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DESIGN AND DEVELOPMENT OF A SMART SHOPPING CART SYSTEM

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ABSTRACT
As population grows and society advances, shopping at the market place is taking a significant overturn with customers demanding a better shopping experience. This thesis discusses the design and development of a smart shopping cart system as a modern marketing infrastructure for the improvement of customer shopping experience. Shopping cart has been a tool used over the years in super markets and malls to pick-up purchased items while shopping, with recent researches advancing towards smart technologies. Several researches have shown that smart shopping carts does improve customer experience and affects purchase decisions at the market place. Contributing to this advancement, this work focused on the use of low-cost sensors and microcontroller technologies to develop a smart shopping cart system. These sensors include a barcode reader for item information acquisation, a loadcell for weight detection and measurement, an RFID card reader for secured payment system, and an LCD display for data presentation on the cart. Following a methodical engineering design approach, all sensing device modules were interfaced with a ESP32 microcontroller which run a control algorithm for the cart's operation. Operational test result of the smart shopping cart system prototype indicates that, items were duly identified and their stored information clearly presented. Items weight were detected and measured with difference greater than ±2% indicating purchase fraud (negative) or over payment (positive) by the customer. Instant payment for purchases at the cart were possible by swiping a pre-funded RFID card across the cart's RFID card reader.

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The retail industry is rapidly evolving with the emergence of new technologies and changing consumer behaviour. One of the key challenges faced by retailers today is how to reduce shopping time and present more purchase options to customers while also improving the operational efficiency of their stores. This has led to new demand for innovative solutions, to provide customers with a more convenient and efficient way to shop.

In recent years, there has been a growing demand for more efficient and convenient shopping experiences in shopping malls and supermarkets (Fan et al., 2013). With the advent of technology, manufacturers, retail shops and malls have been exploring innovative solutions to improve the overall shopping experience for customers (Joe, 2017). One such means is creating more user-friendly, less time-consuming, easy-to-use shopping carts.

Shopping carts in malls and supermarkets are moveable trolleys used by customers to transport selected goods temporarily before payment (AlHakmani & Sajan, 2020).

There has been a need to improve the current traditional shopping and billing methods used in shopping malls which are stressful, time-consuming, inefficient and prone to theft. The development of smart shopping carts could be the future solution for such common problems associated with shopping experiences in malls (Yi, 2014). This can be achieved by the application of modern technologies in microprocessor electronics, sensors, software, and data analytics to support and improve shopping for customers and retailers. These technologies would lead to advanced features that allow customers to add or remove items from their cart at ease, check prices and weight of items as they are added to the cart with automatic billing, letting the customer know the prices of the items purchased without having to go the counter or cashier for payment (Huang et al., 2019; Mohansai, 2021). This also helps the customer stay within his/her budget while shopping.

Since customers will pay for their purchases directly through the cart, customers' valuable time will be saved leading to an improved overall shopping experience.

This work seeks to eliminate challenges associated with traditional shopping carts by developing a smart shopping cart system for an effective and efficient shopping encounter for both the customer and the retailer. The smart shopping cart is a high-tech cart that utilizes sensors and software to detect and weigh items as they are added to the cart. The cart also displays the item names, prices, and the total cost of purchased items in real time. Additionally, the smart cart allows customers to pay for their purchases directly through the cart, eliminating the need for cashiers and streamlining the checkout process.

1.2 MOTIVATION

The motivation behind the smart shopping cart project is to address the challenges faced by retailers and provide a more efficient and convenient shopping experience for customers. By leveraging cutting-edge technologies in sensors, microcontroller electronics and data analytics, the smart shopping cart aims to transform the way people shop and enhance the overall retail experience.

The smart shopping cart also has the potential to benefit retailers by improving their operational efficiency. With the ability to accurately detect and weigh items, the smart cart can help retailers manage their inventory more effectively, reduce waste, and optimize their supply chain operations. Additionally, the smart shopping cart can help to reduce labour costs by eliminating the need for cashiers and other checkout staff (Kulkarni & Barbadekar, 2016).

The smart shopping cart project is also motivated by the increasing demand for contactless and self-service shopping experiences. The COVID-19 pandemic highlighted the importance of contactless shopping solutions (Balaji et al., 2019), and the smart shopping cart is a prime example of a technology that can help address this need. Overall, the smart shopping cart project is driven by the need to improve shopping for customers and enhance the operational efficiency of retailers. By leveraging advanced technologies and innovative solutions, the smart shopping cart has the potential to change the way people shop and set new standards for convenience and efficiency in the retail industry.

1.1 PROBLEM STATEMENT

Despite the advancements in technology and changes in consumer behaviour, the shopping experience at retail stores remains relatively unchanged (Srivastava et al., 2020). Cashiers still have to manually scan items in the cart to register prices and generate the bill at the checkout points (Pangasa & Chauhan, 2019). Customers still have to wait in long queues at checkouts, directly interact with cashiers to resolve purchases, and cannot do self-checkout to complete their purchased items. This traditional shopping process is time-consuming, inefficient, and can lead to frustration and dissatisfaction for customers (Jeyanthy et al., 2022). The process also puts a high staff load on the shop owner, while at the same time puts cashiers on stress edge.

1.2 AIM

The aim of this project is to design and develop a smart shopping cart system for improved shopping operations.

1.3 OBJECTIVE

Objectives of the project are to:

1. Design and build a prototype of the smart shopping cart system.
2. Accurately detect and weigh items with sensors as they are added to the cart.
3. Collect item data, display the item names, prices, and the total cost of the purchase in real-time.
4. Implementing a payment system that allows customers to pay for their purchases directly through the cart.
5. Ensuring the security and privacy of customer information by implementing a debit card payment system.
6. Conduct test with the smart cart prototype to ensure its reliability and functionality.

1.4 SCOPE AND LIMITATIONS

The scope of the smart shopping cart project includes the design and development of a prototype smart shopping cart that utilizes sensors, software, and data analytics to enhance the shopping experience for customers and improve the operational efficiency of retailers. The project will focus on the following key features and functionalities:

1. Accurate detection and weighing of items added to the cart.
2. Real-time display of item names, prices, total weight, expiring date and total cost.
3. Payment system that enables customers to pay directly from the cart.
4. Integration with an in-house inventory via wi-fi management system to optimize supply chain operations.

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1.5 SIGNIFICANCE OF THE PROJECT

The smart shopping cart project has several significant implications for both customers and retailers. The project aims to address some of the major challenges faced by both parties in the current shopping process, and to provide a more efficient, convenient, and satisfying experience for customers, while also improving the operational efficiency and profitability of retailers. Some of the key significances of this project are:

1. **Improved Shopping Experience:** The smart shopping cart will provide a more seamless and convenient shopping process for customers, eliminating the need to wait in long checkout lines, making shopping more enjoyable and increasing the likelihood of increased patronage.
2. **Enhanced Operational Efficiency:** The smart shopping cart allows retailers to optimize their supply chain operations by providing real-time data on inventory levels and able to see costumers purchasing patterns. This enables them to better manage their inventory, reduce waste, and improve overall operational efficiency, resulting in lower costs and higher profits.
3. **Increased Sales:** By providing customers with real-time pricing information and a more enjoyable shopping experience, the smart shopping cart has the potential to increase sales and revenue for retailers because of the easy and convenience people feel while doing their shopping.
4. **Environmentally Friendly:** The use of a smart shopping cart can potentially reduce the use of paper receipts, stamps and other single-use items (paper spools), resulting in a more environmentally friendly shopping experience.

LITERATURE REVIEW

Smart shopping carts are a recent development in the retail industry that utilizes advanced technologies in microelectronics, sensors, and data analytics to enhance the shopping experience of customers and improve the operational efficiency of retailers (Ughade *et al*., 2022). According to recent studies, the global smart shopping cart market is expected to grow from $388 million in 2020 to $1.2 billion by 2025, with a compound annual growth rate of 25.2% (Benjamin, 2020)

Smart shopping carts offer several key benefits over traditional shopping carts, including the ability to automatically detect and weigh items (Rani *et al*., 2024), display real-time pricing information (Syahmie *et al*., 2022), and enable customers to pay directly through the cart (Laxm *et al*., 2018). This reduces the need for customers to interact with cashiers or self-checkout machines, saving time and reducing frustration (Ayoola *et al*., 2019). Smart shopping carts can also help retailers optimize their supply chain operations by providing real-time data on inventory levels and purchasing patterns (Kulkarni *et al*., 2022).

The barcode scanner technology is a key component of smart shopping carts, enabling the cart to automatically detect and identify items as they are added to the cart (Ali & Sonkusare, 2013). The scanners are small devices that contain sensors and lights that enable the device to scan and identify Barcodes and QR codes attached to products (Patel *et al*., 2017). When a product with a barcode or QR code is brought close to a scanner, it scans and detects the code and transmits the detected code to the microcontroller that uses the software in the system program, to identify the product, weight, price, numbers of items in the cart and updates the cart's inventory and other information that are displayed on the display.

2.1 STATE-OF-THE-ART LITERATURE REVIEW

Several smart shopping cart systems have been developed, integrating RFID, barcode scanning, wireless communication, and IoT technologies to enhance shopping experiences.

Wireless Sensor Networks (WSN) and Navigation-Based Smart Carts

- Gangwa et al. (2013) implemented a WSN-based cart to reduce waiting time and detect fraud, but it retains manual payment at the counter.
- Narula et al. (2014) introduced a cart with an Indoor Positioning System (IPS) to navigate product locations, though it lacks pricing details.

RFID and Bluetooth-Based Smart Carts

- Unde et al. (2015) developed an RFID and Bluetooth-based system where pricing data is sent to a central billing system via Bluetooth, reducing queue time.

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- Yewatkar et al. (2016) designed a ZigBee and RFID-based cart that recommends products based on purchase history but lacks automatic payment.
- Chaudhari et al. (2016) integrated RFID-based automatic billing, but customers must still queue for payment.

Barcode and IoT-Based Shopping Carts

- Viswanadha et al. (2018) designed a barcode scanner and touchscreen display system with online payment options, though anti-theft measures were lacking.
- Aslam et al. (2020) proposed an RFID-based IoT cart displaying item details, but checkout queues remain necessary.

RFID, AI, and Mobile-Integrated Carts

- AlHakmani & Sajan (2020) introduced a remote-controlled trolley with RFID-based item detection, helping customers stay within budget via an alarm system.
- Chandan et al. (2020) used RFID and Raspberry Pi for automated billing, but manual payment was still required.
- Martinus et al. (2021) developed a dual-app-based RFID smart cart, though it remained a simulation model.
- Swetha et al. (2021) implemented an IoT-based RFID cart with Wi-Fi and a mobile app, though payment still required a cashier visit.
- Pallavi et al. (2022) introduced a QR code-based smart cart using ESP32 CAM and Arduino, where a mobile app handles total billing.

While various smart cart designs enhance checkout speed, item identification, and fraud detection, many still require cashier interaction for payment. RFID, IoT, and AI-driven carts remain the most effective solutions, but fully automated checkout systems remain an area for improvement.
A summary of existing work showing the technology used, application area, advantages and drawbacks are provided in Table 2.1.

Table2.1: Summary of existing works

S/N	**Author**	**Technology in use**	**Application area**	**Advantages**	**Drawback**
1.	Gangwa *et al.*, (2013)	WSN	Supermarket	Fraudulent activity can be detected	Payment is not automatic.
2.	Narula *et al.*, (2014)	IPS	Supermarket	Saves time in navigating through products	Product details are not known. Payment is not automatic.
3.	Unde *et al.*, (2015)	RFID, Bluetooth	Supermarket	The total cost of items in the cart can be automatically calculated.	Payment is not automatic.
4.	Chaudhari *et al.*, (2016)	RFID	Supermarket	Product information is easily scanned	It is time-consuming. Payment is not automatic.
5.	Yewatkar *et al.*, (2016)	RFID, ZigBee	Supermarket	Product recommendation is made	Payment is not automatic and it is time-consuming.
6.	Viswanadha *et al.*, (2018)	Barcode scanner	Supermarket	Payment can be made online	Prone to theft
7.	Aslam *et al.*, (2020)	IOT, RFID	supermarket	Item information can be known on the mobile app before shopping	It is time-consuming. Payment is not automatic.

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8.	AlHakmani & Sajan, (2020)	RFID	Supermarket	It reduces interaction time between customer and cashier. The purchase budget can be programmed to avoid overspending.	Payment is not automatic.
9.	Chandan *et al.*, (2020)	RFID, Raspberry Pi	Supermarket	Automatic billing is available.	Payment will still have to be made at the counter.
10.	Martinus *et al.*, (2021)	RFID, Visual Studio (VS) Code, Flutter, PostgreSQL and REST	Supermarket	Automatic billing is available.	Payment is not automatic.
11.	Swetha *et al.*, (2021)	IoT, RFID	supermarket	Product information is known and selected before the actual shopping	Payment is not automatic.
12.	Pallavi *et al.*, (2022)	QR Code, Esp32 CAM	Supermarket	Automatic billing is made	Payment is made over the counter.

METHODOLOGY AND SYSTEM DESIGN
3.1 METHODOLOGY
The smart shopping cart system was developed using a bottom-up engineering approach, addressing identified drawbacks in existing solutions. The system aims to automatically identify items, detect fraud, bill customers directly, and process payments without requiring a cashier visit.
System Architecture
The design was modular, initially developing individual components before integrating them into a complete system, comprising:

- Hardware Components:
    - Weight sensing unit (fraud detection)
    - Barcode reader (item identification)
    - RFID reader (tag detection and payments)
    - Alphanumeric display (user interface)
    - Wi-Fi module (server communication)
- Software Components:
    - Algorithms for hardware integration
    - Inventory management system
    - Payment processing system

The hardware and software components collectively form a functional smart cart architecture, ensuring seamless automation and user convenience.
3.2 SYSTEM ARCHITECTURE
The system architecture, as shown in Figure 3.1, is a black box comprising the hardware and software sub-systems. The hardware includes the input/output systems and the central processing unit in which the software runs.

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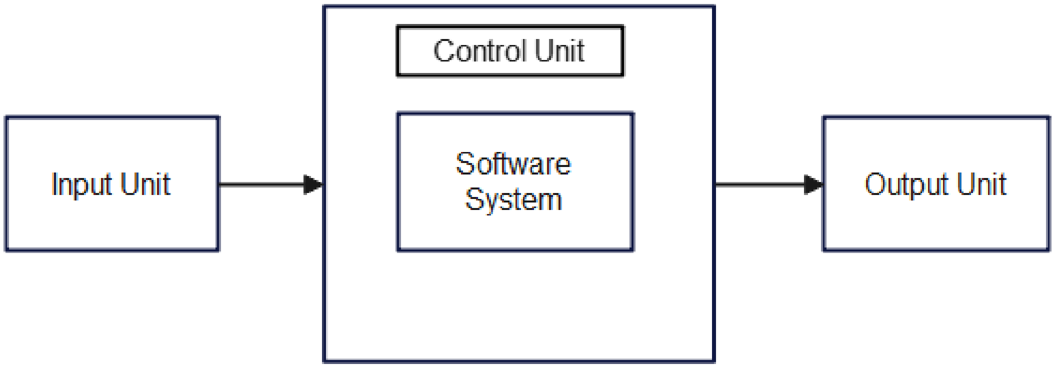

Figure 3.1: System architecture

The input subsystem is responsible for reacting and reading users' actions and presenting them to the control unit for processing. The control unit is a microprocessor-based control system that acts on some predefined instructions (program) to process received input information for presentation at the output. The output subsystem comprises displays and a wireless communication interface to a remote central computer system for information dissemination.

3.3 **The Design Process**

Any design process comprises a basic sequence of tasks that are performed in various situations. This sequence is presented in Figure 3.2.

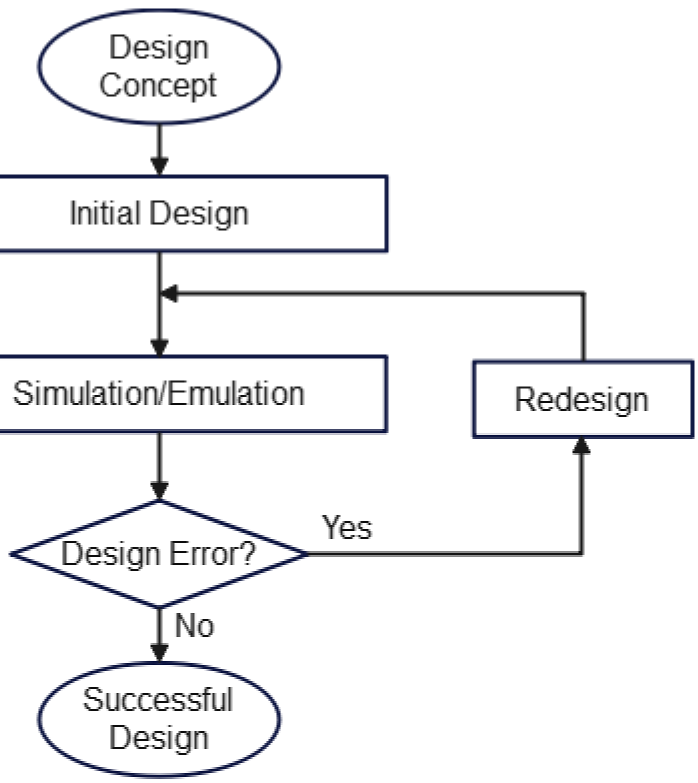

Figure 3.2: The design process loop

The design process begins with an initial concept, translating into a preliminary design based on the designer's expertise and intuition. This stage demands manual effort as each design is goal-specific and must align with functional requirements.

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Simulation and Emulation Phase

To validate the design, simulation/emulation tools are employed, requiring adequate input conditions for testing. The simulator verifies functionality, ensuring the design meets specifications.

If errors are detected, modifications are made, and the redesigned version undergoes further simulations. This iterative process continues until the design performs correctly. Detecting and correcting errors early during simulation is crucial, as late-stage fixes are costly and time-consuming. However, some undetected issues may still emerge in later development phases, requiring additional refinements.

3.4 SYSTEM REQUIREMENT ANALYSIS

Designing an electronic system with a microcontroller requires careful planning, circuit design, PCB layout, and software development. Ensuring all design activities align with user specifications is essential.

A collaborative design approach within a team helps address challenges. Even with careful execution, initial designs may not always succeed, necessitating prototyping, experiments, and laboratory testing to eliminate errors. Hardware construction is typically straightforward, but software development often encounters frequent issues. The first software version is rarely final, requiring debugging and optimization.

To reduce errors and accelerate development, various design tools and testing methods are employed. Digital system designers face two key challenges:

1. Analysis Process – Determining the function of an existing logic network.
2. Synthesis Process – Designing a new network for a desired function.

This project focuses on the analysis process, ensuring the correct functionality of the smart cart system.

The smart cart design utilizes predefined logic networks with existing logic devices, ensuring efficient data processing and automation.

1. Input Subsystem

Data entry is facilitated through a matrix numeric keypad and/or keyboard, allowing multiple selections and user interactions.

2. Output Subsystem

An alphanumeric and/or graphical display provides users with real-time feedback, showing selected functions, item details, and transaction statuses.

3. Item Identification

To identify selected items, a barcode reader and RFID tag scanner retrieve product specifications. This ensures accurate item recognition and seamless inventory management.

4. RFID-Based Payment System

To eliminate checkout queues, customers use RFID payment cards, allowing direct cart-based payments without cashier interaction. An RFID card reader processes transactions securely.

5. Load Cell for Weight Verification

A load cell weight sensor detects added or removed items, comparing recorded weights against stored values to prevent fraud or miscalculations.

6. Control Subsystem and Microcontroller

The control unit requires a high-speed microcontroller with large memory capacity for code execution, data storage, and real-time processing. It must support future software updates and synchronize with multiple peripheral devices.

7. Embedded Software Development

The microcontroller firmware is developed using embedded programming languages like Assembly or C, compiled into hex or binary code for execution. This ensures optimized system control and efficient data handling.

3.5 HARDWARE SUBSYSTEM DESIGN

Following the system requirements, Figure 3.3 further breaks down the black box to reveal detailed component units of the system. As required, a keypad is needed to manually enter item details into the cart and also to search for items by customers. A barcode detection/reading system is needed to detect and read item specifications such as item price, item weight, item expiration data, and so on. A weight detection/measurement system is used to know when items are added or removed from the cart by constantly monitoring the basket weight. This way, items added to the cart basket or removed from the cart without scanning can be detected. When detected, this can help alert customers of their actions through an alarm/display system and as well report fraudulent customer behaviour to the cashier when such actions are not reversed.

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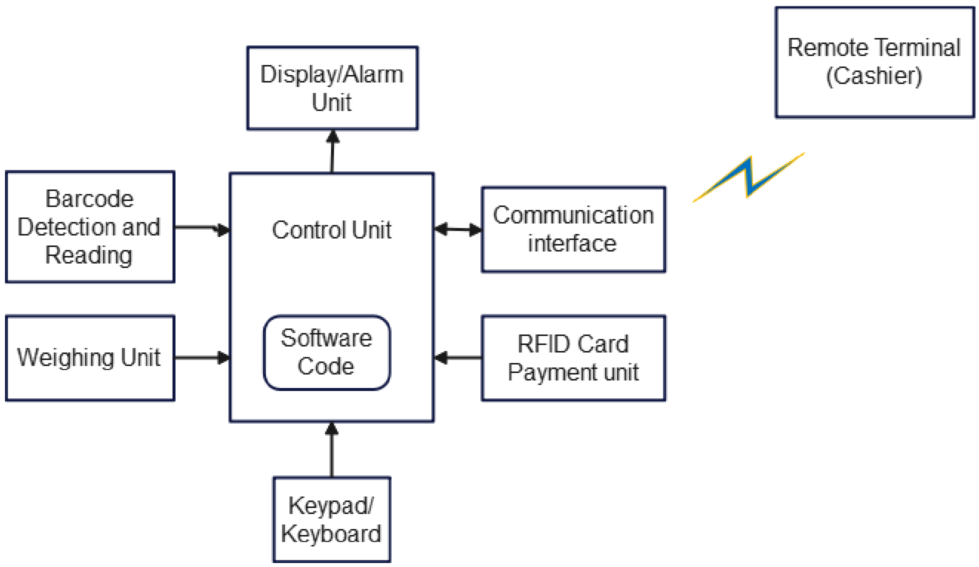

Figure 3.3: Expanded system architecture block

To facilitate seamless payments, an RFID-based debit card system is integrated. Customers acquire and fund an RFID card, enabling cashier-less payments. An RFID card reader attached to the cart processes transactions securely.

Display and Alarm System

The display unit provides real-time feedback on user actions, item selection, and payment confirmation. The alarm system alerts users to errors, unauthorized actions, or incorrect selections, enhancing operational reliability.

Communication Interface

A wireless communication interface links the cart to the cashier server, ensuring real-time updates on item selection and transactions. The cart downloads store item information upon activation, allowing continuous synchronization with the store's central system.

Control Unit and Remote Server

A microcontroller-based control unit coordinates all system functions, processing signals from sensors, payment modules, and the communication interface. At the cashier's end, a remote server or personal computer receives and manages all store operations, enabling carts to access and update product data efficiently. The details of these sub-systems are further discussed thus:

3.5.1 Keypad/Keyboard Unit

The keypad (Keyboard) is a data-entering unit that forms part of the Human-Machine (HMI) interface. There are several types of keypads two of which are needed here. A standard computer keyboard is required for administrative item data and information entry. This is connected to the system through a detachable USB interface. However, a basic numeric keypad with a second function will be adequate for customer operations. This is attached and connected permanently to the system for the user interface.

With sequential logic, keypads do require special circuitry to acquire button press signals. Such circuitry is necessary to remove ripples, generated as a result of the mechanical button depressions, from the actual signals. On the other hand, with programmable systems, the keypad does not require any special circuitry interface with the processing systems. In this case, ripples are easily removed from the generated signal through the application of software delays in a process called debouncing. Standard keyboards, however, come with already decoded ASCII codes that are readily compatible with software processing.

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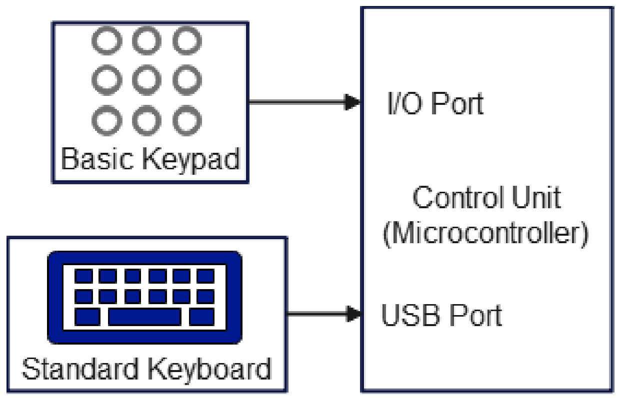


Figure 3.4: Keypad/keyboard interface to control unit

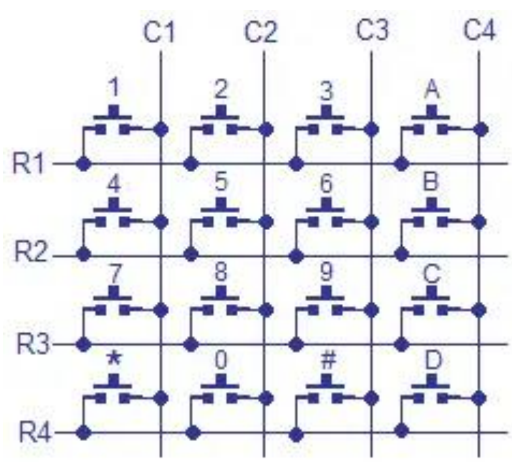
3.5.1.1 Keypad/Keyboard Specification and Circuit Design

The specifications for the keypad are stated in Table 3.1 and help define the various interface requirements for the control system.

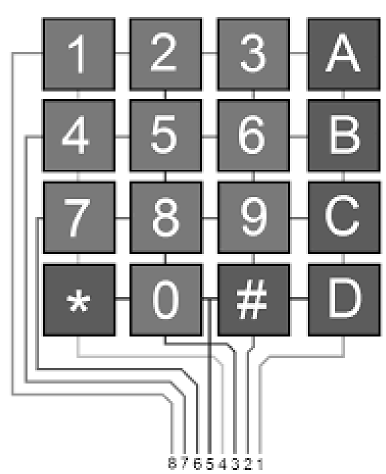
Table 3.1: Keypad/keyboard specification

Specifications	Keypad	Keyboard
Number of characters	16 keys (0 to 9, *, #, A to D)	Standard alphanumeric computer keyboard typically with 101-104 keys
Data format	Text	ASCII
Interface	8 Input/Output pins	USB port

Keypads and keyboards are a matrix formation of non-contact wires and press-to-make buttons at various intersections as shown in Figures 3.5a, 3.5b and Figure 3.6. These matrices form rows and column interface wires with which they can be connected to interfacing circuitry. While the keyboard is designed with a special circuit (chip) that converts any key depression to its ASCII code equivalent, the keypad generates data bits depending on the designer's configuration which can be encoded to some binary pattern or read and interpreted in software.



(a)



(b)

Figure 3.5: Keypad matrix representations

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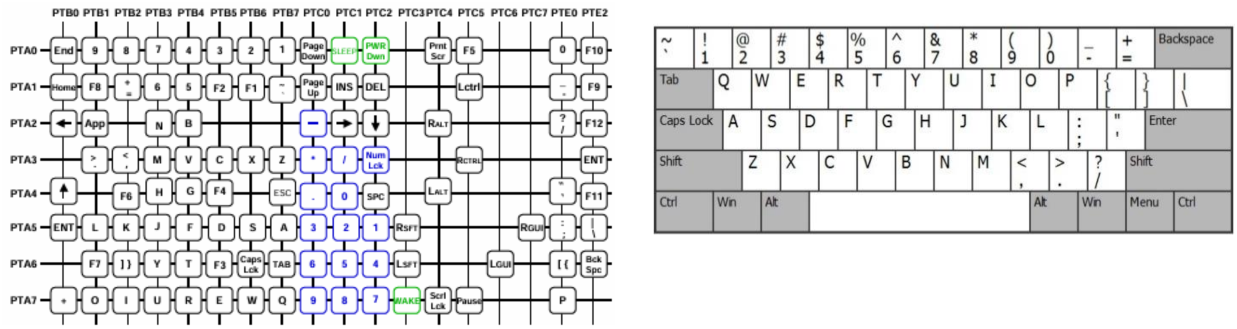

Figure 3.6: Standard PS/2 keyboard

The keypad interfaces with the microcontroller via selected I/O pins, while the keyboard connects via a USB port. If the microcontroller lacks USB input, a USB-to-protocol converter is required. Standard USB/PS2 keyboards can be integrated using minimal coding (Figure 3.7 shows the circuit interface).

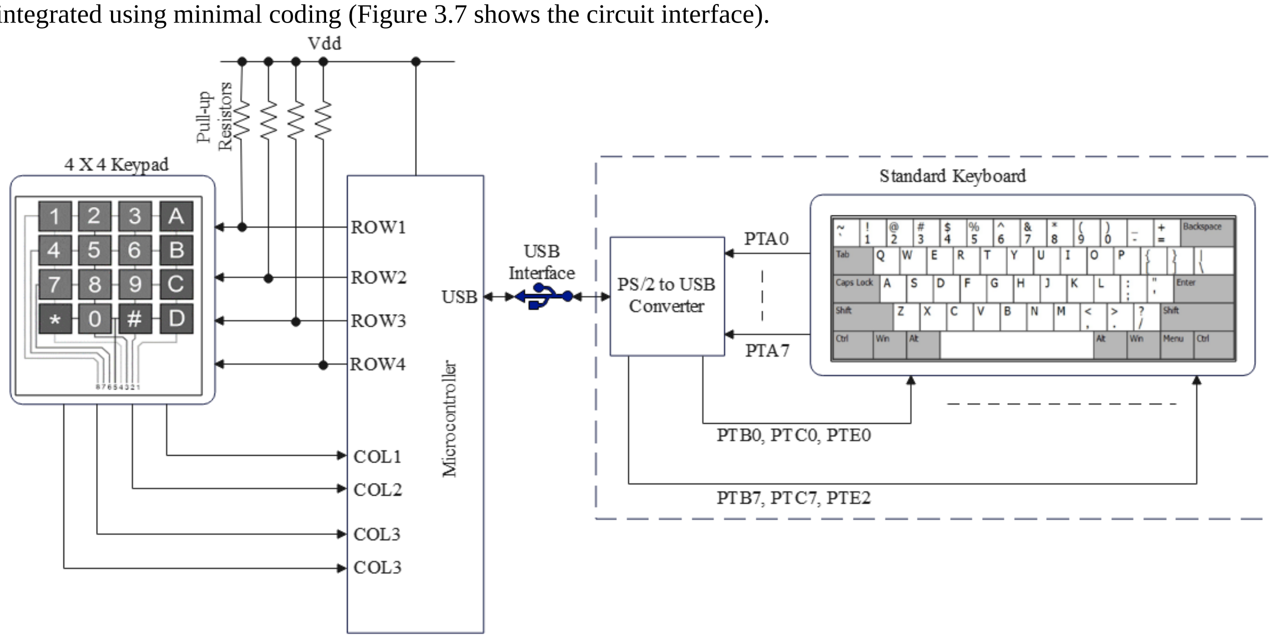

Figure 3.7: Circuit interface of keypad and keyboard to control unit

By design recommendation, the pull-up resistors should be in the range of 3.3kΩ—6.7kΩ.

3.5.2 Barcode Detection and Reading Unit

Barcodes have long been used for product identification, with two primary categories:

- One-Dimensional (1D) Barcodes: Represent data using parallel lines with varying widths and spacings. Common examples include UPC, EAN, and ISBN codes, widely used in retail.
- Two-Dimensional (2D) Barcodes: Encode data in both horizontal and vertical axes, allowing higher data density. Examples include QR codes and PDF417.

As shown in Figure 3.8, around 30 barcode types exist, with UPC-A, EAN-13, CODE-93, GS1 DataBar, and QR Code being the most common in retail applications.

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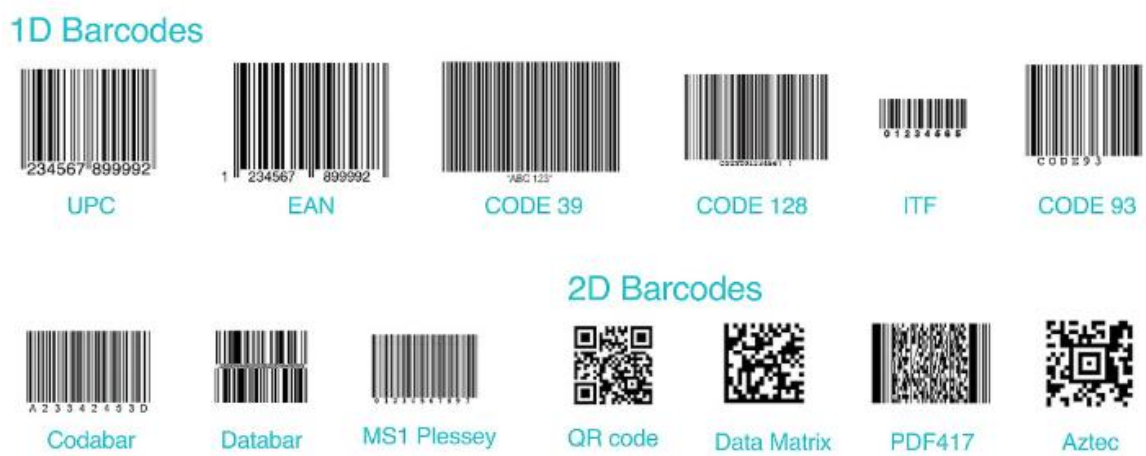

Figure 3.8: Types of barcodes

A barcode reader detects and decodes barcode symbols for item identification in a cart system. It consists of a light source, mirror, and light sensor, converting optical signals into electrical data for processing. The decoder translates barcode patterns into a human-readable format for data manipulation.

Types of Barcode Scanners

- Pen-Type Reader: Uses LED light and a photodiode to scan barcodes by direct contact.
- Laser-Type Scanner: Similar to the pen type, but with a laser beam for higher accuracy.
- Charge Coupled Device (CCD) Scanner: Captures barcode images like a digital camera, eliminating the need for a light source.

Regardless of type, an interface signal conditioning circuit ensures seamless integration with the processing unit (Figure 3.9).

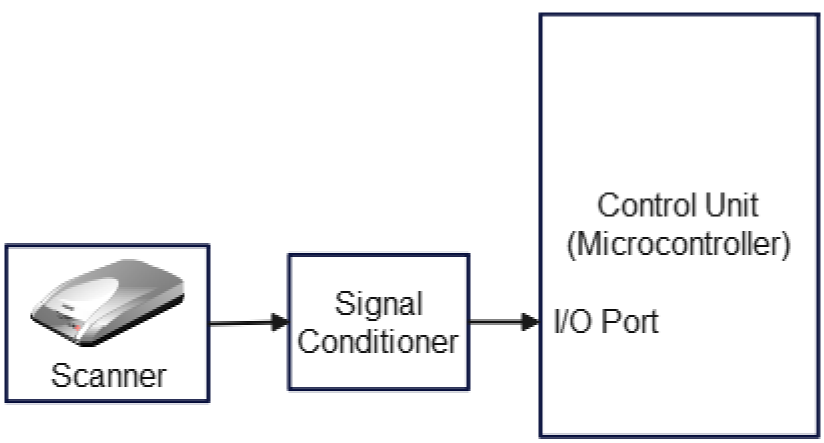

Figure 3.9: Barcode reader interface to control unit

Barcode scanners exist in various types, including handheld, fixed-mount, wireless, mobile, and long-range scanners. Selection criteria include scan rate, resolution, depth of field, interface options, durability, power source, and symbology support (QR code, UPC, EAN, etc.).

The GM805 barcode reader is chosen for its efficient scanning capabilities and UART, I2C, SPI, USB interface compatibility (Table 3.2, Figure 3.10).

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Table 3.2: GM805barcode reader specification

Parameter	Specification
Scan Mode	640*480
Lighting	White LED
Read Code Type	1D: EAN-13, EAN-8, UPC-A, UPC-E ISSN, ISBN, CodaBar,Code 128, Code93, ITF-14, ITF-6, Interleaved 2 of 5, Industrial 2 of 5, Matrix 2 of 5, Code 39,Code 11, MSI-Plessey, GS1 Composite,GS1-Databar (RSS)
	2D: QR Code, Data Matrix, PDF417
Reading Distance	5-30cm
Contrast"	>25%
Scan Angle"*	Roll: 360° Pitch: 65° Yaw: 65°
Viewing Angle	67° (Horizontal) 53° (Vertical)
Interface	TTL-232/USB
Operating Voltage	5V
Operation Current	70mA(Max)
Standby Current	6mA(Typical)

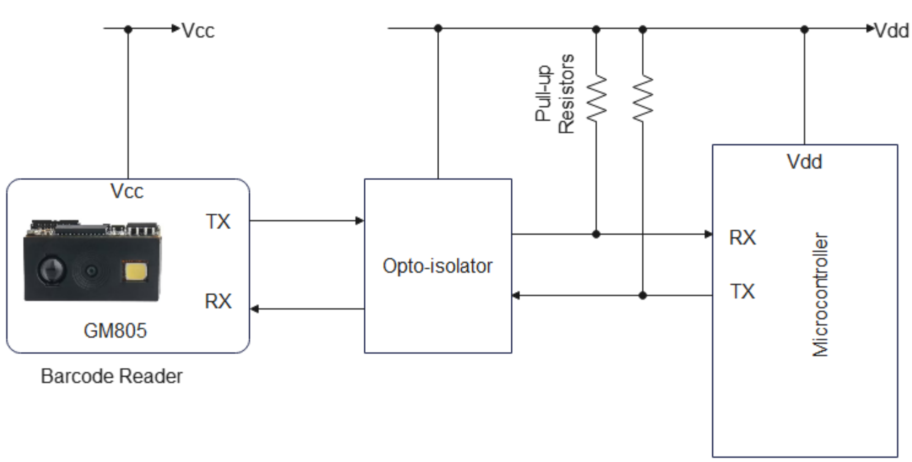

Figure 3.10: Barcode reader to microcontroller interface circuit

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This work utilizes the UART interface, with an opto-isolator to prevent signal loss and voltage mismatch between the 5V barcode reader and 3.3V microcontroller. Pull-up resistors range 3.3kΩ–6.7kΩ.

3.5.3 Weighing Unit

In a cart system, it is desired that the weight of items dropped in the basket is known. The measured item weight will then be compared with the item weight description read from the barcode for confirmation. However, if the basket weight increases without an equivalent item scan, an abnormal customer action or fraud may be detected. To detect and measure the item's weight, a weight sensor is required. There are several weight sensors in use but the most common and accurate is the loadcell. Loadcells are either pneumatic, hydraulic, or strain gauge type. For retail applications such as the smart shopping cart, the strain gauge loadcell is most suitable. The strain gauge loadcell, like every other loadcell, converts a mechanical force (weight) to an electrical voltage level. The voltage signal is passed through signal conditioning (noise removal and signal amplification) and digitized for processing in a control unit as illustrated in Figure 3.11.

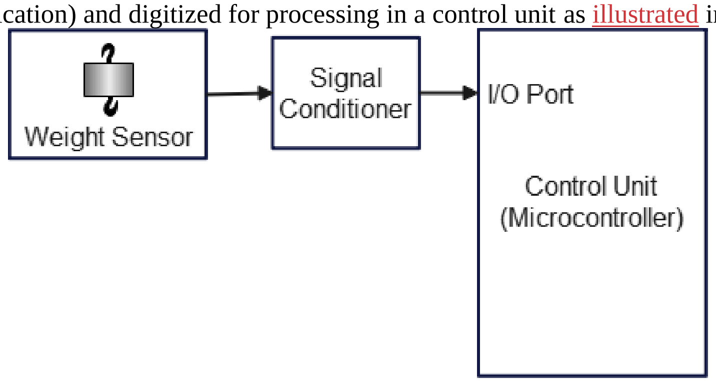

Figure 3.11: Weight sensor interface to control unit

Weighing Unit Specification and Circuit Design

The weight sensor for the smart cart system must support a 10g–100kg measuring range, 75–90% accuracy, 1-3 ±10% mV/V resolution, and ±0.03% linearity error. It should ensure good repeatability and resist temperature and humidity variations.

The HX711 load cell amplifier (Sparkfun Electronics) is selected for its 24-bit ADC precision and direct bridge sensor interface. Features include:

- Two differential input channels
- Low-noise PGA with 32, 64, or 128 gain selection
- On-chip power regulator
- 10SPS or 80SPS selectable output rates
- 2.6–5.5V operation voltage
- -40°C to +85°C temperature range

Figure 3.12 illustrates the HX711 microcontroller interface, ensuring accurate weight measurement in the smart cart system.

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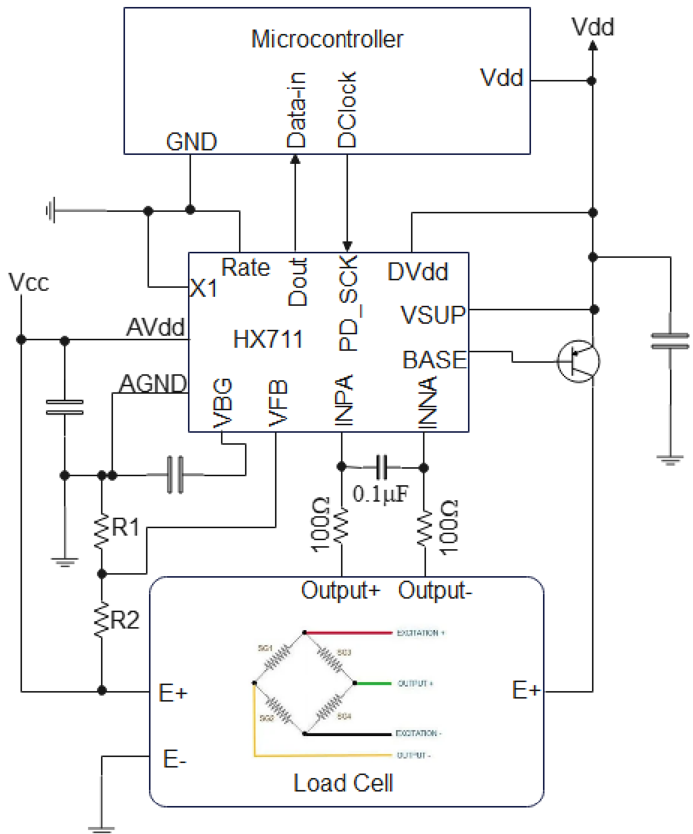

Figure 3.12: Loadcell to microcontroller interface circuit

3.5.4 RFID Card Payment Unit

Payment for item purchases at the store can be made in several ways including cash payment, bank transfer, online debit card, Point-of-Sale (POS) withdrawal, and so on. Many of these payment modes have one challenge or the other, especially from their reliance on third-party network services. One of the methods that could be harnessed in a smart shopping application is using an RFID card for a customised private user account. This account created by the store for users, enables customers to fund their assigned RFID cards before shopping.

RFID as a data communication technology has been used in several industries for item tagging, access control, etc. As a technology, RFID uses a card (transponder) which holds specific operational information, and a card reader (transceiver) which transfers data to the card or receives information from the card. This information coded in radio frequencies is communicated through an antenna attached to the transponder and the transceiver. As indicated in Figure 3.13, the transceiver consists of the antenna and other communication components that help communicate data, clock, and power with the transponder.

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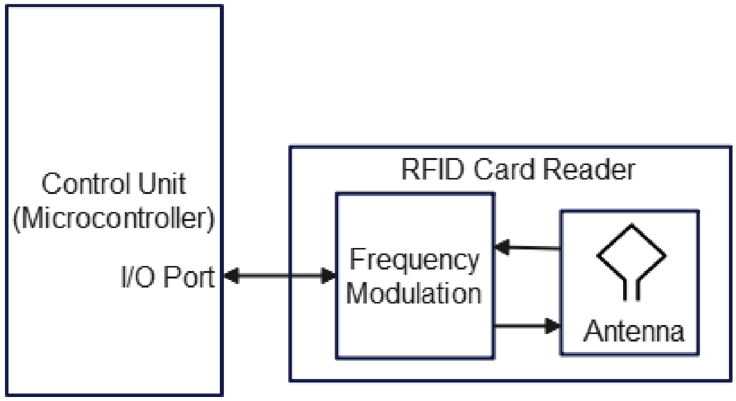

Figure 3.13: RFID card reader to control unit interface

3.5.4.1 RFID Card Reader Interface Circuit Design

Several RFID card reader chips are available today, each conforming to certain interface protocol specifications for different microprocessor devices. The MFRC522 RFID contactless card reader/writer chip was chosen for this design. The MFRC522 is a highly integrated reader/writer IC for contactless communication at 13.56 MHz with several interface specifications, as abbreviated in Table 3.3.

Table 3.3: MFRC522 parametric specification

Parameter	Specification
Interface Support	I2C, UART, SPI
Power supply voltage	2.5 V to 3.3 V
Maximum power-down current (I_{pd})	10
Digital supply current (I_{ddD})	9mA
Analogue supply current (I_{ddA})	10mA

This design used the I^2C communication interface to enable a low-cost, low-pin count serial bus interconnection with a general onboard I^2C bus. Figure 3.14 shows the circuit interface of the MFRC522 with the microcontroller unit. By design recommendation, the pull-up resistors should be in the range of 3.3kΩ—6.7kΩ.

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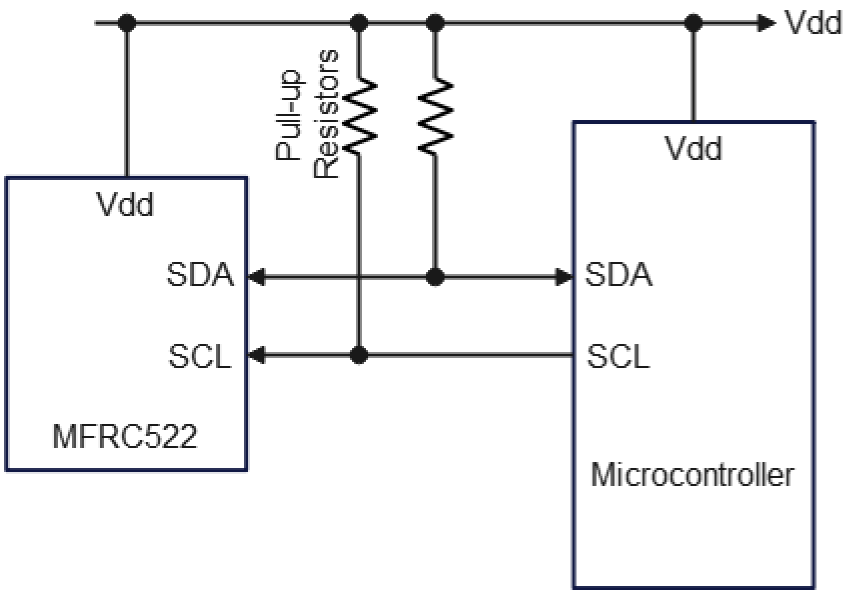

Figure 3.14: MFRC522 I²C interface to Control Unit

Figure 3.15 indicates the full circuit configuration and integration of the MFRC522 to a microprocessor-based system.

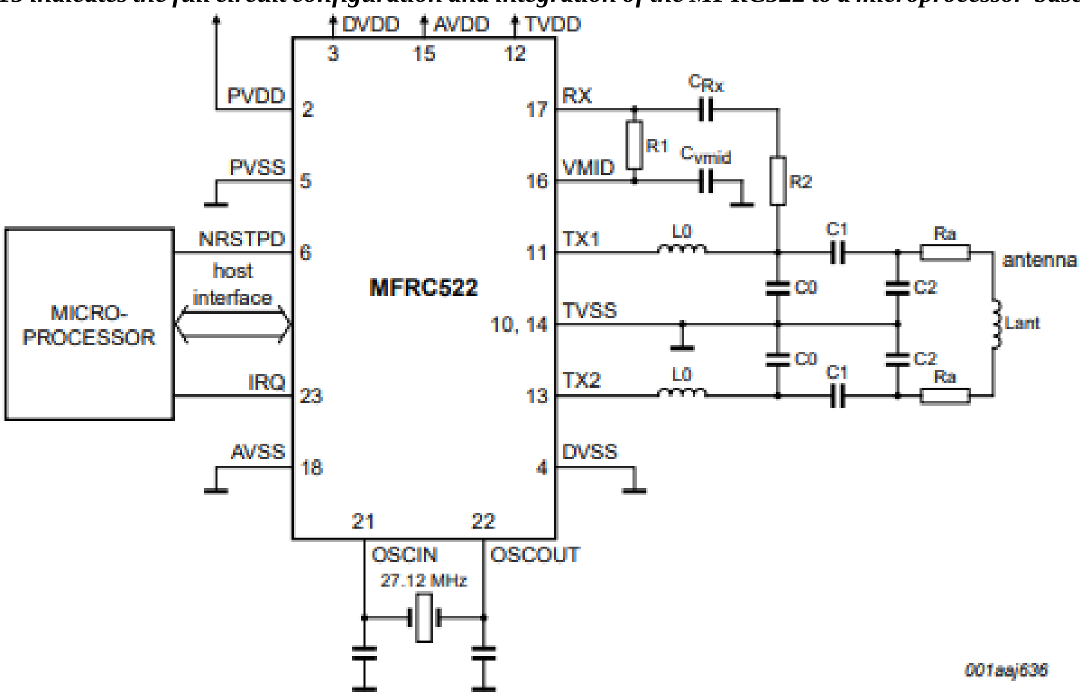

Figure 3.15: MFRC522 RFID card reader circuit interface (NXP Semiconductors)

3.5.5 Display/Alarm Unit

A typical smart cart system will have a display unit with which the user can visually observe the results of actions taken and read instructions regarding operational command options. There are several ways to visually present information

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ranging from simple light indicators to graphical representation. The most commonly used of these display options is the alphanumeric Liquid Crystal Display (LCD) which can present numbers and characters in ASCII representation format. As shown in Figure 3.16, the display unit can connect through a signal driver to the control unit. The driver will usually implement a communication protocol that allows the control unit to access the display system at an increased speed and reduced wiring space.

Aside from visual information presentation, the cart system must draw the customer's attention to read and follow instructions displayed whenever a wrong action is initiated. Therefore, an alarm is required to complement the visual indication, as presented in Figure 3.16.

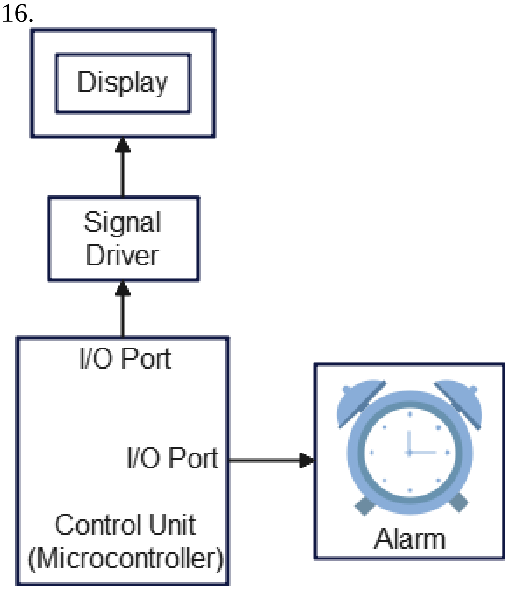

Figure 3.16: Display/Alarm to control unit interface

3.5.5.1 Display and Alarm Circuit Design

This design used a 20-character by 4-line Liquid Crystal Display (LCD) with an I^2C interface module consisting of an on-board contrast control adjustment and backlight. The I^2C Serial LCD module simplifies the circuit connection by significantly reducing the physical wire connections required to drive the LCD. This is achieved by interfacing an I^2C-to-parallel drive conversion module between the LCD and the microcontroller as shown in Figure 3.17. Several LCDs fitted with I^2C conversion modules are now readily available for direct I^2C connection to the microcontroller I^2C bus.

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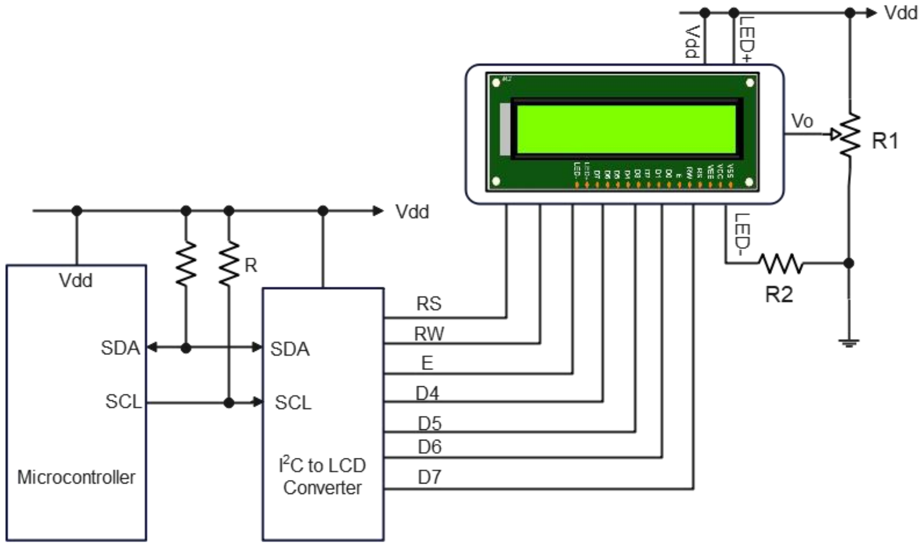

Figure 3.17: Display interface circuit

By design recommendation, the pull-up resistors (R) should be in the range of 3.3kΩ—6.7kΩ, R1=10kΩ, and R2 = 100Ω. The alarm unit consists of a simple buzzer connected directly or through a transistor to any of the digital I/O pins of the microcontroller. Here, a connection through a transistor was used as indicated in Figure 3.18 through a 5V (Vcc) supply line of the system.

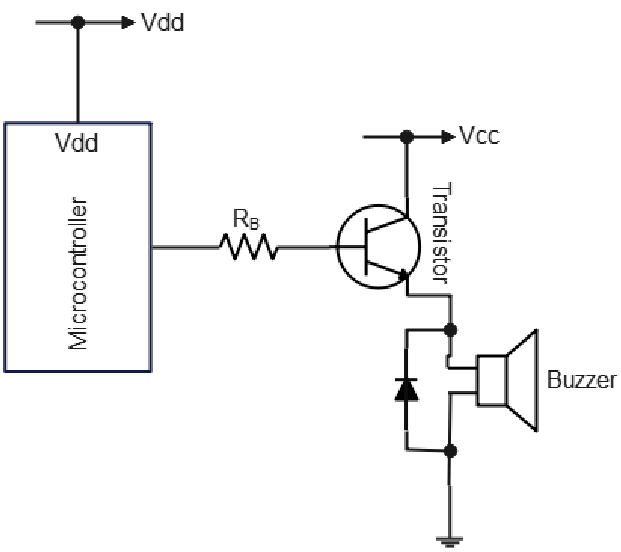

Figure 3.18: Alarm interface circuit

Using Equation (3.1) and the BC377 transistor, the value of R_B can be found as:

$$V_o = I_B R_B + V_{BE} + I_B r_b \quad (1)$$

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$$R_B = \frac{V_o - V_{BE} - I_B r_b}{I_B}$$

V_o = controller pin output voltage = 3.3V
I_B = Transistor base current = 1mA
R_B = Base resistance = ?
VBE = Base-Emitter voltage = 0.7V (silicon transistor)
r_b = Buzzer resistance (typical) = 12Ω

$$R_B = \frac{3.3 - 0.7 - 0.001 \times 12}{0.001} = 2.588k\Omega$$

The preferred practical value is 3kΩ

3.5.6 Communication Unit

The smart cart system requires a wireless communication link for item retrieval and transaction processing with the cashier server system. Since the cart is mobile, wireless connectivity is essential. Various protocols, including Bluetooth, Wi-Fi, ZigBee, LoRa, and GSM, offer different communication ranges and features.

For indoor use, ZigBee's range is too short, while long-range technologies like LoRa and GSM are unnecessary. Wi-Fi (IEEE 802.11) is the optimal choice, offering adequate coverage, low latency, and strong interference resistance within an enclosed retail environment. Numerous Wi-Fi-compatible chips integrate seamlessly with microcontrollers, ensuring reliable data transmission (Figure 3.19).

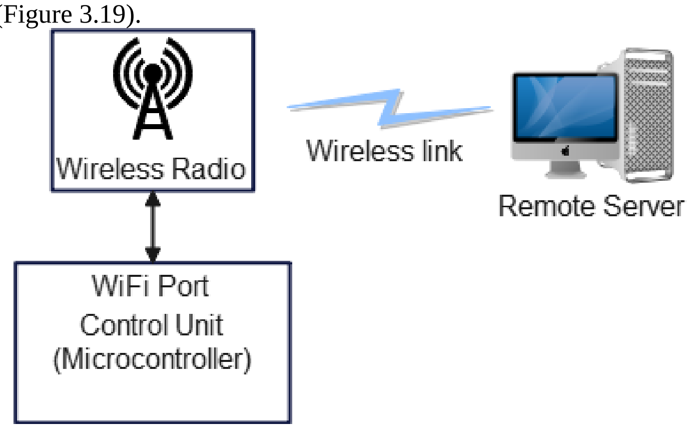

Figure 3.19: Wireless radio to control unit interface

3.5.6.1 Communication Interface Circuit Design

The communication interface circuit consists of a WiFi chip embedded in the microcontroller. The link only requires a setup and configuration for the establishment of communication with other WiFi devices.

3.5.7 Control Unit

The control unit is the core of the smart cart system, interfacing with all components and executing data processing and functional control. Various technologies exist, but an embedded microprocessor-based system is the most suitable. The microcontroller must support multiple communication protocols (UART, SPI, I2C), include analog and digital interfaces, and have sufficient internal or external memory for code storage and real-time data processing, ensuring seamless system operation.

3.5.7.1 Control Circuit

The microcontroller serves as the central control unit for the smart cart system, requiring high-speed processing, sufficient RAM for data handling, and ROM for code storage. It must support communication protocols like UART, SPI, and I2C, feature multiple I/O channels, and operate within 5μA to 50mA current consumption at 3.5V–5V. Additionally, built-in Wi-Fi and Bluetooth capabilities are essential for wireless connectivity.

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Among available options, the ESP32 microcontroller, developed by Espressif Systems, meets these specifications. It offers dual-core processing, low power consumption, integrated wireless communication, and extensive peripheral support, making it ideal for real-time data processing in smart cart applications (Figure 3.20, Table 3.4).

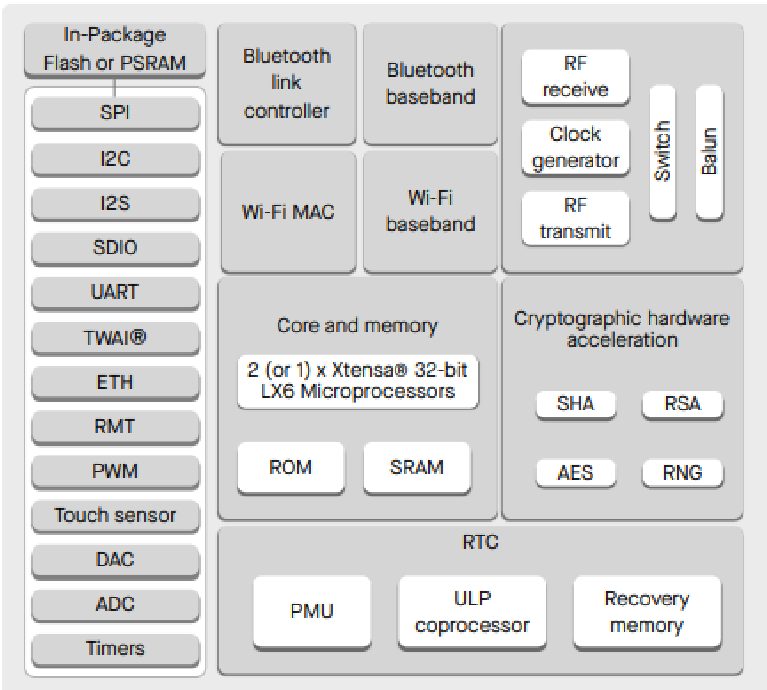

Figure 3.20: ESP32 Functional Block Diagram (Espressif)

Table 3.4: ESP32 features and specifications (Espressif)

Feature	Specification
CPU	Dual-core Tensilica LX6 processor
Clock speed	8MHz internal, 2-60MHz external
Wireless connectivity	Wi-Fi (802.11 b/g/n), Bluetooth
Memory	520kB SRAM, 448KB ROM for booting and core functions, Flash up to 32 MB (Octal), PSRAM up to 16 MB (Octal)
General purpose Input/Output Pins (GPIO)	34
Interface	4-UART, 3-SPI, 2-I^2C, 2-I^2S, PWM
Analogue input (ADC)	18 channels of 12-bit SAR ADCs
Integrated sensors	Hall sensor, temperature sensor
Analogue Output (DAC)	2 channels of 8-bit DACs
Operating voltage (V_{OH})	0.8 x V_{DD}
Operating current (I_{OH})	40mA (typical)
Supply Voltage	1.8 – 3.6V (3.3V typical)
Supply Current	0.5A minimum

The ESP32 was used in this project as the control and processing unit of the smart cart system, with the final block and circuit diagram shown in Figures 3.21 and 3.22, respectively.

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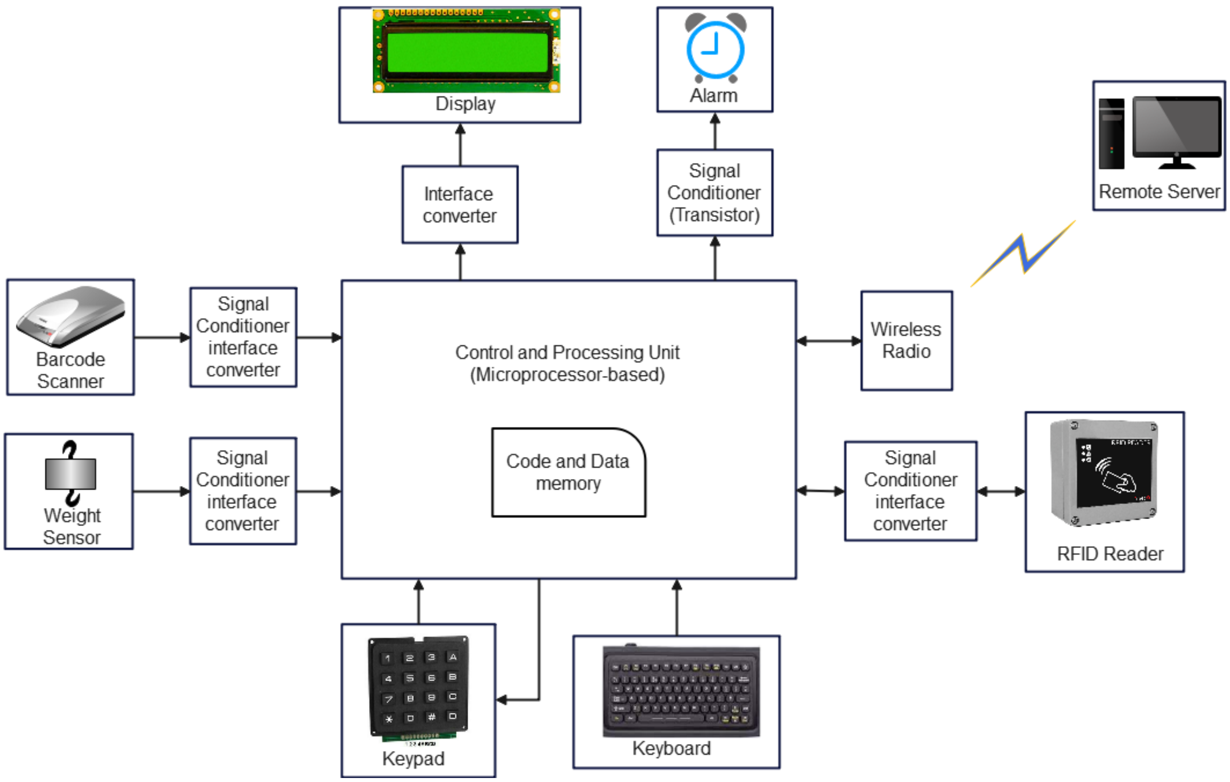

Figure 3.21: Final system block diagram

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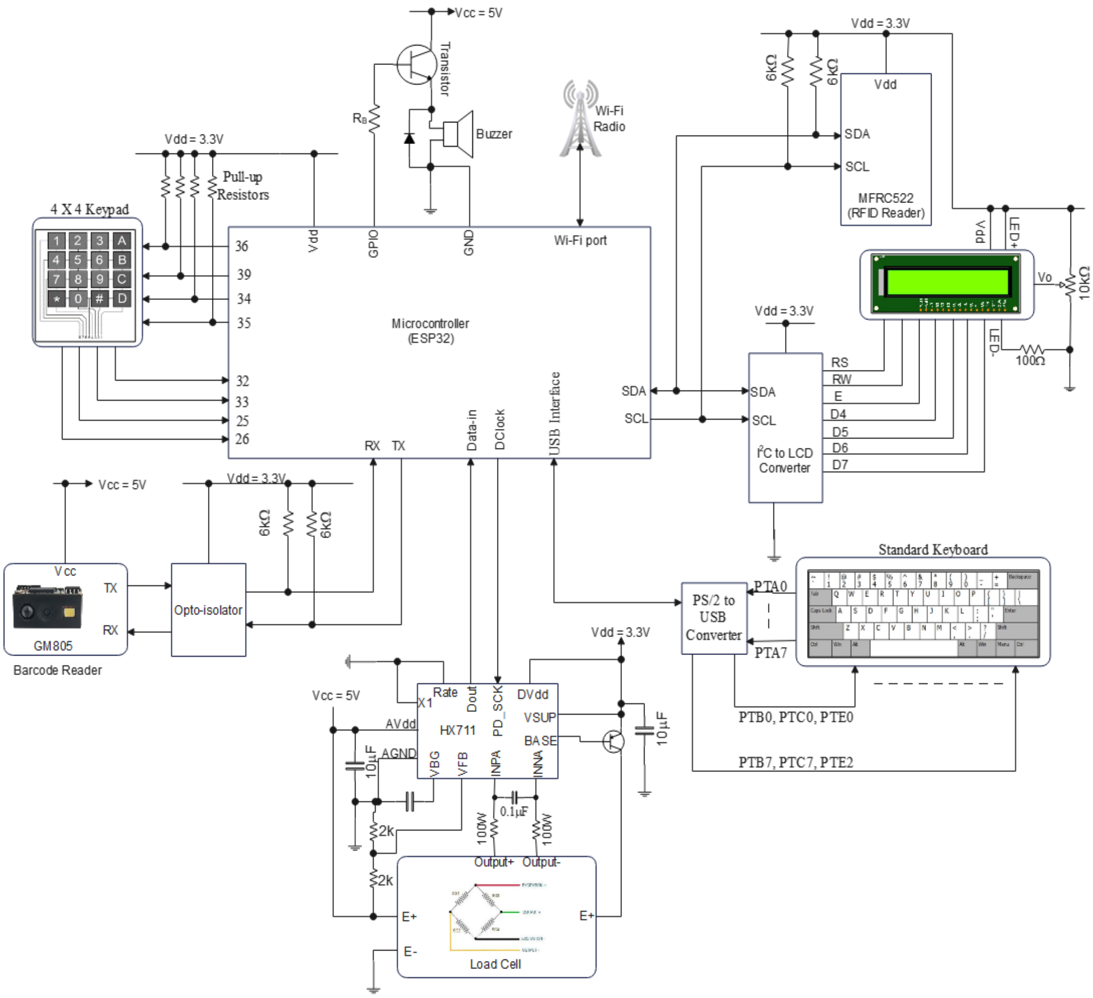

Figure 3.22: System circuit diagram

3.5.8 Remote Terminal

The remote terminal used in this project is a personal computer that runs a program on a web application. All store items' data are stored and hosted in the system and can be accessed via the web with a hosting address. These hosted item data are available to all connected carts through the Wi-Fi link and can be accessed for item list updates and purchase transactions.

3.5.9 Power Supply Estimation

The smart cart system requires a reliable power source for sensor reading, data processing, and wireless communication. While AC power requires conversion to DC, it is impractical for mobile systems due to fixed installations and cable constraints. DC power, particularly batteries, is more suitable but introduces lifespan limitations.

Batteries are categorized as:

- Primary (non-rechargeable) – Single-use, non-replenishable energy.
- Secondary (rechargeable) – Can be recharged, making them ideal for mobile applications.

For portable and re-deployable systems, lightweight, high-energy-density batteries are preferred. The total system power demand must be carefully analyzed to determine the optimal battery type and estimate battery autonomy, ensuring efficient operation before replacement or recharge.

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Table 3.5: Common Primary Batteries and Their Characteristics

Cell Type	Anode/Cathode	Maximum Voltage (Theoretical) (V)	Maximum Capacity (Theoretical) (Ah/Kg)	Working Voltage (Practical) (V)	Energy Density (Wh/Kg)
Carbon-zinc	Zn/MnO_2	1.6	230	1.2	65
Alkaline-MnO_2	Zn/MnO_2	1.5	230	1.15	65
Mercury	Zn/HgO	1.34	185	1.2	80
Silver oxide	Zn/AgO	1.86	285	1.5	130
Zinc-air	Zn/O2	1.6	815	1.1	200
Lithium	$Li/(CF)_n$	3.6	2200	3.0	650
Lithium	Li/CrO_2	3.8	750	3.0	350
Magnesium	Mg/MnO_2	2.0	270	1.5	100

Battery Selection for Smart Shopping Cart System

Various battery types were analyzed for efficiency, shelf life, discharge characteristics, and suitability for high-current applications.

Battery Type Comparisons

- Carbon-Zinc Batteries: Nonlinear discharge curve, poor low-temperature performance, drains quickly under high current demand. Not suitable.
- Mercury Batteries: Stable voltage but sudden depletion makes replacement monitoring difficult. Not ideal.
- Lithium Batteries: High energy density and long shelf life but limited high-current drain capability. Not optimal.
- Silver Oxide Batteries: High pulse current capability but expensive, poor shelf life, and sudden depletion risk. Not recommended.
- Zinc Chloride Batteries: Moderate current handling, better than carbon-zinc but still prone to sudden discharge. Limited suitability.
- Zinc-Air Batteries: High shelf life but limited low-temperature performance. Not ideal.
- Alkaline Batteries: Efficient for moderate-to-heavy continuous current drain, linear voltage discharge, and easy monitoring for replacement.

Final Battery Choice: Alkaline Batteries

The alkaline battery is selected due to its stable voltage discharge, ability to handle continuous high-current drain, and predictable replacement cycle. Though it has lower energy density compared to lithium or silver oxide batteries, its reliable performance under sustained loads makes it the best choice.

The working voltage per cell is 1.15V, requiring a 5VDC source for the smart cart system. This voltage is achieved using multiple cells in series, with a DC-DC converter regulating 5V and 3.3V outputs for system components.

Hence, to achieve this aim, several cells must be combined to produce 5V using Equation (3.2):

$$N = \frac{V_{source}}{V_{cell}} \quad (3.2)$$

N = number of cells

V_{Source} = required source voltage

V_{cell} = cell voltage

Thus,

$N = 5/1.15$

$= 4.35$

To achieve the required 5V supply, approximately four battery cells (4 × 1.15V = 4.6V) fall short, while five cells (5 × 1.15V = 5.75V) exceed safe limits, potentially damaging 5V devices.

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A DC-DC converter resolves this by adjusting voltage levels. Step-up (boost) converters increase low-voltage inputs, ideal for low-current applications, while step-down (buck) converters reduce high voltages, suitable for devices with fluctuating power demands.
A voltage regulator IC maintains stable output voltage. Fixed regulators deliver a constant output, while variable regulators allow adjustable voltage control. However, current limitations (typically 1000mA) require heat sinks or current bypass circuits (Figure 3.24) to enhance efficiency without overheating.

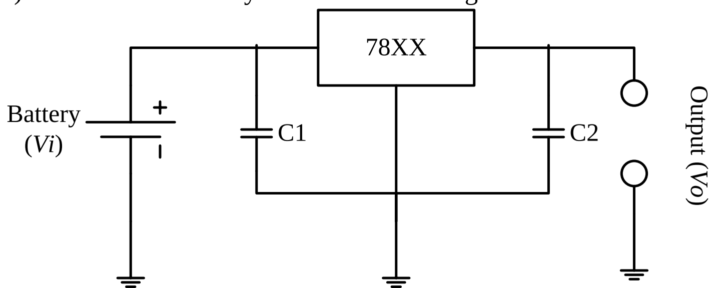

Figure 3.23: Fixed Voltage Regulator as a DC-DC Down-Converter

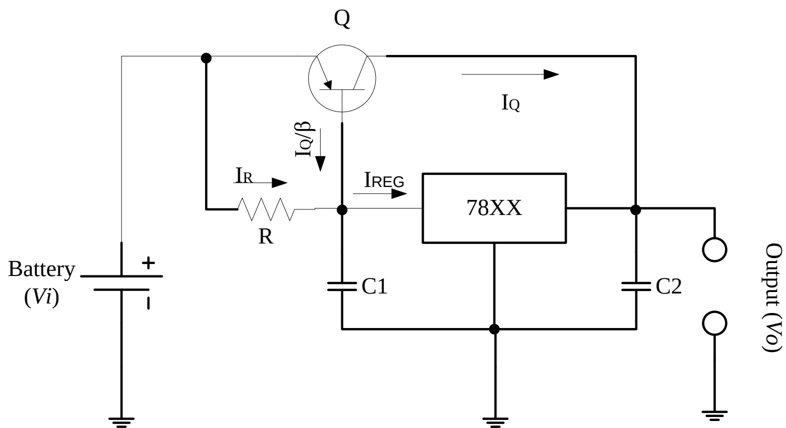

Figure 3.24: Current Bypass in a voltage Regulator DC-DC Down-converter

From analysis,

$$R = \frac{V_{BE}}{I_{REG} - \frac{I_Q}{\beta}} \tag{3.3}$$

$$I_O = I_{REG} + \beta\left(I_{REG} - \frac{V_{BE}}{R}\right) \tag{3.4}$$

V_{BE} = base-emitter voltage of transistor Q
I_{REG} = current allowed through regulator
I_Q = extra current sourced through Q
β = Q current gain
I_O = output current

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In both cases, C1 and C2 are as specified and the input voltage Vi must be the range of $V_i = (V_0 + 2V)$ — $V_{i(max)}$. This means that the regulator is not a perfect converter, and of course, there is no such thing as a perfect converter. There are always power losses as specified by Equation (3.5):

$$P_i = P_o + P_{loss} \tag{3.5}$$

P_i = input power
P_o = output power
P_{loss} = power loss
Power losses are majorly through heat loss and it is therefore necessary to reduce or eliminate heating through good design measures.

Maximum output power demand on the power supply is determined by assuming that all devices within the system are active and functional. The active power requirement of each unit is shown in Table 3.6.

Table 3.6: Maximum Power Demand

Unit	No. of Units	Active Current Demand/Unit	Active Current Drawn	Active Power Demand
Processing and Control (Microcontroller)	1	1200mA	1200mA	4320mW
Wi-Fi Radio	1	240mA	240mA	792mW
Signal Conditioning	5	1.2mA	6mA	19.8mW
Transducers	4	Loadcell = 30mA Barcode = 70mA RFID = 30mA LCD = 10mA Alarm = 120mA	260mA	1300mW
Total			1706mA	6431mA

The total current demand of the system is 1706mA, designing for the worst-case scenario, it is recommended that a minimum of 10% of the total should be added. Adding a chosen value of 20% (341.2mA), results in a total current demand of 2047.2mA and power requirement of 7717.2mW. This power must be delivered by the DC-DC converter. Using LM7805CV voltage regulator the converter is designed thus:
Applying Equation (3.3) therefore:
I_{REG} = 100mA = 10% of the regulator's current rating.
I_Q = 1706mA – 100mA = 1606mA
The recommended transistor Q is BD536.
Assuming β to be = 30 and V_{BE} = 0.7 (for silicon transistor),

$$R = \frac{0.7V}{0.1A - \frac{1.606A}{30}} = 15.06\Omega$$

The preferred standard value is 16Ω ± 5%.
Using Equation (3.4), the expected output current I_O is:

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$$I_O = 0.1A + 30\left(0.1A - \frac{0.7V}{16\Omega}\right)$$

= 1.7875A (1787.5mA)

The resultant DC-DC converter circuit is as shown in Figure 3.25.

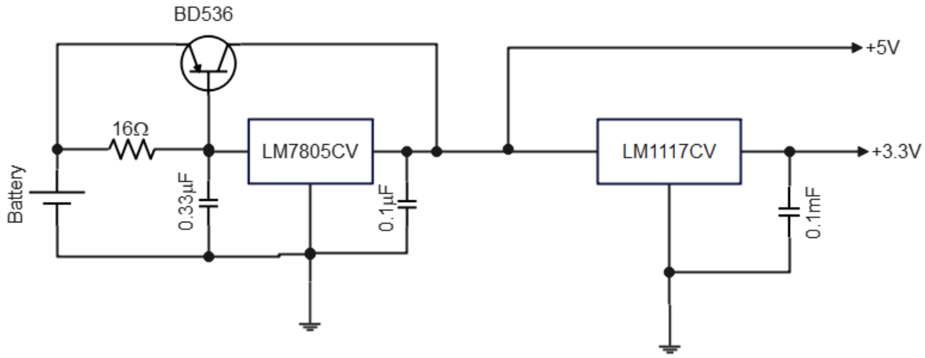

Figure 3.25: Required DC-DC converter Circuit

3.5.9.2 Battery Sizing

Recall that the power requirement is 6431mW (6.431W) and as stated earlier in this section, DC-DC converters are not perfect systems. Most of these types of converters can only deliver about 80% to over 90% of the input power. Thus, the minimum input power needed assuming an efficiency of 85% is:

$P_{i(min)}$ = 6.431W + (15% of 6.431W)

= 7.39565W

As stated earlier in this section, the minimum input voltage will be:

$V_i = V_o + 2V$

= 5V + 2V = 7V

In this report, 12V is used and using Equation (3.2) yields approximately 10 cells connected in series as shown in Figure 3.26.

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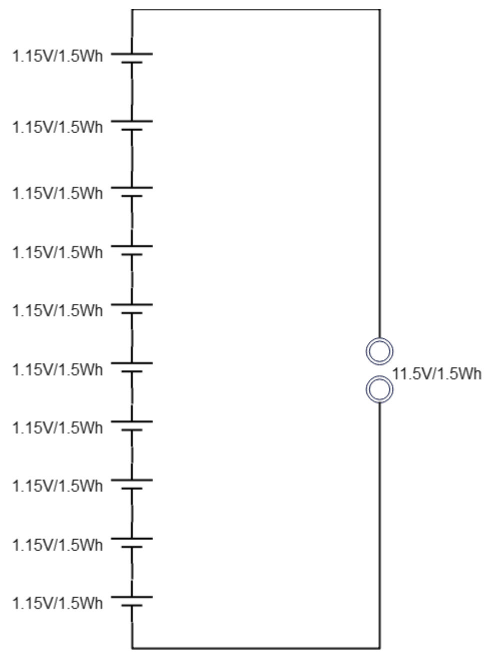

Figure 3.26: Battery Cell Arrangement

The nominal weight of an AA-size alkaline battery is 23g (0.023Kg) and with the energy density of 65Wh/Kg (see Table 3.5) of an alkaline cell, we have:
Cell energy = 65Wh/Kg x 0.023Kg
= 1.495Wh ≈ 1.5Wh
With the 10 cells in series to produce 11.5V, the resultant energy is that of one cell. This energy will power the system for a period of:

$$T = \frac{1.495Wh}{7.39565W} = 0.2022h$$

To sustain the system for a desired period, a number of the serial connections of Figure 3.26 must be connected in parallel. This process could be expensive and very bulky. Using battery types with higher voltage and energy density is more desirable. The values given in Table 3.5 are nominal, there are better batteries in the market with high energy density and good drain.

3.5.9.3 Designing for Low Power Consumption

Using multiple battery cells **in series and parallel increases energy storage but also raises costs and bulkiness. To enhance energy efficiency, alternative power management techniques should be employed.**

In a smart cart system, sensor data transmission is often asynchronous, meaning that different system components do not operate simultaneously. At idle times, non-intelligent components (e.g., sensors, signal conditioning circuits) can be powered down but must feature fast response times. Meanwhile, microcontrollers can operate in low-power sleep mode, consuming minimal energy while listening for incoming instructions.

During active data processing, a dynamic power switching strategy ensures that only necessary components remain powered ON, while others remain OFF. These measures optimize power consumption, allowing for smaller, low-energy batteries with extended operational autonomy.

In this report, the following power activation processes are used:

- The microcontroller operates in sleep mode most of the time and wakes up only on reception of instruction.

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- A sensor and its signal conditioning front-end are turned ON only on request.
- The radio device continuously sleeps while the system is idle.
- The radio device is idle when data acquisition and processing are in progress.
- The radio goes active when data is ready for transfer.

Figure 3.27 shows a block diagram signal flow of how this process can be implemented, while Figure 3.28 is a flowchart implementation of the scheme.

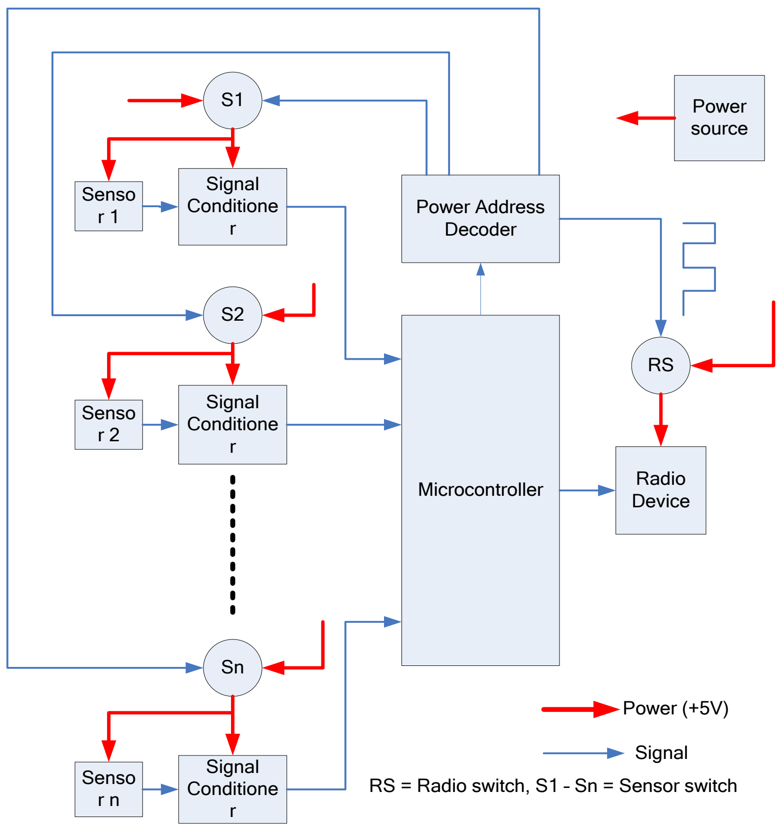

Figure 3.27: Block Diagram Signal Flow for Power

As depicted in Figure 3.27, the system is initialized such that all attached sensor elements and their conditioning units are deactivated, while the radio and the processing units are kept in sleep mode. On reception of any wake-up signal, the radio wakes up, and the signal is validated. If the signal is invalid, the radio goes back to sleep, else for valid data, the processing device wakes up, the radio goes to idle mode and the received instruction is decoded for necessary action. If the instruction is to read existing data from memory, the radio goes to active mode and data are transferred before going back to sleep. If new data are to be collected, the required sensor units are activated, sampled and the output digitized. The sensor units are then deactivated, the acquired data are processed and the radio goes to active mode for data transfer. Next both radio and the processing units go back to sleep.

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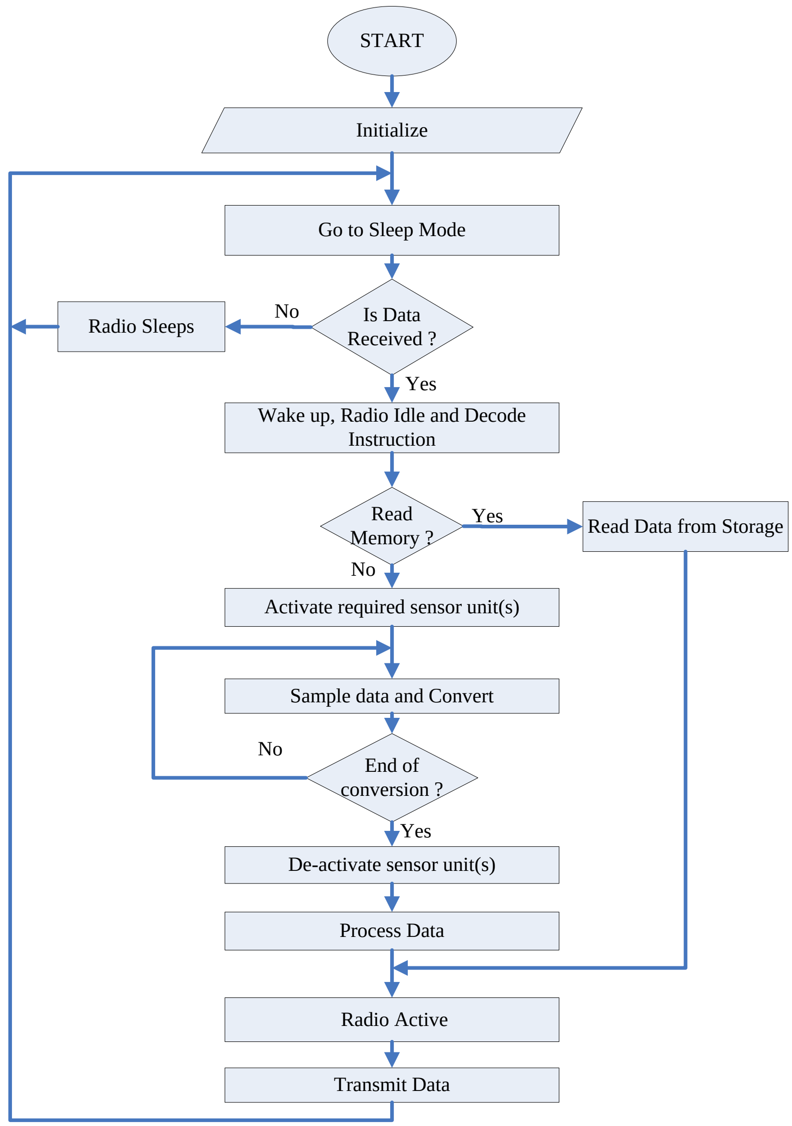

Figure 3.28: Flowchart for Energy Management

This algorithm when implemented helps to reduce the energy demand of the system at all time and better guaranty the system's autonomy.

3.6 SOFTWARE SUBSYSTEM DESIGN

The smart cart system comprises of both hardware and software subsystems. While the hardware is the physical artifact that is visible as the cart, the software subsystem is designed to run on the hardware for data processing and functional execution. Following from system functional description, the software designed is first formulated into an algorithm. This algorithm is represented in a program description language (Pseudocode) and/or a flowchart as presented in Figure 3.29.

- **Pseudocode**

Start
1. INITIALIZE the system

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2. CONNECT to the shop/mall server
3. IF not connected goto 2
4. UPDATE cart inventory from database
5. CHECK for any scanned item
6. IF item_scanned is TRUE, display item data (price, number, weight)
7. ELSE goto 5
8. IF item_Add_to_cart is TRUE, Update purchased_items (number, Amount, weight difference)
9. ELSE goto 5
10. UPDATE cart data to server (display on server webpage)
11. IF payment is TRUE, THEN goto 12, ELSE goto 5
12. Deduct the purchase amount and UPDATE server record
13. IF purchase_confirm is TRUE, RESET cart cache
14. END

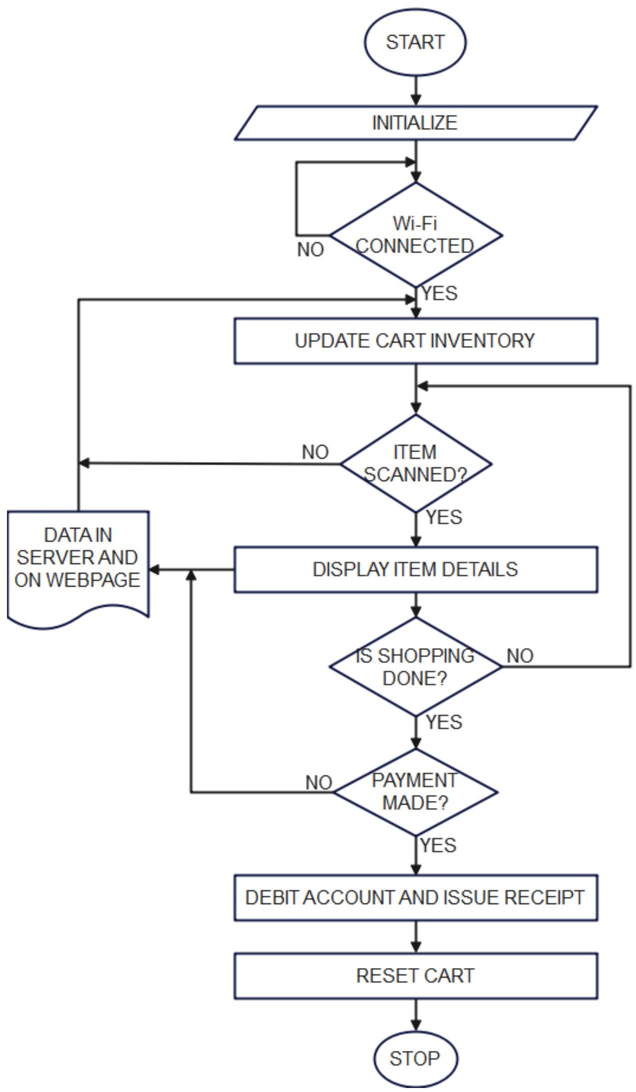

Figure 3.29: System main flow chart

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IMPLEMENTATION AND RESULT

4.1 HARDWARE IMPLEMENTATION

In the hardware implementation, different units of the system were first considered separately by selecting the appropriate devices and components. These devices and components have been built into modules that can interface easily. To this end, different circuit modules that implement each unit were selected and interconnected as indicated in Figure 4.1

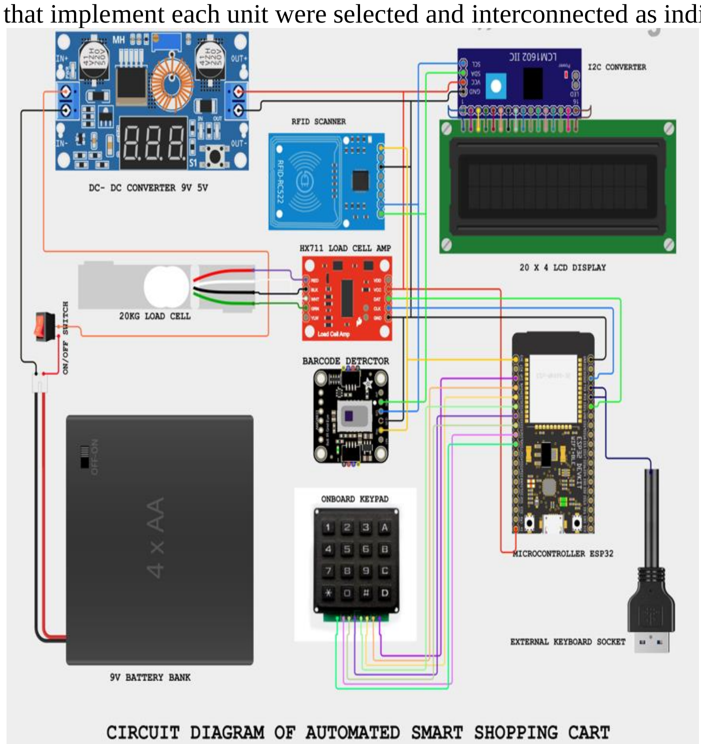

Figure 4.1: Circuit module interconnection

4.1.1 Keypad and Keyboard Hardware Implementation

This work, a 4 x 4 Matrix Keypad and a hp keyboard which are readily available in the market was used. The keypad has 8 pins, which are connected to the GPIOs 36, 39, 34, 35, 32, 33, 25 and 26 of the ESP32 microcontroller module. Figures 4.2 and 4.3 respectively show the keypad and keyboard used for this work.

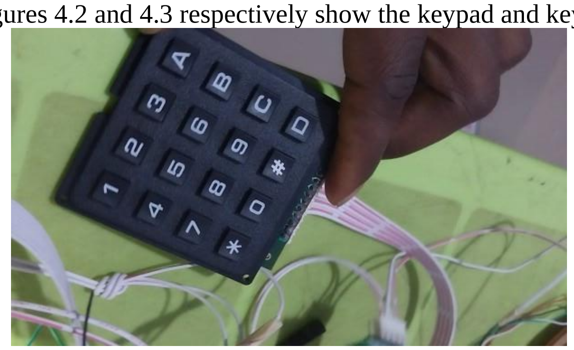

Figure 4.2: 4X4 keypad

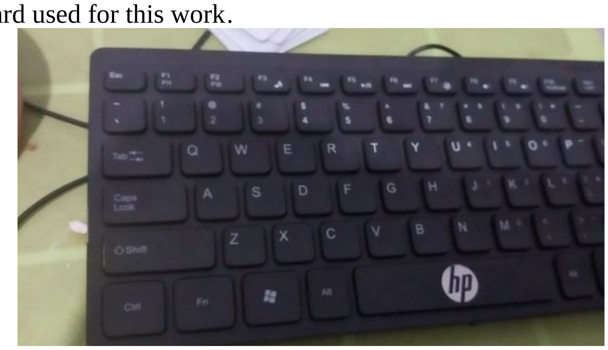

Figure 4.3: System external Keyboard

4.1.2 Barcode Reader Hardware Implementation

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The barcode reader was implemented with the GM805-S module which contains AMG8833 infrared camera module, an LED and other ancillary circuitry as shown in Figure 4.4. The module is made of 6-pins to include Vcc (5V), Vdd (3.3V), GND, SCL, SDA, INT and interface the microcontroller through I^{2}C terminal bus.

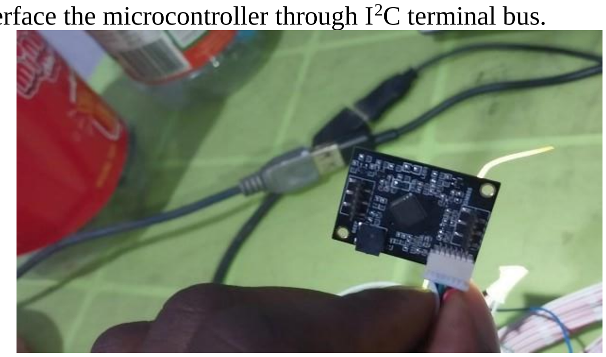

Figure 4.4: GM805-S barcode reader module with AMG8833 infrared camera

4.1.3 RFID Card Reader Hardware Implementation

The RFID card reader was implemented using the RFID**-RC522** reader/writer module shown in Figure 4.5. The RFID module comprises of 8-pins including SDA, SCL, MOSI, MISO, IRQ, GND, RST, and a Vdd of 3.3V. The module I2C (SDA and SCL) was used to interface it with the microcontroller.

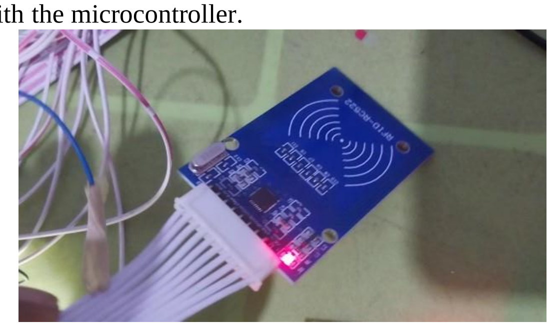

Figure 4.6: RFID card reader

4.1.4 Weighing Unit Hardware Implementation

The weight detection and measurement unit was implemented with a loadcell and the HX711 load cell amplifier module. The HX711 module pin configurations are: Vdd (3.3V), Vcc (5V), DAT, SCK, GND, B+, B-, A+, A-, AVDD. Figure 4.7 shows the HX711 module wire connection.

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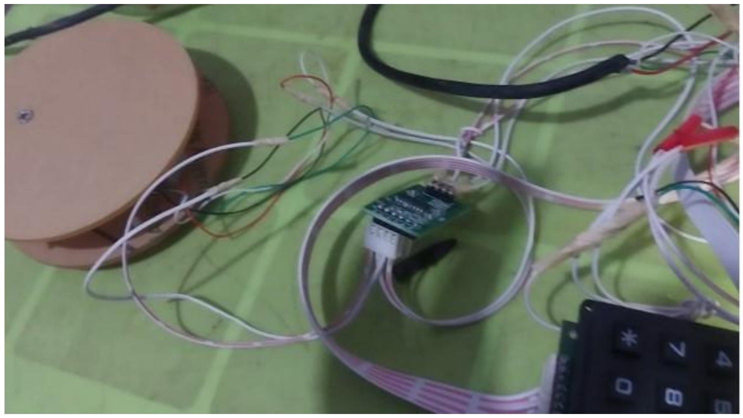

Figure 4.7: HX711 Load cell amplifier

4.1.5 Display Unit Hardware Implementation
A 20-character by 4-line LCD display module with an I2C adapter was used for the design implementation. The I^2C adapter interface the into the serial data bus. Figure 4.8 shows the LCD display module used for this work.

Figure 4.8: LCD Display module

4.1.6 Alarm Hardware Implementation
The alarm system was implemented with a 5V piezo, as shown in Figure 4.9. This small device vibrates and sounds when 5V is applied across its terminal.

Figure 4.9: 5V Piezo

4.1.7 Control Unit Hardware Implementation
The ESP32 microcontroller module shown in Figure 4.10 was used for the control unit implementation. As discussed in section 3.5.7, the ESP32 module has unique features that match this work's design specification. It has an inbuilt Wi-Fi

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and Bluetooth capability. Its pin configurations are: Vdd (3.3V output), Reset, 32 GPIOs (36, 39, 34, 35, 32, 33, 25, 26, 27, 14, 12, 13, 9, 10, 11, 23, 22/SCL, 1/TXD0, 3/RXD0, 21/SDA, 19, 18, 5, 17, 16, 4, 0, 2, 15, 8, 7, 6), GND and Vcc (5V input).

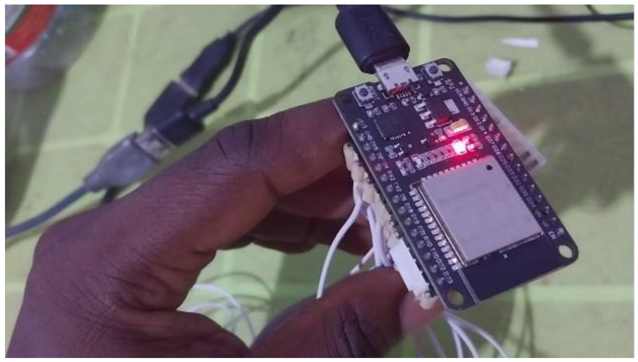

Figure 4.10: ESP32 microcontroller

4.1.8 Power Supply Implementation

The power supply was designed to be sourced from any battery of 5V to 32V and converted to a 5V system through a DC bulk converter. The buck converter as shown in Figure 4.11 is the XL4015/5A DC Buck Step-down converter module. This converter provides an output of 0.8V to 30V and an output current of 4A. To supply this system, the output of the bulk converter was set to 5V and connected to the power supply input of the microcontroller. The microcontroller has an internal 5V to 3.3V voltage regulator which provides a 3.3V system. A single-pole, single-throw toggle switch was connected between the battery and the buck converter to put off the supply when the system was not in use.

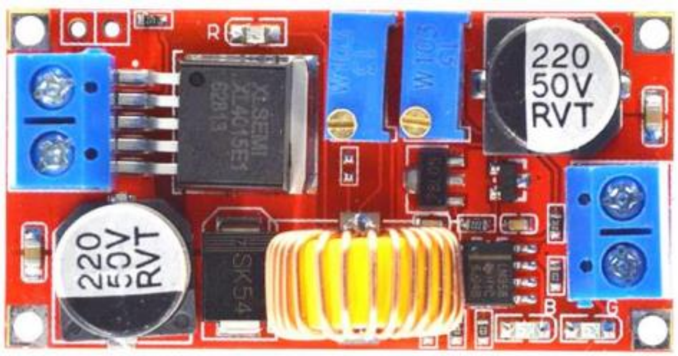

Figure 4.11: XL4015/5A bulk converter

4.1.9 Cart Mechanical Structure Fabrication

The cart carrier was fabricated and packaged in a welded steel frame. Four rolling tires were fixed on the legs to ease movement as shown in Figure 4.12, and the finished cart prototype presented in Figure 4.13

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Figure 4.12: Fabricated Cart

4.2 SOFTWARE IMPLEMENTATION

The algorithm of section 3.6 was implemented with C/C++ software language codes in an Arduino Integrated Development Environment (IDE) software application. The Arduino IDE is an open-source platform that allows users to write, compile, and upload code to Arduino boards and other boards of the Atmega family. It provides a user-friendly interface for programming and debugging codes.

Some features of the Arduino IDE are: it has a code editor with syntax highlighting, auto-completion, and supports C/C++ programming languages. It has a built-in compiler and uploader for Arduino boards, a serial monitor for debugging and communication, and a library manager for easy installation and code management. The program code of the design is given in APPENDIX A.

4.3 RESULTS AND DISCUSSION

The results of the final system operation are discussed in the system setup and functionality of the various sections.

4.3.1 System Setup

The system setup includes the description of how each unit can be used to perform assigned function for proper system operation. This also provide details of system functionality and use as described in the following sub-sections.

4.3.1.1 Keyboard Letter Representation

Some letters in the keyboard are configured to perform key functions as set in the programming. The letters and what they represent are as given in Table 4.1

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Table4.1: Keyboard letter representation

KEY	REPRESENTATION
A	For credit card loading
B	Menu/ Enter
C	Backspace
D	Next/Escape
*/#	For cart weight resetting/setting on the main page. continuous pressing to cancel the current weight on cart and clear to zero.

4.3.1.2 Network Setup

The system is Wi-Fi enabled when it is put ON and searches for available Wi-Fi host whose IP & address has been pre-programmed into it by displaying connecting on the LCD display as shown in Figure 4.14 and Figure 4.15. The Wi-Fi connectivity is to enable the system update the shop's inventory and also to be able to send Email messages to clients that have used their customer's debit card for payment for goods purchased.

Figure 4.14: System for searching for Wi-Fi connectivity

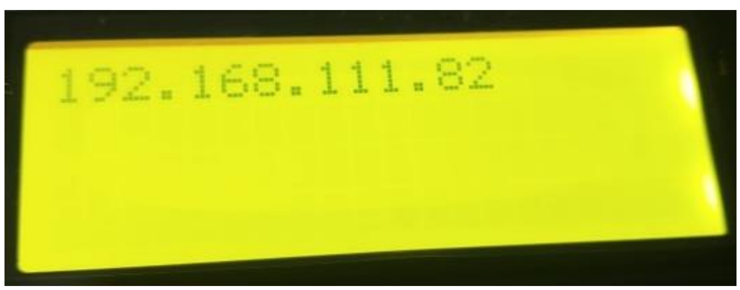

Figure 4.15: programmed IP address

The system locates the HOTSPOT and connects to it. The first page of the display shown on the LCD of the system is the home page and displays the Total item count, Total prices, Total weight—Tw (the actual weight of the item Stored in the inventory) and Current weight—Cw (measured weight) as shown in Figure 4.16.

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Figure 4.16: Cart Homepage

The CW and TW gives a fair value of the difference in weight between the total weight of items as on the shop's inventory and the calculated total weight on the shopping cart.
If the difference is marginal, then there will be no cause for alarm, but if the difference is much then, the cart needs to be inspected at the checkout point.

4.4.1.3 Clearing all items stored in the previous shopping usage

To clear all items stored in the previous shopping page, Press letter C on the keyboard, the system will require the user to input a password so that the previous information can be cleared.
When the default password is (0000), and key C is pressed again, the following will appear on the menu page:

1. Weight Calibration
2. System access
3. Web view item Data
4. Factory reset

Press 4 and the system will request confirmation to clear all previously stored data by pressing Key C for YES and key B for NO. If YES, it will request your password (0000) and the system will initiate a countdown process to wipe all data stored.

4.4.1.4 Adding item to database of the system

Items can be added into the inventory database either directly (through the cart) or via an external computer system that will send the data into a cloud-based inventory. To enter data into the cart's inventory manually, press menu (C), enter the password and then press C. The display will show a menu as follows:

1. Items entry
2. Credit Card
3. Download item data (from cloud)
4. System Setting

Press 1 and then another menu will display as follows:

1. Add item
2. View item
3. Item web view

ADD item – is to add item into the (manual) cart
VIEW item – is to view all items in the system
To manually enter a new item, press 1 on the current page. Scan the barcode, then press Enter (C) to store it (Figure 4.17a, 4.17b). Enter the item name via keyboard (Figure 4.17c), then store. Input the unit price (Figure 4.17d) and press Enter (C). Next, enter the item weight (grams) (Figure 4.17e) and store. Enter the expiry date (DDMMYY) (Figure 4.17f) and confirm. Press YES to save. To view stored items, go back using Backspace (B) and select "View Item"..

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Figure 4.17a: Requesting item barcode scan

Figure 4.17b: Adding item barcode

Figure 4.17c: Entering item name

Figure 4. 17d: Entering item price

Figure 4.17e: Adding item Weight

Figure 4.17f: Item Expiry Date

The system will display the details of the item entered into the system database. To view others, press D (D is the next key). Keep pressing until the last item in the stored data bank is displayed and the system will print "NO MORE ITEM" after the last item on the database is displayed.

4.4.1.5 Viewing items on the web page

To view items on the webpage, Press 3 (item web view). The IP address of the webpage will be displayed as shown in Figure 4.18. Enter it into any web browser and a portal for all items will be displayed. Refreshed, the page and the data entered **into the device will be displayed on the page for viewing with all the particulars of the items.**

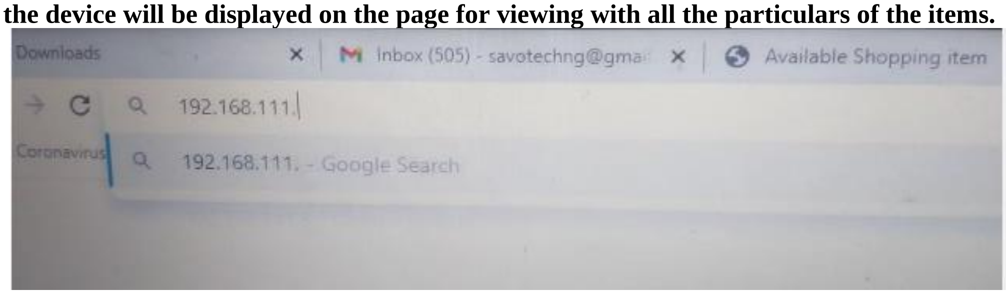

Figure 4.18: Web page IP Address

4.4.1.6 Deleting Items

To delete items in the view items menu, press backspace. The system will ask for the password as shown in Figure 4.19, if the password is entered, then press enter(C), the items will be deleted as shown in Figure 4 .20.

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Figure 4.19: Password request

Figure 4.20: Deleting an Item

4.4.1.7 Putting Items on the Cart while shopping

To select an item of choice while shopping, Scan the item with the barcode scanner as shown in Figure 4.21a, a beep sound will be produced, thereafter add the item into the cart. The following will display on the screen as shown in Figure 4.21b:

1. The total item count,
2. Total weight (TW).
3. Add measured/current weight (CW)
4. Total prices.

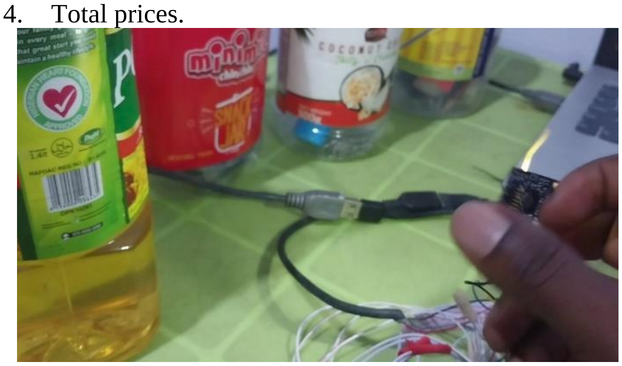

Figure 4.21a: Items being scanned

Figure 4.21b: Item registered on the cart system

At the end of the shopping, one can view all activities on the webpage by entering the IP address for which the cashier will use to confirm shopped items in the cart as shown in Figure 4.22.

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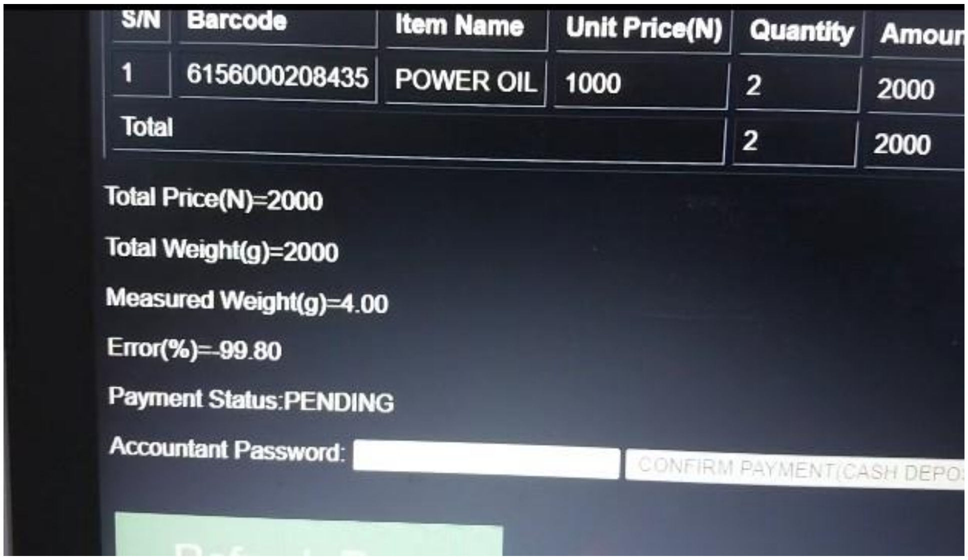

Figure 4.22: Cashier's dashboard on the webpage

4.4.1.8 Making Payment

Payments can be made via cash or RFID card. For cash payments, enter the password (1234) to verify item weight accuracy. If discrepancies are detected, physical confirmation is required. Once resolved, the accountant enters their password to confirm payment. The system updates the status bar as "Paid", indicating payment type (cash or card). The cashier resets the system, clearing previous purchase data for the next customer.

4.4.1.9 Enrolling a Credit Card

To enroll a credit card, press Menu (C) and enter the password 0000. Select:

1. Add Card – Flash the card on the RFID reader to display the card number. Enter the cardholder's name, PIN, phone number, and email, then press Enter to save.
2. View Card – Press Enter to display card number, cardholder's name, PIN, last payment, and available balance (Figure 4.23).

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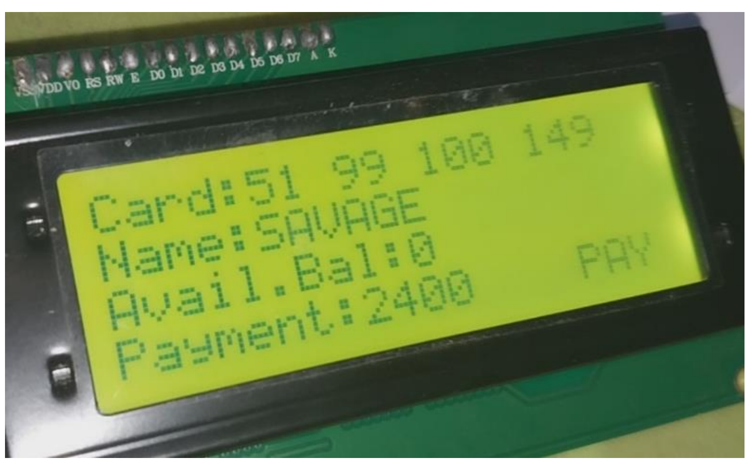

Figure 4.23: Credit Card Information

4.4.1.10 Funding a Credit Card

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To fund a credit card, go to the main home page by pressing enter (A) on the keyboard, the system will ask for password (0000) and then ask for the card to be credited to be flashed on the RFID reader. To enter the amount to be credited, press enter (C) and input the Accountant's password for authorization then press enter.
To make payment using a credit card after shopping, just flash the credited customized card on the device RFID reader and the payment will be made automatically.
This payment can be viewed from the webpage by inputting the IP address into any web browsers and refresh the page and the details of all items and payment method will be displayed on the phone or the cashier's computer for packaging.
The system doesn't allow twice payment for one single transaction that has been done. The status will show paid and send an email to the customer as shown in Figure 4.24. One can check one's email to see the transaction alert, if the card has no sufficient credit, the system will display insufficient credit.
For every payment made with the credit card, the balance of credit card is also displayed with the current amount paid for items. The credit card can also be deleted from the system at any time by clicking delete.

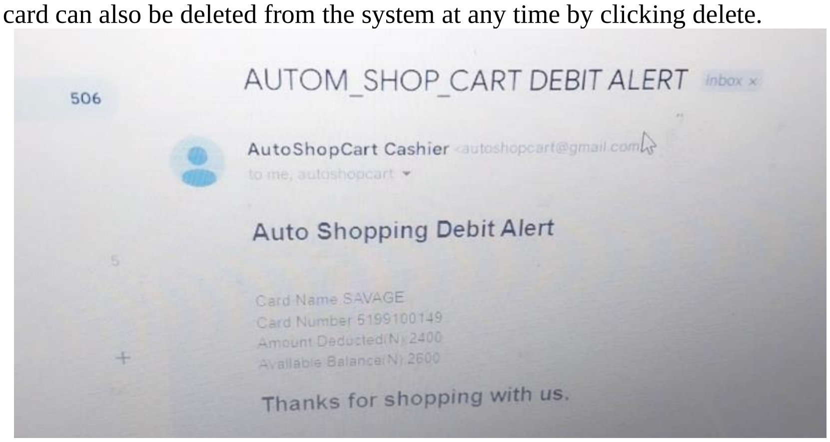

Figure 4.24: Email sent to customer

4.4.1.11 Removing Items from the Cart

To remove an item from the cart, press B on the main menu page. The system will request you scan the barcode on the item you wish to be removed as shown in Figure 4.25. After scanning then press enter (C) to remove the item from the cart.

Figure 4.25: Scanning to remove an Item

4.4.1.12 Weight Calibration

To caliberate the weight of an item from the main page, the following steps is required:

1. Press Enter (C),
2. Enter password (0000)
3. Press 4 (system settings).
4. Then press 1(weight calibration)

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5. then on the weight calibration page the formula will display

$$W = Mx + C$$

Where:
M= gradient
C= Y-intercept
To calibrate, Change the value of M, by pressing * continuously till the desired value and press enter (C). Change the value of C by pressing * and # to the desired value and press enter (C). Then go to main page and see the effect of the changes.

4.4.1.13 Weight Error Checks

The weight error check was carried out using tow customers as a test.

Two items total weight on the inventory is supposed to be 600grams, but the weight on the cart is 17grams, as shown on the cashier's dashboard of Figure 4.26a, the system detects an error of -97.17% (negative%). This means customer A paid for items that are not included in the cart.

Figure 4.26b is for customer B that took more than he/she scanned into the cart. Here the actual weight of the scanned item is 300grams, while the weight on the cart is 506grams and the error shown on the dashboard is 68.67% (positive %). In both cases, the cashier has to confirm the goods before accepting payment and packing the items.

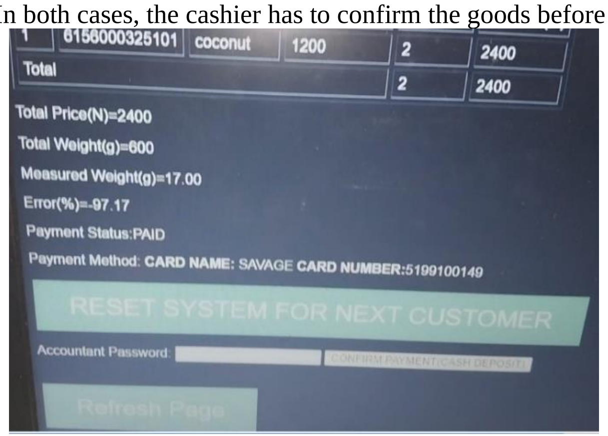

Figure 4.26a: weight checks for customer A

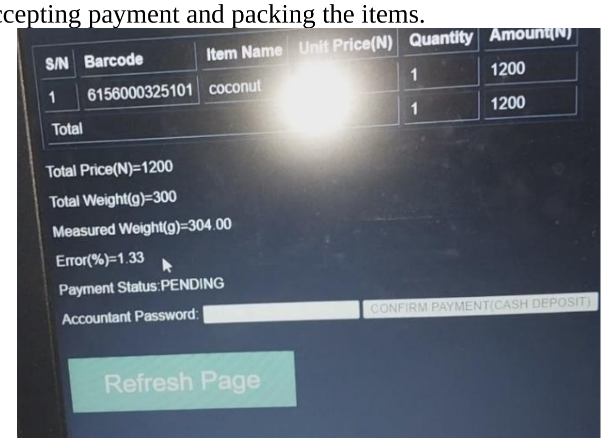

Figure 4.26b: Weight checks for Customer B

As seen in Figure 4.26b, the error is 1.33% (it is positive but the error margin is very small), here the cashier may accept it for payment because of computational error and other conditions that are likely to affect the system such as expansion of the weighing mechanism due to heat from the environment.

4.4.1.13 System Information and Login Details

The following are the system's information and login details:
1. System password – 0000
2. Account password 1234
3. IP Address: 192.168.111.82
4. Device Email : toshopcart@gmail.com
5. Device email password (Not to be changed) :Jnehkmhhqdgdmwzi

4.5 SYSTEM MODE OF OPERATION

The smart shopping cart is designed to ease the shopping experience of customers in a shopping mall or supermarket. The system includes a shopping trolley that house the smart cart device, it has a battery pack at the base of the trolley. A barcode scanner is placed in a position such that the customer can easily scan items before they are placed in the cart's basket. A weight sensor is placed under the basket so that the weight sum of the items is calculated. The system comes with an LCD display to present the modes of the current activities regarding the customers shopping. This display shows the number of items on the cart, the total amount, total items weight, the difference in weight (if any, as %error).

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The system also has an RFID sensor, this sensor is used for making payments on the shopping cart for items shopped, thereby reducing checkout time and avoiding queues at checkout points. A customer can request for a customized debit card that the management will issue to the customer, this card can be credited with some amount that the customer will give to the accountant who in turn will credit the card with the same amount on the card.
A customer may decide to pay in cash at checkout, or may just swipe the card on the cart system and the amount of the purchase will be deducted from the card.

4.6 BILL OF ENGINEERING MEASUREMENT AND EVALUATION

S/N	ITEM DESCRIPTION	QUANTITY	UNIT PRICE(N)	AMOUNT(N)
1	Esp32 Microcontroller	1	4,500	4,500
2	Barcode Reader	1	6,000	6,000
3	Hx711 Weigh Sensor Amplifier	1	2,000	2,000
4	Weigh Bridge Sensor Module	1	5,600	5,600
5	4x4 Alpha Numeric Keypad	1	4,000	4,000
6	External Keyboard	1	5,000	5,000
7	20x4 Lcd Display	1	4,500	4,500
8	Keyboard Extention Sucket	1	500	500
9	12v Battery	1	9,000	9,000
10	Dc To Dc Converter	1	3,000	3,000
11	Connecting Wires		1,000	1,000
12	Casing		600	600
13	Cart frame construction		20,000	20,000
			TOTAL	65,700

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

Smart shopping cart is an important business infrastructure at the mall or supper market. It is a device that will revolutionise and change the way customers make their choices during shopping. This work discussed how the smart cart could be developed from scratch using modern technology to improve customers shopping experience at the market place. To keep to the objectives of this work, a prototype smart cart was developed. The smart cart was equipped with a barcode reader for item information reading, a loadcell for item weight sensing, an LCD for information presentation, a piezo alarm for alerting users, and an RFID reader for payment card data collection. All devices are interfaced to an ESP32 microcomputer which run a control algorithm coded in C/C++ program. With the aid of the program code, items presented to the cart were accurately detected using barcodes and their weight measure with a percentage error less than 2%. Detected and scanned items information including item name, prices, weight, measured weight, amount, and so on were also accurately displayed. Using an RFID technology, a secured private card payment system was implemented and enabled a seem shopping transaction that saves time and reduced shopping queues. A shopping test indicated the smart cart prototype meets its designed functionality and can become more standard with little improvement.
The use of such smart cart systems in market places will enhance shopping operations for both customer and owners of shops. As the use of smart carts at market places gains more popularity, this approach to cart development will result in cost saving, improve shopping efficiency, and reduce shopping fraud.

5.2 Contribution to Knowledge

This work on the design and development of a smart cart system has contributed to the body knowledge by showing that:
1. It is possible to develop a low-cost high-tech solution for improved customer shopping experience at the market.
2. By weight measurement, shopping fraud can be detected and nib at the point of purchase.
3. With the use of secured private RFID card payment system, purchases can be made in time and reduce shopping queue.
4. Smart shopping carts can be locally designed, fabricated and made available for our markets.

5.3 Recommendations

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In this Project, it is suggested that more research can be carried out towards the improvement of the Project. Thus, for technological advancement it is recommended that the following be considered:

1. Micro camera could be added to the cart system for customer visual detection as another security level.
2. The RFID card payment system of the cart can be improved with more intelligent techniques such that customers could fund their account from anywhere and may not need to see the cashier for their transaction.
3. The barcode scanning system can be improved to scan more advanced codes such as the QR-code.
4. Use greater amount of battery capacity with light weight to improve its operation duration.

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