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DESIGN OF AN INTELLIGENT RADIO FREQUENCY IDENTIFICATION (RFID) BASED CASHLESS VENDING MACHINE FOR SALES OF DRINKS

Okafor P. C.[1*], James G. G.[2], and Ituma C.[3]

[1]Department of State Services, Bayelsa State Command, Bayelsa State, Nigeria.
Email: peacindajp@yahoo.com, Tel: 08039325190.

[2]Department of Computing, Topfaith University, Nigeria,
Email: g.james@topfaith.edu.ng, Tel: 081073718671

[3]Department of Computer Science, Ebonyi State University, Abakaliki, Nigeria.
Email: itumachinagulum@gmail.com, Tel: 080256365402

[*]Corresponding Author's Email: peacindajp@yahoo.com, Tel: 08039325190.

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ABSTRACT: *This study examines the evolution of vending machines, emphasizing their integration with RFID technology for cashless transactions. Vending machines have transformed human-machine interaction, offering convenient access to products and services. Transitioning from coin-operated to RFID-enabled systems has revolutionized the industry, enhancing security, reducing costs, and improving user experience. Through exploration of technical specifications and design objectives, the research highlights RFID vending machines' potential to reshape consumer behavior and optimize operations. Traditional cash-based vending machines face challenges such as limited storage, recognition issues, and security concerns. To address these, the paper proposes an intelligent RFID-based cashless vending machine for drink sales. The system incorporates RFID technology for payment, allowing users to swipe cards and select drinks without cash involvement. Prototype development involved software design, utilizing C-language for multiproduct vending. Comparatively, the RFID-based system outperforms cash-based counterparts in efficiency, security, and sales tracking, presenting a superior solution for drink sales.*

KEYWORDS: Radio Frequency Identification (RFID), Vending Machine, Automated Retail, Technology Integration, Microcontroller, Intelligent, Intelligence Cashless System.

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INTRODUCTION

The advancement in technology has allowed human beings to interact with electronic gadgets as though they are human beings. This level of interaction is made possible due to the artificial intelligence exhibited by some of these gadgets.

Consumption has become an essential part of human life's basic routine activities, and machine-based sales play a vital role in today's busy life of our society. Machines are now dominating the modern lifestyle, and as vending machines are one of the machine-based sales, they are affecting human-machine relations positively. Vending machines are the (non-vendor) machines that provide edible and non-edible items such as snacks, beverages, tickets, and coffee and are breaking the limitations of locale and time, by providing its day-to-day services everywhere. Vending machines (VMs) are available in office buildings, shopping malls, metro/bus stations, airports, universities, traffic, and uptown areas. So, its benefits include a reduction in manpower as it doesn't need a vendor, flexibility in time, and time-saving as the distance between humans and Vending Machines (VMs) is less [1].

The core of all electronic gadgets exhibiting intelligence is the microprocessor or microcontroller. The microprocessor can accept inputs from the physical environment and process the input based on a set of instructions stored in memory and then give the desired output. The microprocessor with the memory together contained in a chip is called the microcontroller.

A microcontroller is a compact computing device housed on a single integrated circuit, comprising a processor core, memory, and programmable input/output components. These microcontrollers commonly include program memory in forms such as Ferroelectric RAM, NOR flash, or One-Time Programmable (OTP) ROM, along with a typically limited amount of RAM. Unlike microprocessors found in personal computers, which utilize multiple discrete chips, microcontrollers are tailored for embedded applications. They find extensive use in various automated products and devices, including automobile engine control systems, medical implants, remote controls, office equipment, household appliances, power tools, toys, and other embedded systems. By consolidating essential components onto a single chip, microcontrollers significantly reduce size and cost, enabling cost-effective digital control over a wide array of devices and processes [2].

Over time, the mechanisms and methodologies employed in the development of vending machines (VMs) have evolved to enhance security and better align with human needs. For instance, traditional physical display screens have been replaced with more advanced Liquid Crystal Display (LCD) screens. There has also been a transition from the Finite State Machine (FSM) model to the physical design of cash-based VMs, and now, a cashless-based approach is being introduced in our proposed methodology. The establishment of a cashless vending system has become imperative to address security threats and issues associated with cash billing systems in vending machines. The development and implementation of this system will enable consumers to utilize Radio Frequency Identification (RFID) cards for making payments, thereby enhancing convenience and security in vending transactions [3].

RFID technology has revolutionized payment systems in vending machines by introducing a novel cashless method, replacing traditional cash-based approaches. RFID vending machines (VMs) offer additional security measures and reduce manpower requirements. Security

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features include password protection, with users inputting passwords provided at the time of RFID purchase. An inherent advantage of RFID technology is its self-identification capability, which surpasses other technologies in efficiency. RFID implementation also leads to cost savings in sales expenses. With its versatility and wide-ranging applications, RFID technology is gaining traction and transforming various sectors, contributing to significant advancements in human life.

Vending machine

A vending machine, as described in [4], is a coin-operated device designed for dispensing merchandise. It operates automatically, offering a variety of items such as snacks, beverages, cigarettes, and lottery tickets to consumers upon insertion of money, a credit card, or a specially designed card. The concept of vending machines dates back to the early 1880s in England, where the first modern machines were developed to dispense postcards. Since then, vending machines have proliferated worldwide, with specialized models emerging to provide less conventional products beyond the typical offerings found in traditional machines.

A vending machine serves dual purposes: selling products and providing services to customers. It offers various products installed within its structure, each tagged with its unique price. Upon payment, the vending machine dispenses the purchased product from its bottom slot, making it available to the customer [4].

In vending machines where services are the primary focus, the service becomes accessible once payment is made. An example of such a vending machine is the Money ATM vending machine.

The earliest documented mention of a vending machine dates back to first-century Roman Egypt, in the work of Hero of Alexandria, an engineer and mathematician. Hero's machine functioned by accepting a coin, subsequently dispensing holy water. Upon coin deposition, it would land on a pan connected to a lever [5]. This action would trigger the lever to open a valve, allowing a portion of water to flow out. As the pan tilted under the weight of the coin, it would eventually tip-off, causing a counterweight to lift the lever and shut the valve. Coin-operated machines that dispensed tobacco were being operated as early as 1615 in the taverns of England. The machines were portable and made of brass [6]. An English bookseller, [7] devised a newspaper dispensing machine for the dissemination of banned works. Simeon Denham was awarded British Patent no. 706 for his stamp dispensing machine in 1867, the first fully automatic vending machine [6].

In the early 1880s, London, England saw the introduction of the first modern coin-operated vending machines, which dispensed postcards [4]. In 1883, Percival Everitt invented the machine, which quickly gained popularity at railway stations and post offices in London, England, distributing envelopes, postcards, and notepaper. The Sweetmeat Automatic Delivery Company, established in 1887, was the first company dedicated to installing and maintaining vending machines. By 1893, Stollwerck, a German chocolate manufacturer, had expanded vending machine usage, selling chocolate in 15,000 machines. They established separate companies in different regions to manufacture vending machines, offering a range of products including chocolate, cigarettes, matches, chewing gum, and soap.

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The first vending machine in the U.S. was built in 1888 by the Thomas Adams Gum Company, selling gum on New York City train platforms [6]. In 1897, the Pulver Manufacturing Company introduced a new concept by incorporating small figures into their machines, which would animate upon the purchase of gum. This innovation marked the inception of a novel type of mechanical device referred to as a "trade stimulator," aimed at further incentivizing purchases through added entertainment value.

Today, a multitude of vending machines exist, offering diverse products and services. Examples include soft drink vending machines, phone card vending machines, snack vending machines, ticket vending machines, and beverage vending machines. Notable options currently available in the market include the Kingston vending machine and the Sony vending machine, as depicted in Figure 1 below.

Figure 1: Kingston Vending Machine [4]

At airports, Kingston has installed vending machines offering a range of USB flash drives and SD cards. The aim is to expand these memory vending machines to major airports, mainline stations, and underground stations, with plans for additional high-traffic venues shortly [4].

Figure 2: Sony Vending Machine [4]

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The machine depicted in Figure 2 dispenses electronics such as Sony PSPs, memory cards, headphones, and various media formats including UMDs, DVDs, and CDs. This advanced machine features approximately 50 SKUs and a 15-inch touch panel interface. Sony utilizes sensors and internet connectivity to monitor the movement of products [8].

Vending machines employ three payment methods. While many machines offer change, modern ones accept paper money or credit cards. These machines can be categorized based on their payment methods as follows:

• Coin-operated vending machines.

• Note-operated vending machines.

• Prepaid operated vending machines.

There are three major problems with the payment method nowadays. That is a tank full of coins, the notes cannot be read and also the notes or coins are always stuck in the machine.

Once the coin box or tank reaches full capacity, the vending machine cannot accept any more coins, rendering it unable to facilitate further purchases, resulting in its temporary cessation. Some vending machines utilize a spiral mechanism to segregate and hold products. During vending, the spiral rotates, pushing the product forward for dispensing. Misalignment between the products and the spiral may impede the complete release of the product despite the spiral turning [4]. When a product becomes lodged in the middle of the vending machine, it obstructs the vending process. In response, the vending machine automatically halts its operation until the issue is resolved.

Another issue pertains to the payment method, where notes and coins may not be accurately read by the vending machine. For machines accepting notes, the bills must be in good condition, meaning they should be undamaged, unfolded, and original. Notes that are crumpled or dirty are often rejected by the vending machine's reader. Additionally, certain machines may not accept specific coins, such as quarters, leading to payment rejections [5] [9].

If coins or notes are inserted incorrectly into the vending machine, it can lead to payment issues and potential jams. In such cases, the only solution is to contact the vending machine company for repair assistance. Moreover, there's the challenge of using foreign currency coins that resemble the accepted coins, allowing users to purchase items at lower prices. This can result in discrepancies in the change given and may cause payment jams as the machine struggles to recognize different coins, leading to payment obstructions [4].

Design Components

i. Hardware Components

The choice of materials is not arbitrary but was done based on the engineering standards guiding each of the components used in the design work. For every expected output from a module of the vending machine work, components with slightly higher ratings and capacity are used for effective and better operation of the system.

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a. Switch-Mode Power Supply

A switch-mode power supply (switching-mode power supply or SMPS) is an electronic power supply that incorporates or uses a switch regulator to convert or control electrical power efficiently. Like other power supplies, an SMPS transfers power from a DC or AC source to DC loads, such as a personal computer, while converting voltage and current characteristics. This higher efficiency (thus lower heat dissipation) is the chief advantage of a switched-mode power supply.

b. The Microcontroller Unit

A microcontroller (sometimes abbreviated µC, uC, or MCU) is a small computer on a single Integrated Circuit (IC) containing a processor core, memory, and programmable input/output peripherals. Program memory in the form of Ferroelectric RAM, NOR flash, or OTP ROM is also often included on the chip, as well as a typically small amount of RAM. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general-purpose applications [10].

The microcontroller as used in the design work is the component that is saddled with the responsibility of carrying out the logical reasoning of the machine. The logical reasoning of the microcontroller is by the program written into the microcontroller. Arduino Mega is the microcontroller used for the machine design.

c. Arduino Mega Board

The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.

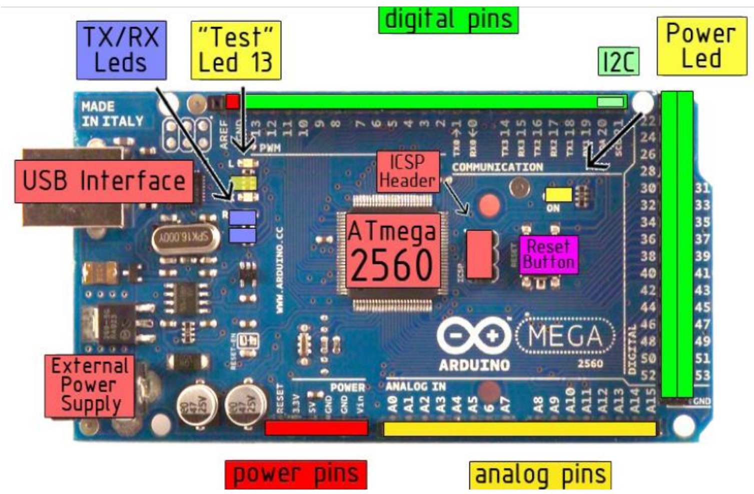

Fig. 3: Arduino Mega board

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The Arduino Mega2560 can be powered via a USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or a battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and V_{in} pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The Mega2560 differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

The power pins are as follows:

V_{IN}. The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.

5V. the regulated power supply is used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.

3V3. A 3.3 volt supply is generated by the on-board regulator. Maximum current draw is 50 mA.

GND. Ground pins.

Each of the 54 digital pins on the Mega can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

Serial: 0 (RX) and 1 (TX); Serial 1: 19 (RX) and 18 (TX); Serial 2: 17 (RX) and 16 (TX); Serial 3: 15 (RX) and 14 (TX). Used to receive (RX) and transmit (TX) TTL serial data. Pins 0 and 1 are also connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip.

External Interrupts: 2 (interrupt 0), 3 (interrupt 1), 18 (interrupt 5), 19 (interrupt 4), 20 (interrupt 3), and 21 (interrupt 2). These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.

PWM: 0 to 13. Provide 8-bit PWM output with the analogWrite() function.

SPI: 50 (MISO), 51 (MOSI), 52 (SCK), 53 (SS). These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language. The SPI pins are also broken out on the ICSP header, which is physically compatible with the Duemilanove and Diecimila.

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LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

I2C: 20 (SDA) and 21 (SCL). Support I2C (TWI) communication using the Wire library

The Mega2560 has 16 analog inputs, each of which provides 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and analogReference() function?

ii. The Software Design

The hardware components discussed earlier in this chapter would work independently on their own unless the software is introduced. The software interconnects the individual hardware by controlling the signal flow of each of the hardware components so as to function as one unit. The choice of programming language depends solely on the type of Microcontroller used [11-13]. Since the Arduino mega board was used for this work, the Arduino programming language was also employed to control the signal flow of hardware components. Though the Arduino Integrated Development Environment (IDE) can support both C & C++ programming languages. But the Arduino programming language was chosen which happens to be a blend of C & C++ programming languages though is more flexible and easy to understand because it is closer to human language [14-18].

a. UML Use-Case Diagram of the Proposed System

The use case diagram depicts all the actors in the RFID-based vending machine and how they interact with the system. The machine operator inputs new card information and updates the database accordingly. The customers use the card to purchase products from the vending machine.

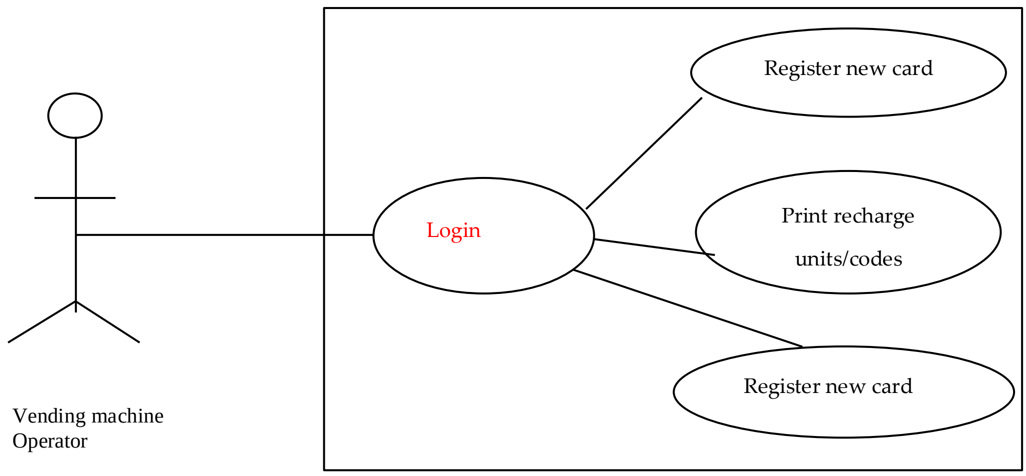

Fig. 4: Operator Use case diagram

Operator is role of person who is looking after new card registration and card maintenance.

The customers can use their card to make payment for products and they can also check the balance on their payment card.

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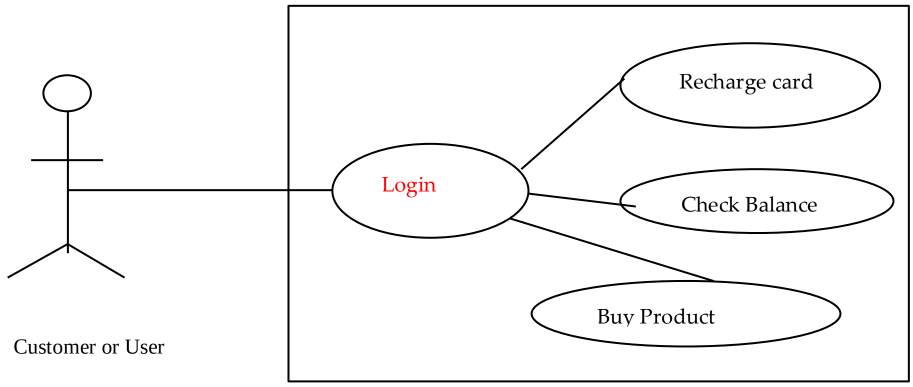

Fig. 5: Customers Use case diagram

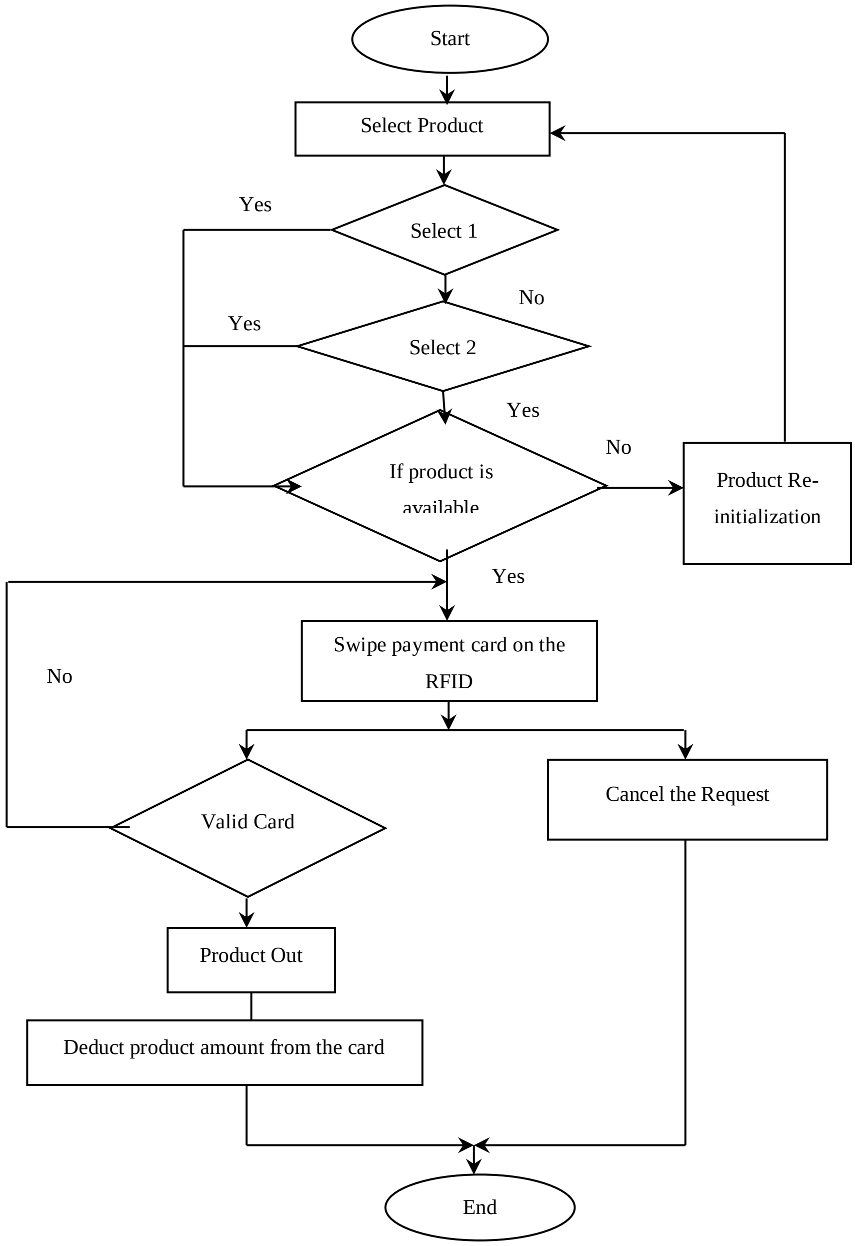

Fig. 6: Data Flow Diagram of the proposed Model

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METHODOLOGY

Methodology is the study of how to perform scientific research. It is the part of any analysis or research that is used to find out what type of data is maintained, what facts to find and look for, how to find them, and how to record them for usage [11]. Many methodologies include a diagramming notation for documenting the results of the procedure; an approach for carrying out the procedure; and an objective (ideally quantified) set of criteria for determining whether the results of the procedure are of acceptable quality [12].

i. In this work, prototyping methodology was used. A prototype is an original type, form, or instance of something serving as a typical example, basis, epitome, or standard for other things of the same category [13]. A prototype is built to test the function and feel of the new design before starting production of a product. Prototyping is the process of quickly putting together a working model (a prototype) in other to test various aspects of design, illustrate ideas of features, and gather early user feedback. Prototyping is often treated as an integral part of the system design process, where it is believed to reduce project risk and cock. Early visibility of the prototype gives the user an idea of what the final system looks like [14] [13].

The prototype used in this thesis considered the previous paying bills method for vending machines, the technology was developed to make a payment by using coins or notes. Here, we are making bill payments by rechargeable prepaid card and also making the link between the main systems to the subsystem to determine and detect the data like products available in subsystems and also whether the data subsystem is working properly or not. In the proposed system every single user is provided with an RFID tag card, by using this card, each one can access or buy the available products at the centers. Before using this card, we have to recharge these cards because it is prepaid cards. To vend the products the card must be swiped on the RFID reader module, which is interfaced to the microcontroller with serial interfacing. The microcontroller reads the information from the reader or module and asks the user to select the product required, which will be shown on the LCD of the screen. Then the user is required to select the required product number through a potentiometer which acts as an input to the microcontroller. After reading the value the microcontroller will check for the required balance in the smart card, if it is sufficiently available then the product selected will be dropped on the can. If there is no cash in the card, the system will communicate with the user by displaying “insufficient balance” on the LCD [19-22].

Data Collection Methods

The researcher relied on the following for data collection:

i. **Interview Method:** An unstructured interview is conducted with a few individuals within the sample frame to find out their opinions about the subject matter of the research. The operational method of cash-based vending machines was obtained.

ii. **Libraries:** Intensive and extensive use of the libraries both public and private ones are made. Secondary data are obtained from materials such as books, periodicals, Journals, magazines, and dailies. Such data are used mainly to provide the theoretical framework for the study. Also, materials were downloaded from the internet for this research work.

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Design Objectives of the Proposed System

The first objective of this project is to design a vending machine for the sale of drinks using RFID technology. To realize this objective, the following steps are taken:

i. Design a vending machine with a prepaid payment system (RFID card).

ii. Build the mechanical part of the vending machine.

iii. Build the electrical part of the vending machine.

iv. Build the software part of the vending machine.

v. Assembling and testing the vending machine that uses the prepaid system for payment method.

vi. Make the vending machine multiproduct, able to sell three different types of goods/items.

Specifications

A. Specifications of RFID Vending Machine

Table 1: Technical specifications of RFID

Type	Specificaions
Model	Mifare MFRC522
Type	Passive
Battery	Batteryless
Host Interfaces	SPI (serial peripheral interface)
Success/Accurate rate	Low power, high frequency
Strength from tag to reader	Very low
Frequency spectrum	HF (High frequency spectrum)/Passive
Frequency ranges in Hertz	13.56MHz (HF, Passive)
Bytes in UID (unique identification number)	4bytes
Range in meters	< 1m (3 feet)

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B. RFID Interfacing with SPI Bus Protocol

SPI (serial peripheral interface) a high-speed, small communication protocol is used to serially communicate data between the devices in SPI mode i.e., from SPI master to SPI slave and vice versa, in Figure 23. SPI is used for communication in a small range of distance, and developed by Motorola. RFID's three possible interfaces are SPI, serial UART, and I2C. In the proposed methodology, only SPI protocol for interfacing RFID is used, because the selected RFID model RC522 communicates in a small range of < 1 meter.

Microcontroller Arduino Mega (AT-mega 2560) acts as an SPI master, and RFID RC522 as an SPI slave in serial communication from master to slave. SCLK serial-clock generated by SPI master, MOSI master-output slave-input (master to slave serial-data transfer), MISO master-input slave-output (slave to master serial-data transfer), and SS slave-select when low allows that particular slave to start communication with master, are the four prime bus-lines of SPI bus protocol used in communication. SPI data communication is done by an 8-bit data shift register i.e., in one clock, one bit of data goes from master to slave, and in the next clock one bit goes from slave to master, this is how in 16 clocks the contents of 8-bit master and 8-bit slave register are swapped [23-25].

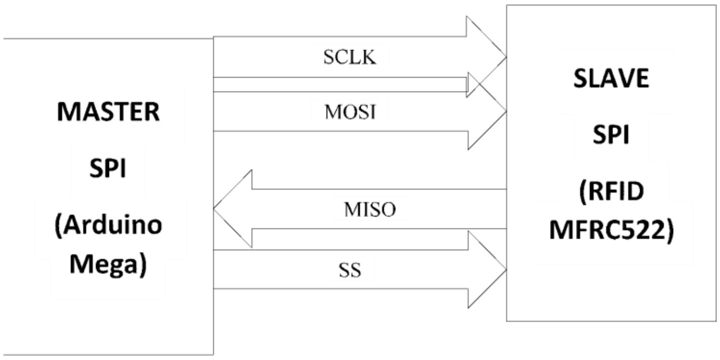

Fig. 7. SPI Arduino Master, RFID Slave serial interfacing

Data communicates with a B_D baud rate that shows the number of symbols transmitted per second. B_D is generated in master mode, with a sequence of divider (2 to 128 range) stages. The Baud rate register contains 8 data that help to initialize a value that divides the bus clock. The baud-rate division is done by the following equations:

$$B_D divisor = (SPI_{PB} + 1).2(SPI_{SB})$$

$$B_D = B_{clk} / B_D divisor$$

Where:

BD = Baud Rate

SPIPB = SPI baud rate pre selection bits

SPISB = SPI baud rate selection bits

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BCLK = Bus clock

BD divisor = Baud Rate Divisor

C. IR Sensor Specification

IR sensors consist of a transmitter and receiver LED for detecting the object according to adjustment of sensitivity. Its working is based on Reflected light incidents on reverse-biased IR sensors. When photons are incident on the reverse biased junction of this diode, electron-hole pairs are generated. As a result reverse leakage currents were found. This IR sensor is used for detecting the motor rotation, according to a selection of an item and also the amount of an item.

Fig. 8: IR Sensor

D. Arduino Mega microcontroller Specification

The Arduino Mega is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins of which 15 can be used as PWM outputs), 16 analogue inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a reset button, a power jack, and an ICSP header. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started.

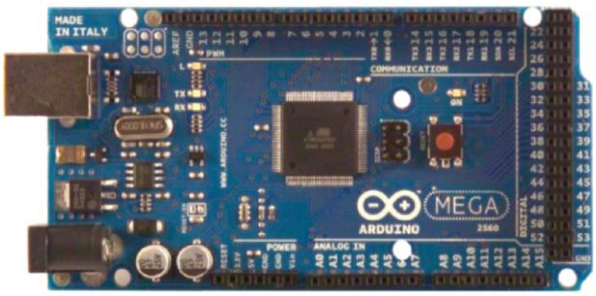

Fig. 9. Arduino Mega

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Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	54 (of which 14 provide PWM output)
Analog Input Pins	16
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	256 KB of which 8 KB is used by bootloader
	SRAM 8 KB
EEPROM	4 KB
Clock Speed	16 MHz

Schematic Diagram of the Vending Machine

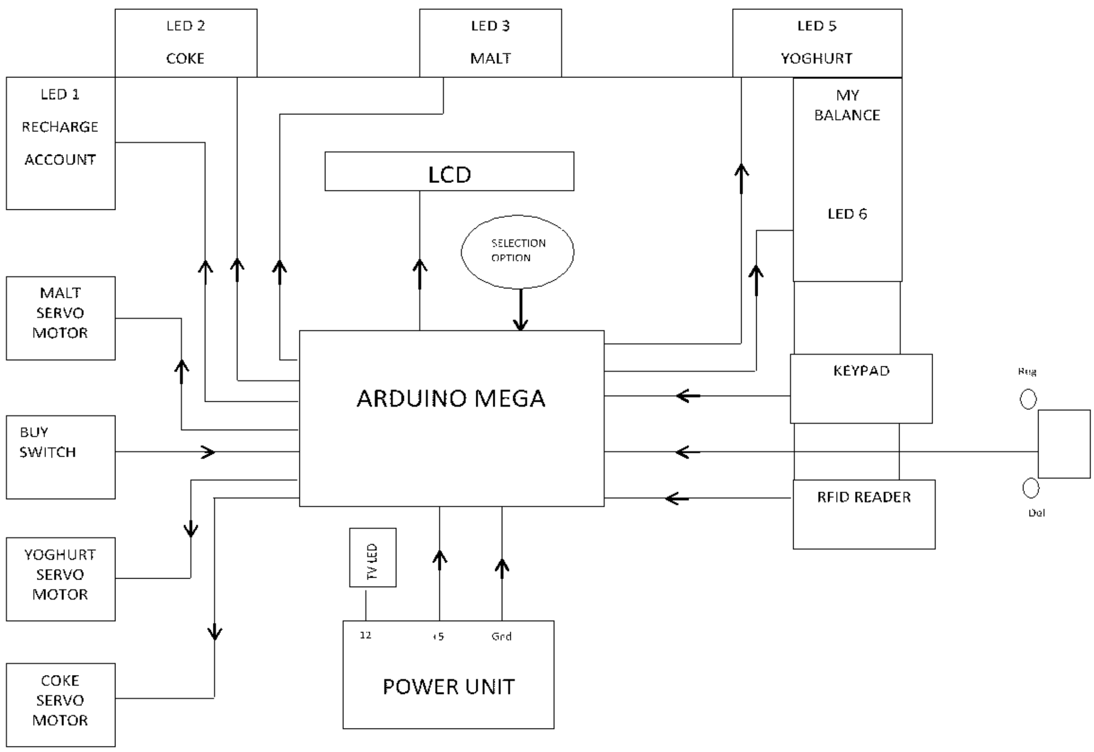

Fig. 10: Schematic diagram of the Vending Machine

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In the above figure 10, the layout of the vending machine is shown. As shown in the figure when the system gets a power supply the microcontroller will go on stage and it will run the loaded program. According to the program "Welcome, please swipe card" will display on the LCD screen. Then customer will swipe a valid card and select the required product by pushing the respective pushbutton. Then the microcontroller will further process the amount and make the deduction. Once deduction is made, the LCD will show the balance left while the servo motor will turn as programmed in the microcontroller and the items will fall at the bottom of the vending machine. The system is divided into two cards; the master card and the customer card.

In the program, a certain card(s) number(s) is/are specified as MASTER. The system on START, waits until a card is swiped. It reads the card and checks if it is the MASTER. (The master card should only be used by the machine owner and only when he intends to either Register a New Account (New customer) or Delete an existing one. Before the MASTER card is used, the operator should check the DEL/REG Switch to make sure his choice is selected. If DEL is selected, the program asks the operator to swipe the card he wishes to terminate the account. When the card is swiped, the card reader reads it, and checks to see if the card has an account. If the card doesn't have an account with the machine, a message saying the same is printed else the account will be deleted and the holder will not be able to make use of it. The message, DELETE SUCCESS will be printed. The program returns to wait for the customer.

If REG is selected, the program asks the operator to swipe the card he wishes to register an account with. When the card is swiped, the card reader reads it, and checks to see if the card has an existing account. If the card has an account with the machine, a message saying the same is printed else the new account will be created and the holder can now make use of the card and the account. In creating the new account, the program asks for the holder's first name which should be typed in, creates a purse with BALance = 0, then prints the message, REG SUCCESS.

On the other hand, If the card swiped in the first place is not a MASTER card, the program goes to a set of customers list and searches to see if the customer's card Num is there. If it is not, it prints an INVALID CARD and then waits for another customer.

If YES, the program asks the customer to select the product/Option of his interest (1, 2, 3, 4or 5) and then press the BUY button. The Options run through.

1. Maltina

2. Coke

3. Yoghurt

4. Recharge

5. Check BAL

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If Option 1 is selected, the program compares the current Balance with the product cost. If the Balance is less, it prints “INSUFFICIENT BALANCE” else it executes the signal that will dispense a can of Malt. The customer’s new account Balance is computed and printed. (Note: A message of appreciation is also printed). The program returns to wait for another customer.

If option 4 is selected, the program prompts the customer to enter a recharge code which it reads. It compares the code with an already uploaded code in the Recharge codes array. If not found, print INVALID CODE. If found, the program decodes the Naira value of the entered code and adds it to the current Balance. The new account balance is printed. The program returns to wait for another customer.

If Option 5 is selected, the program finds and prints the customer’s Balance. The program returns to wait for another customer.

E. Infrared (IR) Sensor

The Infrared (IR) sensor transmits Infrared light and receives its echo. Echoes can only be received when the infrared light hits a target then the reflected rays will be received by the IR sensor. It is much more like a RADAR system [26-27]. This is the device that senses whether there are products in the vending machine or not. The IR Sensor adopted for this design is the Sharp GP2Y0A21YK0F which is shown in Figure 11 below.

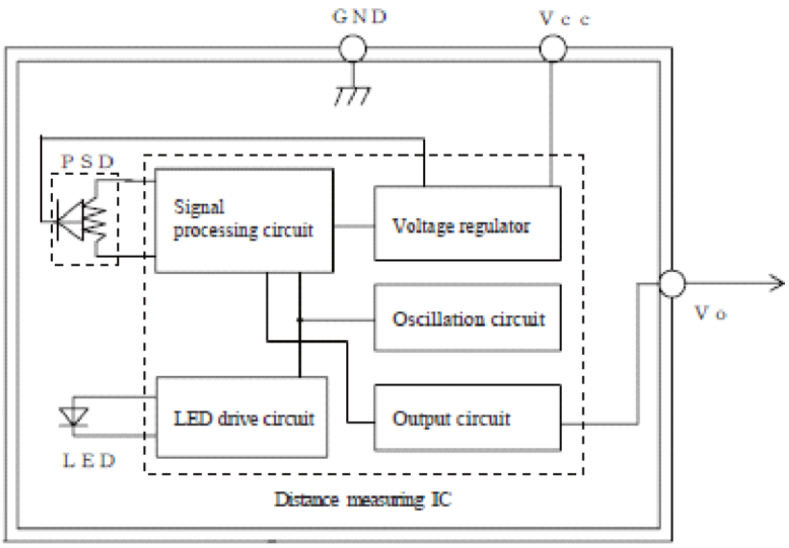

Fig. 11: Block diagram of IR Sensor (source: Sharp GP2Y0A21YK0F data sheet)

The GP2Y0A21YK0F Distance Measuring Sensor unit, is composed of an integrated combination of PSD (position sensitive detector) IRED (infrared emitting diode), and a signal processing circuit. The variety of the reflectivity of the object, the environmental temperature, and the operating duration do not influence easily to the distance detection because of adopting the triangulation method. This device outputs the voltage corresponding to the detection distance. So this sensor can also be used as a proximity sensor. The sensor has a Distance measuring range of 10 to 80 cm, its output signal is Analog output type, it has an approximate Consumption current of 30 mA, and Supply voltage of 4.5 to 5.5 V.

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As used in this design, if there are products in the vending machine the proximity distance will be shorter, but when the distance goes beyond a chosen range, it will indicate no product on the machine.

Vending Machine Block Diagram Design

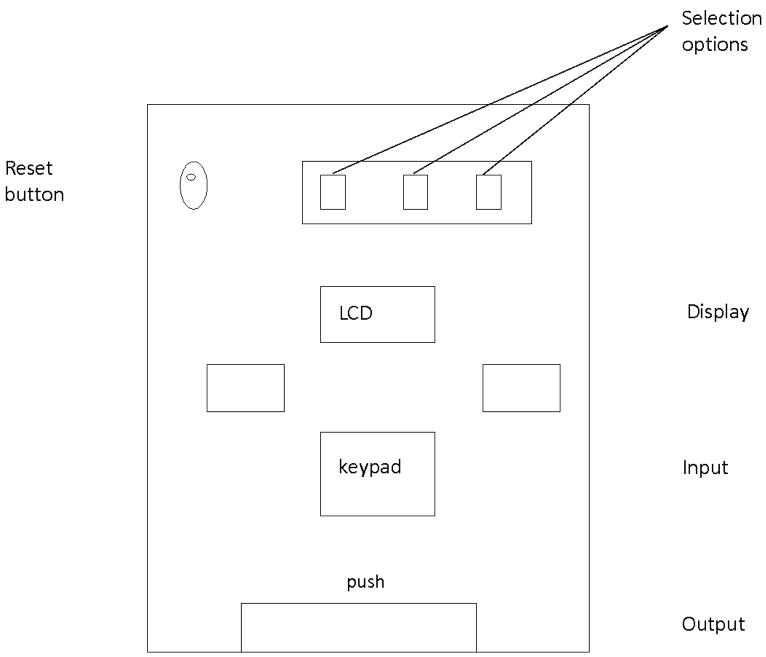

Fig. 12: Vending machine block diagram

Algorithm

The approach considered in this research is the AES algorithm. It is a key-iterated block cipher: it consists of the repeated application of a round transformation on the state. The number of rounds is denoted by N r and depends on the block length and the key length. The ciphering key is expanded to a schedule key that is used (partitioned to round keys) for encryption, which converts plaintext to an unintelligible form called ciphertext; decrypting the ciphertext however, converts ciphertext back into its original form, called plaintext. AES algorithm has three different combinations according to Nk that might be 4, 6, or 8 words as shown in Table 2.

Table 2: Ciphering Key-block combinations

Key Length (N_k words)	Block Length (N_b words)	Number of Rounds N_r
4	4	10
6	4	12
8	4	14

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The algorithm is designed to use keys of length 128, 192, or 256. It works on one block of 128 bits at a time, producing 128 bits of ciphertext. There are 10 rounds, after an initial XOR'ing (bitwise addition mod 2) with the original key (assuming a key length of 128). These rounds, except for the last, consist of 4 steps (layers), called **ByteSub**, **ShiftRow**, **MixColumn,** and **AddRoundKey**.

The four fundamental transformations of the algorithm are as follows:

- **SubBytes:** In this part, the elements of the input are substituted by values from the sBox matrix.
- **The Shiftrows:** In this part, the rows of the state are cyclically shifted over different offsets. Row 0 is not shifted; row 1 is shifted 1 byte, row 2 over 2 bytes, and row 3 over 3 bytes.
- **MixColumn:** In this part, the columns of the state are considered as polynomials over GF (2^8) and multiplied modulo $x^4 + 1$ with a fixed polynomial c(x) given by:

  $C(x) = \text{'03'}\ x^3 + \text{'01'}\ x^2 + \text{'01'}\ x + \text{'02'}$
- **Key Addition:** In this part, the round key is applied to the state by simple bit-by-bit XOR.

Generating Fixed Key Algorithm

Function generating the fixed keys. Output matrix of 2048 elements.

```
Begin
  For i = 0 to 2047 step by 1
Fixedkey = generate a random number
End for
Return the generated numbers
End Function
```

Cipher Algorithm

The ciphering algorithm is shown below.

```
Function decipher
Input Nk plain file
Output ciphered file
Begin
Open ciphered file for writing
Open plan file for reading
```


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While it is not the end of the file do

Read 16 bytes from the input file

Convert the 16 bytes to hexadecimal format

Call scheduled key from a fixed matrix

Ciphered data block = cipher (Nk, input, schedule key)

Write ciphered data block to the output file

End while

End function docipher

Deciphers Algorithm

Function do Decipher

Input: ciphered file, schedule key start point, Nk

Output: Plain file

Begin

Open the ciphered file for reading

Open plain file for writing

While it is not the end of the file

Read 32 bytes as a ciphered data block

Schedule key = fixed keys

Plain text = decipher (Nk, schedule key, ciphered data block)

Convert plaintext from hexadecimal to string

Write the plain block to the plain file

End while

End Function

CONCLUSION

In conclusion, the integration of RFID technology into vending machines represents a significant milestone in the evolution of automated retail systems. By enabling cashless transactions and enhancing security measures, RFID vending machines offer unparalleled convenience and efficiency to both consumers and operators. The adoption of microcontrollers and advanced sensors further enhances the functionality and versatility of these machines,

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paving the way for innovative applications and improved user experiences. As the vending industry continues to evolve, it is imperative to embrace emerging technologies and design methodologies to meet the changing needs and expectations of modern consumers.

Future work

Future work of this vending machine should be improved by adding toll-free number in case of any failure.

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