi to move the robot arm.
- Controls the motors for the robot arm to pick up and place items.
- Uses digital I/O pins to drive the motor drivers connected to the robot arm motors.
- Clock speed: 16 MHz
- Digital I/O pins: 14 (6 PWM outputs)
- Analog input pins: 6
- Flash memory: 32 KB

4.1.3 Integration of the Circuit

1. Raspberry Pi

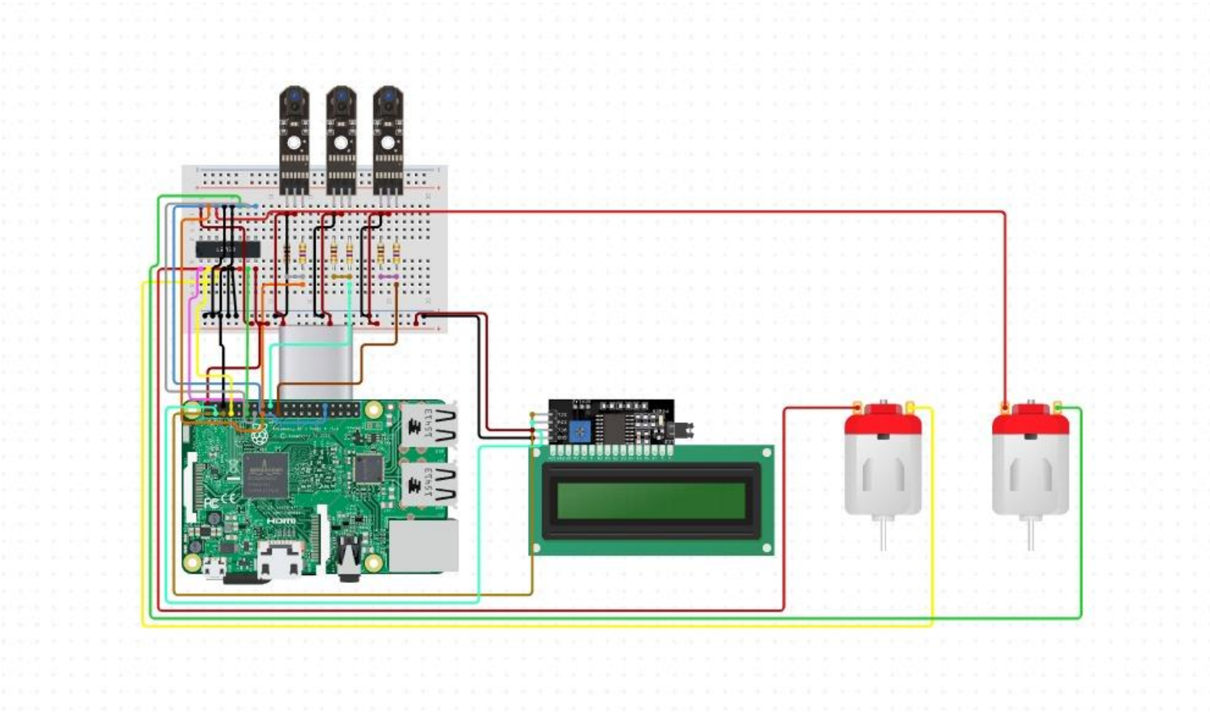

Figure 12: Raspberry Pi Circuit Diagram

Connections:

i. Webcam: Connects via USB to capture images and videos for item identification and QR code scanning.
ii. Stopper IR Sensor: Connected to GPIO pin 5.
iii. Line Following IR Sensors: Connected to GPIO pins 11 and 13.
iv. LCD Display: Connected to GPIO pins 15, 16, 18, 21, 22, 23, and 24 for displaying status messages and information.
v. Motor Driver-1 (for TT Motors):
Motor control pins connected to GPIO pins 32, 36, 38, and 40 to drive the shopping bot's wheels.

2. Arduino Uno

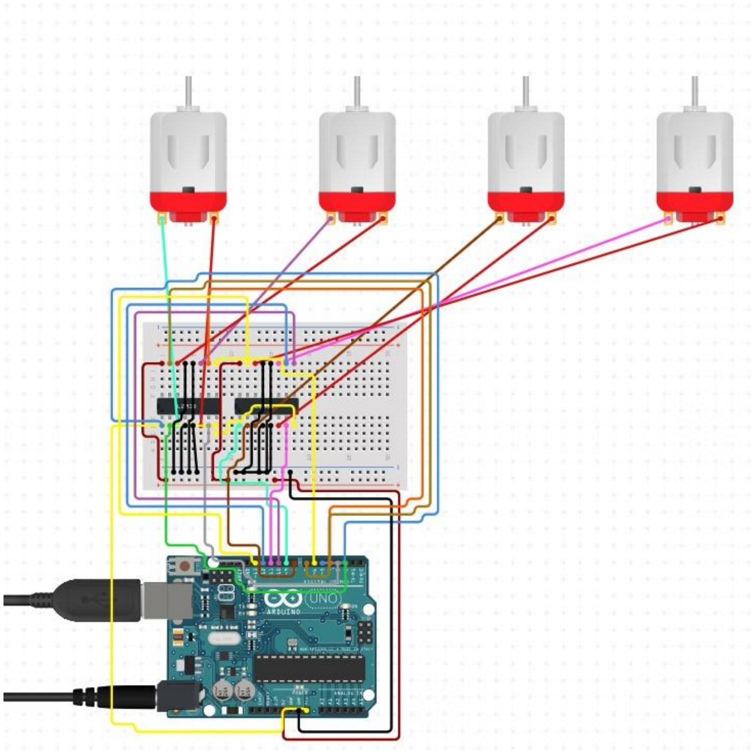

Figure 13: Arduino Uno Circuit Diagram

Connections:

I. Motor Driver-2:

Motor 1 (Rotation): Connected to digital pins 2 and 3.

Motor 2 (Vertical Movement): Connected to digital pins 6 and 7.

II. Motor Driver-3:

Motor 3 (Horizontal Movement): Connected to digital pins 4 and 5.

Motor 4 (Gripper Movement): Connected to digital pins 8 and 9.

III. Communication with Raspberry Pi: Typically done through a serial connection (USB) or via GPIO pins using serial communication protocols (e.g., UART).

4.1.4 Detailed Wiring

Raspberry Pi Setup:

I. Connect the webcam to a USB port.

II. Connect the IR sensors:

III. IR Sensor (Stopper) to GPIO pin 5.

IV. Line Following IR Sensors to GPIO pins 11 and 13.

V. Connect the LCD display:

RS to GPIO pin 15.

E to GPIO pin 16.

D4 to GPIO pin 18.

D5 to GPIO pin 21.

D6 to GPIO pin 22.

D7 to GPIO pin 23.

VSS to GND and VDD to 5V (from the Raspberry Pi).

VI. Connect Motor Driver 1:

IN1 to GPIO pin 32.

IN2 to GPIO pin 36.

IN3 to GPIO pin 38.

IN4 to GPIO pin 40.

OUT1 and OUT2 to TT Motor 1 (left wheel).

OUT3 and OUT4 to TT Motor 2 (right wheel).

VII. Arduino Uno Setup

Connect Motor Driver 2:

IN1 to digital pin 2 and IN2 to digital pin 3 (Motor 1 - Rotation).

IN3 to digital pin 6 and IN4 to digital pin 7 (Motor 2 - Vertical Movement).

OUT1 and OUT2 to Motor 1.

OUT3 and OUT4 to Motor 2.

Connect Motor Driver 3:

IN1 to digital pin 4 and IN2 to digital pin 5 (Motor 3 - Horizontal Movement).

IN3 to digital pin 8 and IN4 to digital pin 9 (Motor 4 - Gripper Movement).

OUT1 and OUT2 to Motor 3.

OUT3 and OUT4 to Motor 4.

Power Supply:

Ensuring all components are powered appropriately. The Raspberry Pi and Arduino Uno can share a common power source if their voltage requirements are met using a 5V power supply for the Raspberry Pi, Arduino Uno and a separate 12V battery for the Motor Driver so as to provide sufficient power to run the motor.

4.2 Bill of Material

Sl. No.	Part Name	Material	Quantity (no.)
1.	IR Sensors	Electronic	3
2.	DC-Gearbox Motors(Johnson)	Electronic	6
3.	Raspberry Pi 4 Model B	Electronic	1
4.	Web Cam	Electronic	1
5.	LCD Display	Electronic	1
6.	Motor Drivers(L293/D)	Electronic	3
7.	12V Battery	Electronic	1
8.	Arduino UNO	Electronic	1
9.	Cardboard	Cardboard	2
10.	60mm Wheels	Plastic	4
11.	Screw and nut	MS	10
12.	L-shaped metal support	Aluminium	4

5.1 Objective 5

Fabrication, Testing and Demonstration of prototype

5.1.1 Fabrication of the Shopping Bot

The fabrication of the shopping bot involves assembling various components, ensuring structural integrity, and integrating the electronic parts.

Dimensions and Structure

- Shopping Bot Base: The base of the shopping bot is made from 6mm thick cardboard with dimensions 330mm x 500mm. This forms the main platform for all components.
- Storage Box: Positioned at the back of the bot, the storage box measures 243mm x 320mm x 80mm. providing a volume of 6144 cm^3.
- QR Code Stand: The stand is 240mm in height. The QR code is placed at a height of at least 180mm to ensure it is within the camera's view, considering the camera height restriction.

Robot Arm:

- Height Reach: The robot arm has a reach of 50mm.
- Gripper Reach: The gripper at the end of the arm extends up to 70mm.

Mechanical Components

- Wheels: The bot has four wheels, with the rear wheels being powered by DC gearbox motors for rear wheel drive transmission.
- Support Structures:

  L-Hinged Shapes: Four L-hinged supports are used to provide structural integrity to the bot. These are secured with screws and nuts.

  Screws and Nuts: Used extensively to secure components and provide stability.

Electronic Components Placement

Front Section:

The front section houses the Raspberry Pi, Arduino Uno, motor drivers, and IR sensors. This section is crucial for handling the electronics and processing.

Webcam: Positioned at the front to capture QR codes and identify items on shelves.

Path Navigation

Path: The bot follows a path created using black tape on a white sheet. This path is crucial for the bot's navigation using line-following IR sensors.

Assembly Process

Base Construction:

- Cut a 330mm x 500mm base from 5.5 mm thick cardboard.
- Secure the storage box at the back, ensuring it is firmly attached to the base.

QR Code Stand:

- Construct a 240mm high stand from cardboard.
- Ensure the QR code is placed at a minimum height of 180mm from the base.

Wheels and Motors:

- Attach four wheels to the bot, ensuring the rear wheels are connected to the DC gearbox motors.
- Secure the motors using screws and nuts.

Support Structures:

- Attach the L-hinged shapes at strategic points to provide additional support to the structure.
- Ensure all hinges are secured with screws and nuts for stability.

Electronics Placement:

- Mount the Raspberry Pi, Arduino Uno, motor drivers, and IR sensors in the front section.
- Ensure all components are securely fastened and properly wired.

Robot Arm:

- Attach the robot arm and ensure it has the required reach of 50mm height and 70mm gripper extension.
- Test the movements to ensure the arm can pick and place items into the storage box.

Webcam:

- Position the webcam at the front, ensuring it has a clear view for scanning QR codes.

Final Testing:

- Conduct thorough testing of the bot's navigation, item picking, and storage capabilities.
- Adjust any components as needed for optimal performance.

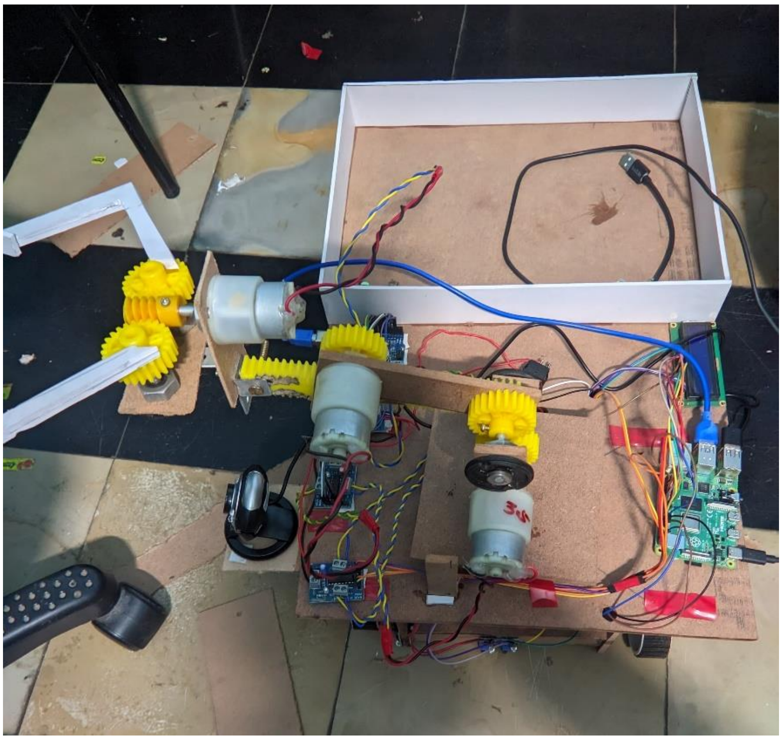

Figure 14: Assembly of the product

5.1.2 Test the prototype functionality

1. Initial Power-On and Connectivity Check

- **Power Supply**: Ensure that all components (Raspberry Pi, Arduino Uno, motor drivers, sensors) are connected to a stable power source.
- **Connections**: Verify that all connections between components are secure. Check for loose wires or connections.
- **Boot Sequence**: Power on the Raspberry Pi and Arduino Uno. Confirm that both devices boot up properly and are ready for operation.

2. Web Application and Server Testing

- **Web App Interface**: Access the web application hosted on the Raspberry Pi through a web browser. Ensure the interface loads correctly and is responsive.

- **Item Selection and Checkout**: Simulate a user selecting items and checking out. Verify that the web app communicates these selections to the Raspberry Pi.

3. Sensor Functionality

- **Line Following IR Sensors**:
    - Place the bot on the black tape path.
    - Observe the bot's movement to ensure it follows the line accurately.
- **Stopper IR Sensor**:
    - Place obstacles or markers along the path to simulate racks.
    - Verify that the bot stops at each marker correctly.

4. QR Code Scanning

- **Webcam Positioning**: Adjust the webcam to ensure it has a clear view of the QR codes at the specified height.
- **QR Code Detection**: Place QR codes at the appropriate height (minimum 180mm).
    - Test the bot’s ability to scan and recognize QR codes.
    - Confirm that the scanned QR code data matches the user’s selected items.

5. Robot Arm Functionality

- **Arm Movement**:
    - Test the rotation, vertical, and horizontal movements of the robot arm.
    - Ensure that the arm can reach the required height of 50mm and the gripper can extend to 70mm.

- **Item Picking and Placement**:
    - Place items within the bot’s reach.
    - Verify that the arm can accurately pick up items and place them in the storage box.

6. Motors and Mobility

- **Wheel Motors**:
    - Test the forward, stopping and turning movements of the bot.
    - Ensure smooth and precise control over the bot’s movements.
- **Robot Arm Motors**:
    - Verify the operation of each motor controlling the arm’s rotation, vertical, horizontal, and gripper movements.
    - Check for any lag or irregular movements.

7. Integration Testing

- **Full Operation**:
    - Simulate a complete shopping cycle from item selection to item pickup and storage.
    - Observe the bot’s behavior throughout the cycle to identify any issues or areas for improvement.

- **Error Handling**:
    - Introduce potential errors, such as an item not being in the expected location, and observe how the bot handles these situations.
    - Ensure that the bot can recover from errors or notify the user appropriately.

8. Performance and Optimization

- **Speed and Efficiency**:
    - Measure the time taken for the bot to complete a shopping cycle.
    - Identify any delays or inefficiencies in the process and work on optimizing them.

- **Battery Life**:
    - Monitor the bot's battery consumption during operation.
    - Ensure the power supply is adequate for the bot's intended usage duration.

5.1.3 Demonstration of the Prototype

Shopping Bot Demonstration

1. Initialization:

- The Raspberry Pi is powered on and starts hosting the web server.
- Users access the web interface from their devices to select items for purchase

2. Item Selection:

- Users browse through the web page hosted on the Raspberry Pi and select the items they wish to purchase.

- Upon checkout, the selected items are sent to the Raspberry Pi which prepares the navigation path for the bot.

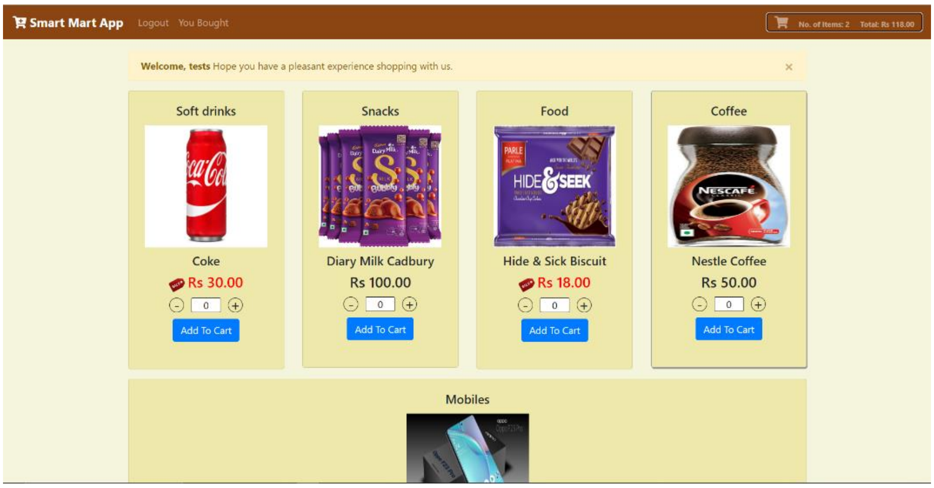

Figure 15: Customer interactive webpage

3. Navigation Setup:

- The bot is placed on a predefined starting point on the path marked with black tape on a white surface.
- Line-following IR sensors (connected to the Raspberry Pi) detect the path and guide the bot along the correct route.

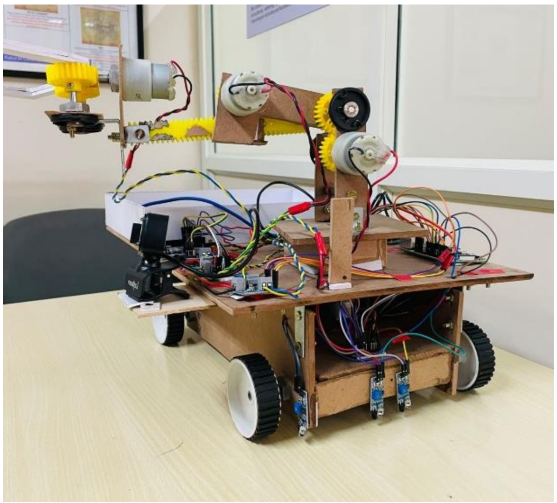

Figure 16: Sensor Placement in the Bot

4. Stopper Detection:

- As the bot follows the path, it encounters stopper points identified by another IR sensor.
- When the bot reaches a stopper, it halts and activates the webcam to scan the QR code placed at a height suitable for camera visibility (minimum 180mm).

5. QR Code Scanning:

- The webcam captures the QR code which contains the item information.
- The Raspberry Pi decodes the QR code to determine the item name.

6. Item Retrieval:

- The decoded item name is compared to the user-selected items.
- If there's a match, the Arduino Uno controls the robot arm:
    - Motor 1 rotates to position the arm correctly.
    - Motor 2 adjusts the arm vertically to reach the item.
    - Motor 3 moves the arm horizontally for accurate positioning.
    - Motor 4 activates the gripper to pick up the item.

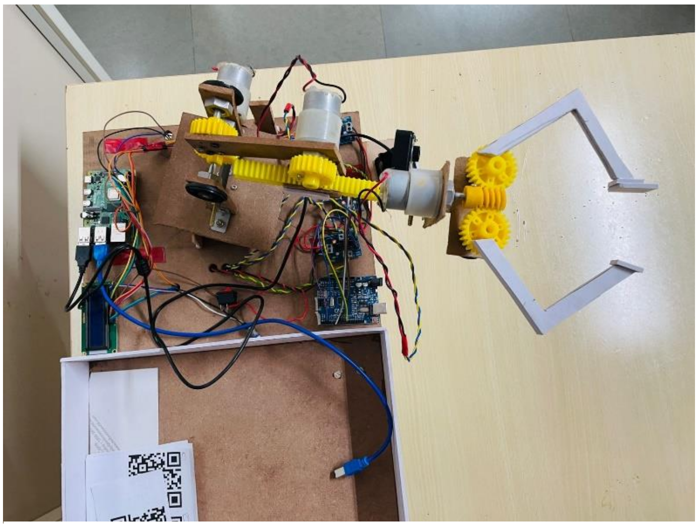

Figure 17: Gripper for item retrieval

7. Storage and Continuation:

- After picking up the item, the bot places it in the storage box located at the back of the bot.
- If the item doesn't match or is unavailable, the bot skips the item and proceeds to the next stopper point.

8. Completion and Final Destination:

- The bot continues along the path, stopping at each designated point to scan and collect items until all selected items are retrieved.
- Once all items are collected, the bot navigates to the endpoint without stopping at any additional stoppers.

9. Feedback and Confirmation:

- Throughout the process, the LCD display connected to the Raspberry Pi provides status updates and confirms actions taken by the bot.
- Users receive a completion message on the web interface once all items are successfully collected and the bot reaches the endpoint.

5. Results

The shopping bot project successfully bridged the gap between robotics, electronics, and web technologies, demonstrating their seamless integration to revolutionize retail operations. This innovative solution automates item collection through advanced robotics and intelligent navigation systems, ultimately enhancing efficiency, accuracy, and customer satisfaction in retail environments.

Key Achievements:

- **Autonomous Navigation Mastery:**

  The bot navigates with exceptional precision using line-following technology and IR sensors. This enables it to traverse designated paths, including curves and intersections, even under varying lighting conditions.

- **Swift and Accurate Item Recognition:**

  Equipped with a high-resolution webcam and powerful Raspberry Pi processing capabilities, the bot efficiently scans and decodes QR codes, facilitating rapid and accurate item identification.

- **Enhanced Workflow Efficiency:**

  The robust payload capacity of 7kg allows the bot to collect multiple items in a single run, significantly improving workflow efficiency and reducing overall retrieval time.

- **Precise Robotic Arm Control:**

  The Arduino Uno-controlled robotic arm offers a comprehensive range of functionalities, including rotation, vertical and horizontal motion, and gripper control. This allows for precise item retrieval and placement within designated storage areas.

- **Streamlined User Experience:**

  A user-friendly web interface empowers customers to browse, select, and purchase items with ease. Real-time order status and bot location updates are provided, ensuring transparency and enhancing the overall shopping experience.

These achievements demonstrate the shopping bot's potential to revolutionize retail operations. By laying the groundwork for future advancements in automated retail solutions, this project paves the way for a future of increased efficiency, accuracy, and a more customer-centric shopping experience.

Figure 18: Project Group Photo

6. Project Costing

The development of the shopping bot showcases the potential of robotics and web technology to transform retail. Project costing is essential, as it provides critical analysis of economic feasibility and investment requirements. This evaluation will ensure the project's long-term viability and pave the way for future optimizations within the realm of automated retail solutions.

Sl. No.	Part Name	Material	Quantity (no.)	Unit Cost (Rs)	Cost(Rs)
1.	IR Sensors	Electronic	3	70/-	210/-
2.	DC- Motors	Electronic	6	200/-	1200/-
3.	Raspberry Pi 4 Model B (Pi4B)	Electronic	1	6000/-	6000/-
4.	Web Cam	Electronic	1	1000/-	1000/-
5.	LCD Display	Electronic	1	350/-	350/-
6.	Motor Drivers(L293/D)	Electronic	3	250/-	750/-
7.	12V Battery	Electronic	1	750/-	750/-
8.	Arduino UNO	Electronic	1	450/-	450/-
9.	Cardboard	Cardboard	1	600/-	600/-
10.	12mm Wheels	Plastic	4	60/-	240/-
11.	Screw and nut	MS	10	20/-	200/-
12.	L-shaped metal support	Aluminium	4	40/-	160/-
13.	Miscellaneous	-	-	2000/-	2000/-
				Total	13910/-

7. Conclusions and Suggestions for Future Work

Conclusion

The development of the shopping bot prototype signifies a significant accomplishment, successfully achieving all project objectives. This innovative solution stands as a testament to the potential of robotics and web technologies to revolutionize the in-store shopping experience. By automating product retrieval and streamlining the checkout process, the shopping bot offers a glimpse into a future where customer convenience and efficiency reign supreme.

The core functionalities implemented within the prototype provide a springboard for further development. These functionalities include controlled environment navigation using line following sensors, product identification achieved through QR codes, and basic product manipulation with a robotic arm. This foundation paves the way for the creation of a more advanced shopping bot capable of seamlessly integrating into real-world retail settings.

Suggestions for Future Work

- **Advanced Navigation:** Integrating obstacle detection and avoidance using LiDAR or IR sensors would enable the bot to navigate real-world store environments with dynamic obstacles.
- **Enhanced Object Recognition:** Transitioning beyond QR codes to computer vision techniques would allow direct product identification, streamlining the process and enhancing user experience.
- **User Interaction and Mobile App:** Developing a user-friendly mobile app would facilitate customer interaction with the bot, allowing them to browse product selections and control its movements remotely.
- **Increased Payload and Dexterity:** As the bot evolves, increasing the payload capacity and incorporating a more sophisticated robotic arm would broaden the range of items it can handle.

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Link to the Codes Library

https://docs.google.com/document/d/1aok107mh_1FCVV1vEuwUN36ynzVetZkVJTUJSzqcjhU/edit?usp=sharing