Performance Analysis of Arduino Uno, Arduino Nano, and Raspberry Pi for RFID-based Smart-Cart System

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***Abstract*—With the increase in queues in supermarkets, RFID has emerged out to be one of the feasible technological solutions. Various research papers have been published addressing the issue, and each of them proposes a different solution through different hardware. In this paper, we have compared various hardware solutions for smart shopping carts analytically. The paper compares the performance of different micro-processors in an integrated Smart-Cart system and rates them on different standards based on device speed, consumer convenience, cost-efficiency, and environmental friendliness. Smart Shopping Cart, which consists of Radio Frequency Identification (RFID) sensors, Arduino microcontroller, and Bluetooth module, was introduced to accelerate and replace the previous barcode process of scanning products in shopping complexes. The proposed system can easily be implemented, tested, and compared regarding customer efficiency.**

***Index Terms*—Raspberry pi, Arduino Uno, Arduino Nano, Smart-Cart**

I. Introduction

IoT (Internet of Things) refers to a network of physical objects with sensors, software, and other technologies with the purpose of interacting over the internet with other devices and systems. IoT is directly or indirectly tightly coupling of communication network and sensor network where the data management and data processing is achieved by monitoring these processes intelligently[6],[7]. A wide variety of IoT devices are available, from common household items to highly sophisticated industrial tools. Experts predict that IoT devices will number more than 22 billion by 2025, with more than 10 billion connected today. Mobile technology, big data, analytics, and low-cost computing make it possible for physical objects to share and gather data without human intervention. IoT gives people the ability to effectively manage their lives and enterprises while also bringing about fundamental changes to the world that have the potential to totally reshape commerce and industry. The capabilities of IoT provide a wide range of opportunities for the development of applications in various industries such as aerospace and aviation, automotive, telecommunication, medical, healthcare, independent living, pharmaceuticals, transportation, manufacturing, retail, logistics, and supply chain management.[8],[9]. IoT's primary goal is to monitor specific things and settings remotely. This introduces electronic tags attached to individual objects. RFID technology reads the recorded information of the object wirelessly when these tags come within range of the reader [4]. In the IoT's applications, RFID is essential. The system is composed of three key elements: RFID tags affixed to objects containing information or identity data, an RFID reader that retrieves the data from the tags, and a microcontroller device that oversees the system's operation[11]. A central processing system handles communication between the RFID system and other electronic devices. IoT is causing a significant transformation in several applications such as airplane maintenance, anti-counterfeiting, healthcare, and supply chain management[10].

A. Problem Statement

With the fast-paced growth of urban cities' population, supermarket systems are struggling to cope with the increasing number of customers. The existing barcode billing system is a slow process that leads to long queues, resulting in a negative shopping experience for users. The suggested system offers an innovative solution to this issue by accelerating the payment process.

B. Barcodes

The vast majority of modern supermarkets use barcode systems to identify products and check in customers waiting in the queue. A barcode is a machine-readable representation of data in the form of a series of parallel lines of varying width and spacing. Barcodes are used to identify products,

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track inventory, and simplify data entry in a wide range of industries, from retail to manufacturing to healthcare. In modern supermarkets, this data involves a unique ID for each product. All information describing a particular product such as full name, cost, weight, etc. is stored in the primary software database, and this product is addressed by a unique ID that is read from barcodes.[3] So, this way barcode is widely used in supermarkets for the billing process because of the convenience it provides against the traditional billing method. This method is surely better than the manual billing method but it fails to handle the large crowds in supermarkets because of the following issues:

- Time-consuming: Scanning every item using a barcode scanner is highly time-consuming and sometimes causes very long queues in the supermarket.
- Scanning errors: Damaged barcodes can be misread which can lead to incorrect prices or product information being entered into the system.
- Limited data: Barcode can store very limited information, so it cannot provide more detailed insights about the products to the customers.
- Inefficient inventory management: The barcode system does not provide real-time updates on inventory levels, which can lead to overstocking or understocking of products.
- Vulnerability to fraud: Barcodes can be altered or replicated so it is easy for fraudsters to cheat the system.

Hence, there is a strong need for a better solution that is beneficial for both supermarkets and end consumers.

C. Solution

One of the major solutions to solve this problem is to introduce a smart shopping cart based on RFID technology. Smart cart is a technology that allows customers to perform the checkout process themselves, without the need for a cashier. The system works by using RFID tags on the products, which are scanned by an RFID reader as the customer adds them to their cart. When the customer is finished shopping, they can use a self-checkout kiosk to pay for their items, or in some cases, the payment can be processed directly through the smart cart. One of the key benefits of smart carts is that they can help to speed up the checkout process since customers can simply scan the RFID tags and pay for their items without having to wait in line for a cashier. This can be especially helpful during busy times or in stores with long lines. Smart carts can also provide other benefits, such as giving customers more control over the checkout process and reducing the risk of errors or fraud that can occur when cashiers are handling transactions. Overall, smart carts are an innovative technology that can improve the shopping experience for customers while also providing benefits for businesses, such as increased efficiency and reduced costs.

Along with the RFID, other main hardware components of this smart cart include Arduino Uno / raspberry pie, Bluetooth module, and LCD display. The main objective of this paper is to compare various processors/microcontrollers which can be used to make a smart trolly. The two most prominent and widely popular processors are Arduino Uno and raspberry pie. These are compared on a variety of parameters such as cost, processing power/speed, compatibility with other hardware and software parts, etc.

II. IoT AND RFID TECHNOLOGY

a) Radio Frequency Identification Technology: RADIO frequency identification system (RFID) is an automatic technology and aids machines or computers to identify objects, record metadata or control individual target through radio waves[5], [23]. It is more resistant, safer, identifies products in a unique way, can provide other types of information, can make several simultaneous readings and it has a high range[20]. RFID systems typically consist of two components: an RFID tag and an RFID reader. UHF RFID tags are globally standardized under the ISO 18000 in particular and GS1 standards on EPC Global based on its application[22]. The RFID tag is a small electronic device that contains a microchip and an antenna. The microchip stores data, such as an identification number, and the antenna allows the tag to communicate with an RFID reader[2]. It is not necessary that this tag be directly within the reader's line of sight in order to be scanned. There are two types of RFID tags:

- Passive RFID tags: They do not have a power source and rely on the energy from the RFID reader to transmit data. They are typically smaller and less expensive than active RFID tags but have a shorter range.
- Active RFID tags: Active RFID tags have a battery that powers the tag and allows it to transmit data over a longer distance. They are typically used for tracking large items, such as shipping containers or vehicles.

The RFID reader is a device that emits radio waves and receives signals from RFID tags. When an RFID tag is within range of the reader, it communicates with the reader and sends data. The reader then processes the data and sends it to a computer system for further processing.

RFID technology is used in a variety of applications, such as tracking inventory in retail stores, tracking baggage in airports, tracking livestock on farms, and timing sporting events[21]. It has the advantage of being able to track objects without the need for a direct line of sight, which makes it more flexible than other tracking technologies.

b) IoT based on RFID Technology: IoT (Internet of Things) and RFID (Radio-Frequency Identification) technologies are often used in smart shopping carts to enhance the overall shopping experience for consumers. Here are some ways in which these technologies are used in smart shopping carts:

- RFID tags on products: RFID tags will be placed on products in the store, and RFID readers on the smart shopping cart can scan these tags to identify the products being added to the cart. This can help in keeping track of the items in the cart and can also help in automating the checkout process.

- Inventory management: IoT sensors are used to monitor the inventory levels in the store. This information is used to update the availability of products on the smart shopping cart, so customers can see which items are in stock.
- Personalized recommendations: IoT sensors can also be used to collect data on the customer's shopping behavior, such as the items they pick up, the products they spend time looking at, and their purchase history. This data can be analyzed to provide personalized product recommendations to the customer through the smart shopping cart's interface.
- Self-checkout: With the help of RFID and IoT technology, customers can use smart shopping carts for self-checkout. The smart cart can automatically detect the items in the cart, and the customer can pay using a digital wallet, credit card, or other payment methods through the smart cart's interface.

Overall, the use of IoT and RFID in smart shopping carts can help in making the shopping experience more efficient, convenient, and personalized for customers.

III. PROPOSED ARCHITECTURE FOR SMART CART:

- Bluetooth HC05 : It is used for short-range wireless data communication between two microcontrollers (a mobile app and a trolley). In comparison with other methods, the Bluetooth module can facilitate wireless serial data transmission easily [16]. Its operating frequency is among the most popular 2.4GHz ISM frequency band [4]. In Bluetooth 2.0, devices transmit signals at intervals of 0.5 seconds, reducing the workload of the Bluetooth chip and saving more sleeping time for Bluetooth. The module is equipped with a serial interface, making it easy to use and simplifying the overall design and development cycle[17].
- RFID RC522 Reader : This RFID RC522 Reader Module with a frequency of 13.56MHz is the cheapest RFID reader based on MFRC522, easy to use in various practical applications. The reader has an operating current of 13- 26 mA/3.3 volts DC, a standby current of 10-13 mA/3.3 volts DC, and sleep and peak currents of less than 80,30 microamps each. Its card reading distance is 0-60mm.
- RFID Tag : RFID tags provide the storage to store data. RFID passive tags which do not need any power supply from any battery has been used for the scope of this research, that's why RFID passive tags are much more efficient than active tags. When RFID passive tags come in a range of Electromagnetic waves produced by RFID reader then induction produces flux. Due to this flux in coil power generates to the chip[4],[12].
- Arduino UNO : Arduino Uno is a microcontroller board that utilizes the ATmega328 series controller [18],[19]. Arduino Uno provides developers and programmers with an integrated development environment that allows for easy execution of various operations such as writing, compiling, and uploading code to the microcontroller. It is an open-source prototyping platform that uses user-friendly hardware and software. Arduino Uno has a total of 14 digital input and output pins, as well as six analog inputs that enable communication with electronic components such as sensors, switches, motors, and more. Arduino Uno includes an ATmega328P MCU IC and other essential components like a crystal oscillator, serial communication, and voltage regulator that supports the microcontroller. The board operates at 5V, with a recommended input voltage range of 7-12V and an input voltage limit of 6-20V. The DC power on I/O pins is 40mA, and the DC power on 3.3V pins is 50mA. The board features 32 KB of Flash memory (0.5 KB used for the bootloader) and 2 KB of SRAM.

IV. COMPARISON BETWEEN ARDUINO UNO, RASPBERRY PI AND ARDUINO NANO ON VARIOUS INDUSTRY PARAMETERS:

Points Of Comparison	**Arduino Uno**	**Raspberry-Pi**	**Arduino Nano**
1. Cost	Rs.300-500	Rs.6000-8000	Rs.2000-3000
2. Memory	32 KB-Flash Memory 2KB - SRAM 1KB - EEPROM	1-4 GB RAM	32 K Bytes-Flash Memory 2K Bytes - SRAM
3. Clock Speed	16MHz	1.5Ghz	16MHz
4. Processor	ATmega328p	Quad-core 64-bit ARM-Cortex A72 running at 1.5GHz	ATmega328 16

Points Of Comparison	**Arduino Uno**	**Raspberry-Pi**	**Arduino Nano**
5. Power Requirements	The board can operate on an external supply of 6 to 20 volts.	Pi4B requires a good quality USB-C power supply capable of delivering 5V at 3A.	Arduino-Nano can operate at the 6-20V unregulated external power supply (pin 30), or 5V regulated external power supply (pin 27).
6. Power Consumption	200MW.	700MW.	200MW.
7. Temperature Range and Thermals	(-40 - 85) degree Celsius	(0-50) degree Celsius	40 - 85) degrees Celsius
8. Operating Voltage	5V	5V	5V
9. Memory Used	Program storage space (26%) Dynamic Memory(17%)	CPU usage - 25%	Program storage space (26%) Dynamic Memory(17%)
10. CPU Architecture	8-bit architecture	16-bit architecture.	8-bit architecture

V. METHODOLOGY

When a customer wishes to buy an item, they are required to add the product to a shopping cart[13],[14],[15]. Subsequently, an RFID reader located on the cart scans the RFID passive tag that is affixed to each product. The product information will be shown on the mobile app attached to the customer's shopping cart. The proposed system offers various services that customers can easily access through the interface. With these services, customers can efficiently select products, add them to their cart, and the cost will be added to the total bill. Once the shopping is completed, customers can make the payment, and the details will be sent to the central server. The system's map will also help customers locate products in the mall with sectional specifications for their convenience. This system enables customers to purchase a large number of products with minimal effort and in less time.

VI. RESULT

- Our analysis of the Arduino Uno and Arduino Nano microcontrollers revealed that both use similar amounts of program storage space and dynamic memory, with 26% program storage space and 17% dynamic memory being used while functioning.
- Additionally, both microcontrollers are suitable for implementing the RFID-based smart shopping cart project. In comparison, the Raspberry Pi has a 25% CPU usage and uses a VM size of 15.7 MB and RSS of 9.5 MB. Although it uses slightly more resources than the Arduino microcontrollers, the Raspberry Pi provides more flexibility for adding features. It is ultimately up to the specific needs of each project as to which microcontroller should be used. A more cost-effective choice for store applications is the Arduino Uno or Nano. Alternatively, the Raspberry Pi is recommended for more complex applications.

VII. FUTURE SCOPE

RFID-based smart cart systems can provide intelligent recommendations based on the customer's systems can be integrated with AI and ML algorithms to predict maintenance requirements for the carts. This can help retailers to proactively identify issues and perform maintenance before they become a problem, ensuring that the smart carts are always in good working condition.RFID-based smart cart systems can ensure secure communication between the carts and other devices, such as point-of-sale terminals, inventory management systems, and other systems that use RFID technology. This can help to prevent data theft or tampering during transmission. to offer personalized product recommendations, improve customer satisfaction, and increase sales. RFID-based smart cart purchase history, preferences, and real-time shopping data. This can help retailers proved to be suitable for implementation in retail stores of any size.

VIII. CONCLUSION

In conclusion, the RFID-based smart shopping cart project offers an efficient and convenient shopping experience with numerous advantages over traditional shopping carts, including faster checkout times, reduced human error, and improved inventory management. Our comparison of microcontrollers - Arduino Uno, Raspberry Pi, and Arduino Nano - for the project revealed that each has unique advantages and limitations. However, all three components The storage space required by each microcontroller is minimal, as most of the computation is being performed in the mobile app. The Raspberry Pi offers more flexibility for adding features, but at a higher cost than the Arduino Nano or Uno. The Arduino Nano and Uno are similar in functionality, with the Nano being more compact and portable but also more expensive than the Uno. In addition, the project's integration with a mobile app allowed for seamless transactions and ease of use, with additional features such as item information, discounts, and payment options. The compact size of all three components ensures minimal space usage, making it ideal for implementation in various retail environments.

Overall, the RFID-based smart shopping cart project has enormous potential for implementation in various retail environments, and the choice of microcontroller depends on the specific requirements of the project. For light applications in a store, the Arduino Uno is a more cost-effective choice, while the Raspberry Pi should be considered for more complex features.

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