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Implementation of a Radio Frequency Identification (RFID) Based Cashless Vending Machine

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ABSTRACT: This paper reports the Implementation of a Radio Frequency Identification (RFID)-based multiproduct vending machine. It is designed to automatically dispense drinks such as coke, malt and yogurt using RFID prepaid method system. After a careful analysis of the existing system, noting its shortcomings, a new system was designed and developed such that the shortcomings of the old system were carefully overcome. The system was designed using Microcontroller (Arduino Mega board), RFID tag/card reader, servo, Liquid Crystal Display (LCD) and other electronic devices. A prototyping methodology was adopted and the machine parts (hardware and software) were designed in modules. These modules were then separately tested and found to be functioning as desired. They were then integrated to form the finished product. A C-language-based software that is able to drive a multiproduct vending machine was designed and implemented in this work and it made the hardware components function in a well-coordinated manner. The customer can buy a product using an RFID card by swiping the card across the RFID card reader, then the embedded system reduces the amount from the card, shows the balance on the LCD display, and the product which is stacked in the machine plunges out of each funnel inside the machine (this is controlled by a servo attached to the microcontroller) and accessed via the dispensing unit outlet. The vending machine developed in this thesis uses a PC as a guide to connect to the machine, especially for generating recharge codes. The RFID-based multiproduct vending machine was compared with the cash-based alternative and found to outperform it in terms of flexibility, efficiency, and security and has a better way of managing the financial return to the business due to the prepaid method of recharging the RFID card.

Keywords: LCD, Microcontroller, multiproduct vending machine, RFID-based Multiproduct.

1. INTRODUCTION

The vending machine is a coin-operated machine for selling merchandise (*Holcombe, 2017)*. A vending machine is an automated machine that provides items such as snacks, beverages, cigarettes, and lottery tickets to consumers after money, a credit card, or a specially designed card is inserted into the machine. The first modern vending machines were developed in England in the early 1880s and dispensed postcards. Vending machines exist in many countries, and in more recent times, specialized vending machines that provide less common products compared to traditional vending machines have been created and provided to consumers.

A vending machine has two functions namely, selling of products and services to the customers. A vending machine sells the products that are installed into the body, each with its own different price. After paying, a product may become available by the machine releasing it at the bottom of the vending machine (Holcombe, 2017). For the vending machine that provides service as its main function, the service also may become available after payment is inserted. An example a of service vending machine is a Money ATM vending machine.

There are three techniques of payment used with vending machines. Many vending machines are capable of giving change, and some of the more modern ones accept paper money or credit cards. Vending machines may be classified according to the technique of payment as follows:

2. • Coin-operated vending machines.
3. • Note-operated vending machines.
4. • 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.

5. When the coin box is filled, no more coins can be accepted. When the tank is filled, no more coins can be accepted. This will mean that no more purchases can be made, thus vending machines will stop. Certain vending machines use a spiral kind of mechanism to separate and hold the products. When the machine vends, the spiral turns, thus pushing the product forward and falling down to be vented. If the products and the spiral are misaligned, the spiral may turn but not fully release the product (Kerry, 2002). The product will stick in the middle of the vending machine. The vending machine automatically will stop operation when this condition occurs.

Secondly, the problem related to the payment method is notes and coins cannot be read. For vending machines using notes as a method of payment, the notes must be in good condition. The term good condition refers to the good shape of the notes, not folded, and the original one. When using notes in bad condition such as crumpled and dirty, the vending machine cannot read the note and then rejected the payment. Also, some machines may not accept quarters and other coins.

Actually, when the coin or the notes inserted are not in the right direction, this problem will occur. The only way to remove the notes or coins stuck is to call the vending machine company to repair that machine. There is, also, the problem of using a coin of a foreign currency that has the same size and shape as the coin accepted by the machine to get cheaper merchandise and sometimes change that might have more value than the originally inserted foreign coin. Using different coins will make the vending machine have a problem with recognition and lastly the payment will stuck into the machine (Kerry, 2002). The first RFID application was the "Identification Friend or Foe" system (IFF) [Wiki-RFID]

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[Wizard Wars] and it was used by the British in the Second World War. Transponders were placed into fighter planes and tanks, and reading units could query them to decide whether to attack. The successors of this technology are still used in armies around the world. The first commercial RFID application was "Electronic Article Surveillance" (EAS). It was developed in the seventies as a theft prevention system. It was based on tags that can store a single bit. That bit was read when the customer left the store and the system would sound alarm when the bit was not unset. In the end-seventies, RFID tags made their way into agriculture for example for animal tagging. In the eighties, RFID technology got a boost when Norway and several US states decided to use RFID for toll collection on roads [EZ-Pass]. In addition to toll collection, the following decade brought a vast number of new applications, such as ski passes, gasoline cards [Speed Pass], money cards, etc. In 1999 the Auto-ID Center at MIT was founded. Its task was to develop a global standard for item-level tagging. The Auto-ID was closed in 2003 after completing the work on the Electronic Product Code (EPC). At the same time, the newly founded EPC Global Inc. continues the work. The probably first paper related to RFID technology was the landmark paper by Harry Stockman, "Communication by Means of Reflected Power" in October 1948. The first patent on RFID was issued in 1973 for a passive radio transponder with memory [US. Patent 3,713,148].” (C Jechlitschek, 2006). This paper proposes the design of an intelligent RFID-based cashless vending machine for the sale of drinks. The proposed system is made up of a multi-select drinks machine with RFID based payment system. The user will swipe RFID payment Card on the machine and then select the drink he/she wants to buy. The card system includes the RFID which consists of an RFID reader and RFID tags. Using these tags drinks can be vented without human interaction or the involvement of fiscal cash. A prototyping methodology was used to achieve the software design aspect of the proposed system which considers the previous paying bills method for vending machines and makes payments by using coins or notes. C-language-based software that is able to drive a multiproduct Vending Machine was developed in the course of this paper; An RFID payment system was also incorporated to make the Vending Machine cashless in operation. When this RFID-based Vending Machine is compared with the cash-based alternative, it is noted that the RFID-based has outperformed the cash-based one in terms of efficiency, security, and sales tracking and it is, therefore, a better machine used for the sale of drinks.

2. LITERATURE REVIEW

Physical object identification has become increasingly more important as trade and transport markets have grown. The first automatic identifier for products which is still used on a large scale today was the barcode. Barcodes, however, have their flaws such as the need to align the barcode with the scanner and being able to only scan one product at a time. Better auto-ID systems have therefore been developed. A well-known auto-ID system that lacks the aforementioned flaws is radio frequency identification (RFID). RFID technology which uses radio waves in order to identify or track a small chip (RFID tag) that is attached to a physical object is envisioned as a replacement for its barcode counterpart.

An RFID device-frequently called an RFID tag is a small microchip designed for wireless data transmission. It is generally attached to an antenna in a package that resembles an ordinary adhesive sticker. The microchip itself can be as small as a grain of sand, some 0.4mm2 (Juels, 2005). An RFID tag transmits data over the air in response to interrogation by an RFID reader. Advocates of RFID see it as a successor to the optical barcode familiarly printed on consumer products with two distinct advantages:

i. **Unique Identification:** A barcode indicates the type of objects on which it is printed e.g. “This is a 100g bar of ABC brand, 70% chocolate”. An RFID tag goes a step further. It emits a unique serial number that distinguishes it among many millions of identically manufactured objects; it might indicate e.g. that “This is 100g bar of ABC brand, 70% chocolate, serial No: 897348738”.
ii. **Automation:** Barcodes, being optically scanned require line-of-sight contact with readers and thus careful physical positioning of scanned objects. Barcode scanning requires human intervention. In contrast, RFID tags are readable without line-of-sight contact and without precise positioning. RFID readers can scan tags at rates of a hundred per second. For example, an RFID reader by a warehouse dock door can scan stacks of passing crates with high accuracy (Juels, 2005).

Radiofrequency identification (RFID) is the wireless use of electromagnetic fields to transfer data, for the purposes of automatically identifying and tracking tags attached to objects. The tags contain electronically stored information. Some types collect energy from the interrogating radio waves and act as a passive transponder.
Other types have a local power source such as a battery, and operate at hundreds of meters from the reader. Unlike a barcode, the tag does not necessarily need to be within the line of sight of the reader and may be embedded in the tracked object. Radiofrequency identification is one method for Automatic Identification and Data Capture. A sample of RFID tags and readers is shown in Figure 1 below.

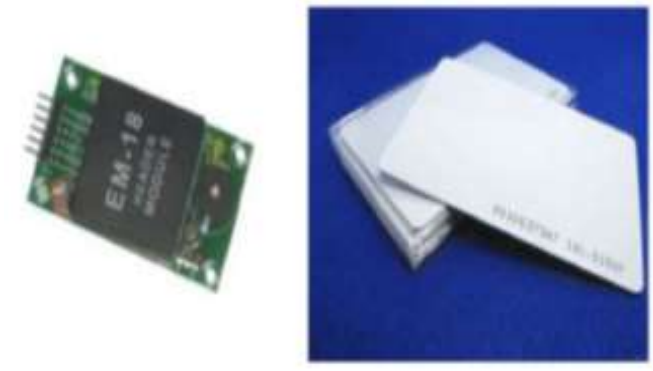

Figure 1: RFID tag and reader (Juels, 2005).

A radio frequency identification system uses tags or labels attached to the objects to be identified. Two-way radio transmitter-receivers called interrogators or readers send a signal to the tag and read its response. RFID tags can be either passive, active, or battery-assisted passive. An active tag has an onboard battery and periodically transmits its ID signal. Tags may either be read-only, having a factory-assigned serial number that is used as a key into a database, or may be read or written, RFID tag contains two parts: an integrated circuit for storing and processing information, modeling and demodulating a radio frequency signal and antenna for receiving and transmitting the signal. Tag information stored in nonvolatile memory. RFID reader transmits an encoded radio signal to interrogate the tag (Juels, 2005).

The RFID tags receive the message and respond with its identification and other information. This may be a unique tag serial number or other specific information.

2.1 How the Radio Frequency Identity Works

The Government of the Hong Kong Special Administrative Region (2008), in their report on "RFID SECURITY," explains that "Radio Frequency Identification (RFID) technology is a non-contact, automatic identification technology that uses radio signals to identify, track, sort and detect a variety of objects including people, vehicles, goods and assets without the need for direct contact (as found in magnetic stripe technology) or line of sight contact (as found in bar code technology). RFID technology can track the movements of objects through a network of radio-enabled scanning devices over a distance of several meters".
They said a "device called an RFID tag (or simply a tag) is a key component of the technology. An RFID tag usually has at least two components:

1. An integrated circuit for modulating and demodulating radio signals and performing other functions;

2. An antenna for receiving and transmitting the signal.

An RFID tag can perform a limited amount of processing and has a small amount of storage. RFID tags are sometimes considered to be enhanced "electronic barcodes". RFID tags that do not have any integrated circuit are called chipless RFID tags (also known as RF fibers). These tags use "fibers or materials that reflect a portion of the reader's signal back and the unique return signal can be used as an identifier". Systems that make use of RFID technology are typically composed of three key elements:

1. An RFID tag, or transponder, carries object-identifying data.

2. An RFID tag reader, or transceiver, reads and writes tag data.

3. A back-end database, that stores records associated with tag contents.

Each tag contains a unique identity code. An RFID reader emits a low-level radio frequency magnetic field that energizes the tag. The tag responds to the reader's query and announces its presence via radio waves, transmitting its unique identification data. This data is decoded by the reader and passed to the local application system via middleware. The middleware acts as an interface between the reader and the RFID application system. The system will then search and match the identity code with the information stored in the host database or backend system. In this way, accessibility or authorization for further processing can be granted or refused, depending on results received by the reader and processed by the database".

3. SYSTEM ANALYSIS

3.1 Analysis of the Existing System

Here, a description of VM including intelligent approach and challenges are considered. Basically, VM provides several different types of items when money is inserted into it. The VMs are more practical, easy to use, and accessible for users than the standard purchasing method. They can be found everywhere for different kinds of products such as snacks and cold drinks, coffee, tickets and diamonds, and platinum jewelers. The efficient implementation of these machines can be done in different ways by using a microcontroller and FPGA board. Figure 2 shows an abstract example of a VM.

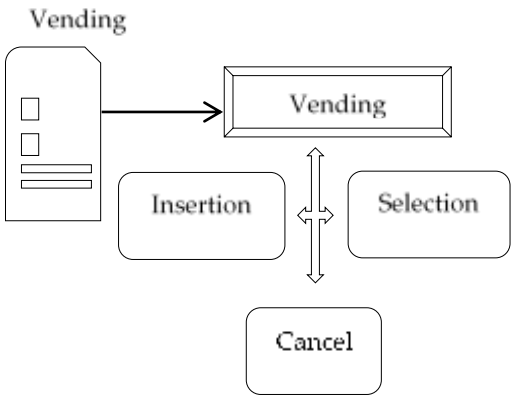

Figure 2: Basic Operations of VM.

3.2 Basic Operation of VM

1. The user inserts money, money counter sends to the control unit the amount of money inserted in the VM by the user.

2. The operation buttons are active to choose the products that people like. According to the VM's internal program, VM dispenses the products when people insert the correct amount.

3. If the program is designed to return the change, VM will return the change.

4. When a selected product is not available, VM will reject the service.

Initially, after switching on the power supply, the reset button is pressed to initiate the machine. After this, the product is selected and then the coin has to be inserted into the coin slot. Then, the coin sensor checks the validity of the coin and if it is valid, according to the training given to the box, it will accept it or else if it finds the coin invalid it will return it back. The machine will check whether the product is available or not. If the machine has a product, then the machine will go to product state and it will be delivered at the product output. If the product is not available in the machine then the control unit will demand servicing, and after service, the machine will be reset. Then the desired output or selected product will come out.

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3.3 Limitations/weaknesses of the Existing System

The existing vending machine payment system suffers from the following challenges.

1. Since vending machines are usually displayed in public areas they can suffer vandalism especially due to the money tank/holder installed in the body.

2. Logistics can also be challenging, as a coin vending machine requires someone to empty the machine each day as the coin holder can fill rather quickly.

3. Some older coins are not easily readable by the mechanisms.

4. If the product is out of stock, then also the vending machine will accept the money and the client will not get their money back.

If a fake coin of the same thickness, metal, and weight is made then, the coin detector might accept it, but it won't have 100% efficiency.

4. THE PROPOSED SYSTEM

The design of vending machines has two approaches; the hardware component design and the software design.

This paper was implemented using various components that are organized in a specific way so that the device is small and portable. Each component has a specific function to perform. The project is basically divided into three parts: mechanical, electronics, and display unit. The vending machine is designed and operated by using RFID in place of using coins. The internal circuit consists of a servo motor, LCD display, keypad, servo drive motor, Arduino Mega microcontroller, Potentiometer, RFID card reader, 2way switch, Push button, buzzer, and IR sensor.

4.1 Advantages of the Proposed System

The proposed system has the following advantages.

1. The whole process is automated such that one can be able to use it when the transaction is done in the correct way according to how the machine is programmed.

2. It gives the clients a free choice to purchase products at any time of the day. One can shop for his or her intended product 24x7 hours, throughout the year.

3. Diversity in terms of the products can be handled by the vending machine.

4. Most vending machines are stationed at strategic points, which makes it convenient and time-saving because of the surety of getting what the customer wants.

5. It is card payment based and therefore the issue of lost money by the vendor is eliminated

6. It is a one-time investment on the side of the owner who doesn't need a lot of running expenses to operate. Reduction of overhead costs by not hiring staff only increases the profit margin for the owner making it a success-bound venture.

5. RESEARCH METHODOLOGY

Methodology is the study of how to perform scientific research. It is 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. 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. There are different types of software design and research methodologies which include:

1. OOADM- Object-Oriented Analysis and Design Methodology
2. SSADM- Structured Systems Analysis and Design Methodology
3. Waterfall Methodology
4. Prototyping Methodology

In this thesis, 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. 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.

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 like subsystem is working properly or not. In the proposed system each and every single user is provided with a 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 on the card, the system will communicate with the user by displaying "insufficient balance" on the LCD.

5.1 Data Collection Methods

The researcher relied on the following for the purpose of data collection:

1. **Interview Method:** Unstructured interview is conducted with a few individuals within the sample frame to find out their opinion about the subject matter of the research. The operational method of cash-based vending machines was obtained.
2. **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 the purpose of this research work.

5.2 Specifications of RFID Vending Machine

Table 1: **Technical specifications of RFID vending machine**

Type	Specifications
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)

6. SYSTEM IMPLEMENTATION

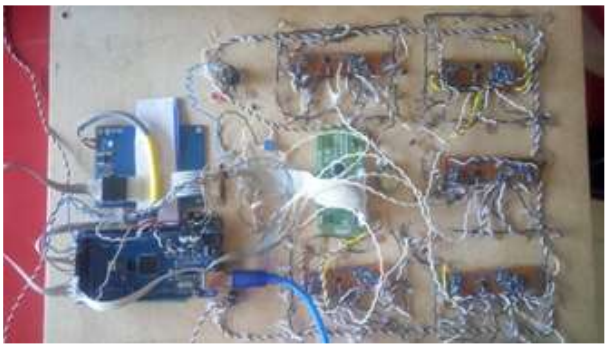

Figure 3: Development Board Implementation: 89V51RD2 Flasher Board–Interface–RS232

This board is a general purpose 40 pins 8051 development board with an onboard power supply circuit, RS232 port for serial interface with a computer and other serial devices, reset switch, power status LED and a general-purpose switch and LED. The board is compatible with the AT89S51/52 and the P89V51RD2 microcontrollers. The P89V51RD2 allows serial programming and can be programmed directly with this board through a serial connection to a PC without the need for an additional external programmer.

(a) Features

i. Onboard MAX232 interface circuit for easy communication with a computer and other serial devices
ii. DC plug-in jack for power input
iii. The onboard bridge rectifier enables the board to accept both AC and DC input voltages
iv. Onboard 5V regulator(LM7805) with filtering capacitors and heatsink
v. Power Status LED(Green) and a general

(b) Purpose User LED(Red)

i. Onboard quartz crystal 11.0592 MHz oscillator circuit
ii. Port extensions for all ports
iii. External pull-up resistors for Port 0
iv. Vin, 5V and Gnd bus provided

Figure 4: Product Input Box

The machine is designed to have provisions for the following:

1. Product Selection Box
2. Account Recharge
3. Check Balance
4. Card Swipe
5. Delete button
6. Reg button

Each of the buttons executes a particular function assigned to it as shown in Figure 5.

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The vending machine is loaded with drinks for customers to buy. For the design of the vending machine operations, it is required that the customer will have a card for making payment for the purchases.

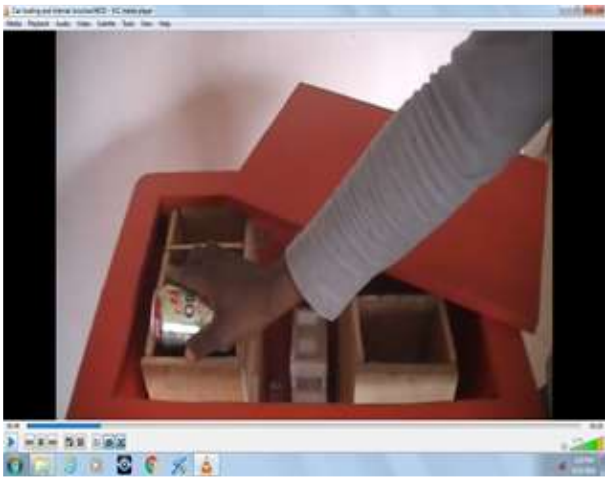

Figure 5: The vending machine loading slot

It is specified that the customer should swipe the card on the machine to validate the payment card and check if it has enough balance to proceed with the purchase as shown in figure 8.

Figure 6: Machine requesting for Card to be swiped

After swiping the card, the machine displays the customers balance as shown in Figure 9

Figure 7: Vending machine showing the customer's account balance

The machine will request that the user should select the product that he/she wants if the card is well-funded as shown in Figure 10.

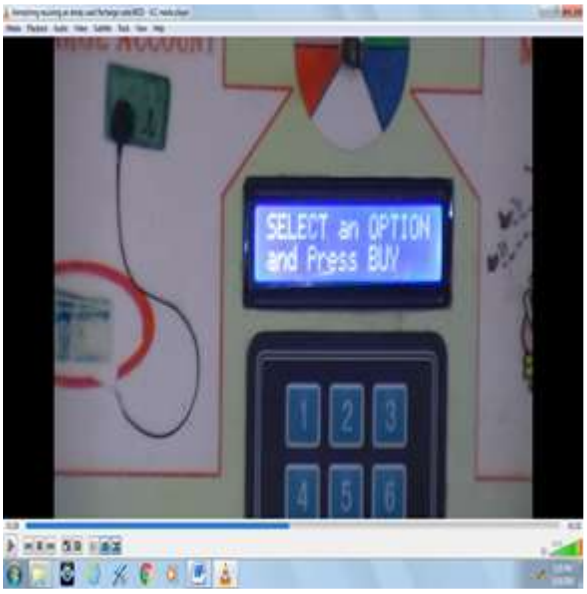

Figure 8: Specification for Product Selection

Once the product is selected, it drops the product from the machine

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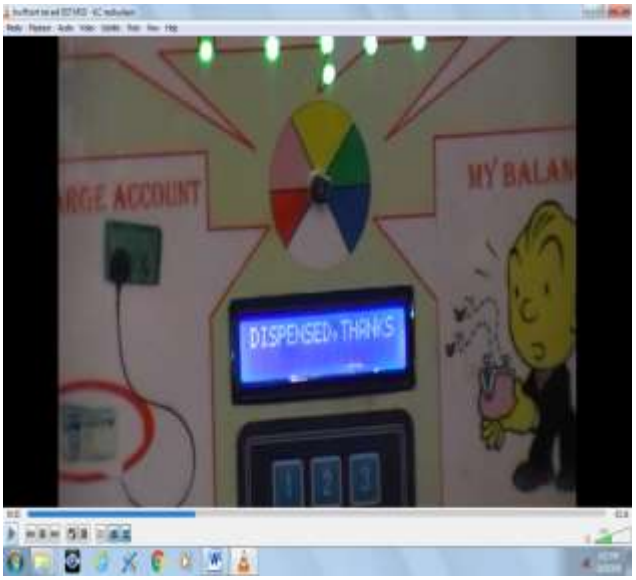

Figure 9: Message displayed once product is dispensed

Figure 10: The vending machine displaying the balance after the transaction

To recharge the card, the customer is expected to enter the recharge code as shown in Figure 13.

Figure 11: Specification for Card Recharge

Once the code is entered, the machine displays a message showing that the recharge was successful as shown in Figure 14. Payment for the recharge is paid to and gotten from a registered vendor

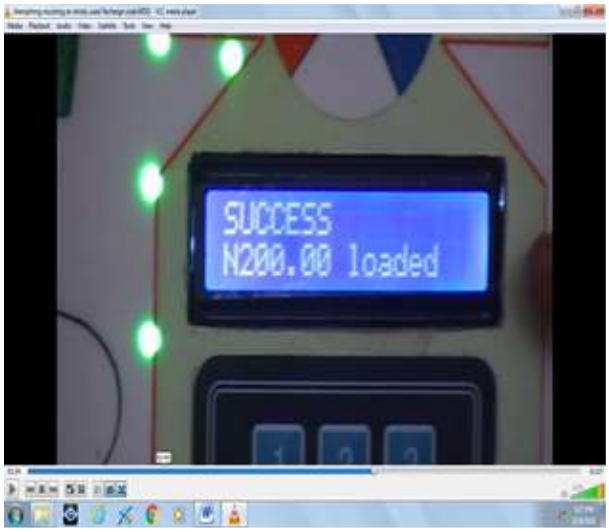

Figure 12: The Display after card Recharge

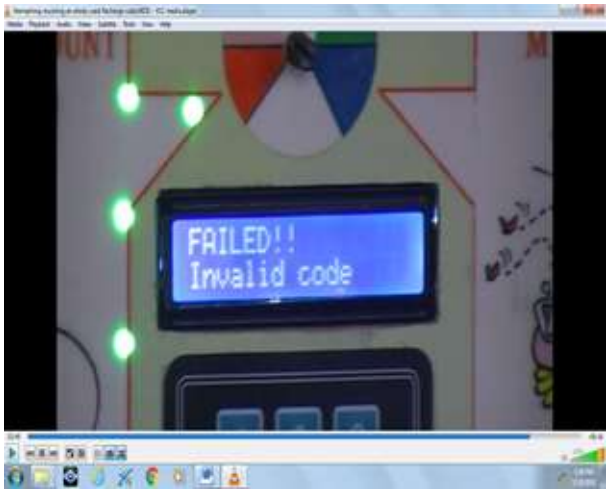

Figure 13: Message displayed if the card recharge failed

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Figure 14: Message displayed if the card has insufficient balance

6.1 Hardware and Operating System Requirements

In the system developed, the following are required.

6.1.1 Hardware / Components Requirement

The materials used in the construction of the product are Stainless Steel Sheet Metal and Cast Iron. For the container that holds the dispenser and electronic circuit, wood is cut and joined at the edges. The RFID reader is bolted to the front side of the container. At its back, is the power connection, and on top is a door hinged for accessing the dispenser.

The requirements for the implementation of the vending machine are:

i. Single CH Relay Module
ii. 2CH Relay Module
iii. 4CH Relay Module
iv. 8CH Relay Module
v. IR Distance Sensor
vi. 9g Servo
vii. 48g Servo
viii. Bluetooth module
ix. Arduino UNO R3
x. LCD 602
xi. LCD 2004
xii. Keypad 4x3
xiii. Buzzer
xiv. Resistors, LED, Diode
xv. RFID card reader
xvi. RFID card
xvii. Colour Sensor
xviii. Stepper motor

6.1.2 Software Requirements

The software part of programming was through Arduino Mega software (IDE). It is easy to write code and upload it to the board. C and C++ languages are used for programming.

6.2 Detailed Implementation Plans

The vending machine was implemented in phases.
Step one: Design the circuit diagram

6.2.1 System Testing

This section is chiefly the implementation of the application and testing for issues and non-functional properties such as speed and robustness. The test is simply the execution of the implemented application with sample data to ensure that all specified objectives have been met appropriately in order to ensure a high-quality, user-friendly application. In this section, we will show a tabulation of the summary of the result that we got when the machine (model) was tested. Each control button on the machine's control software was tested and its effect on the model was observed. Table 5 below shows the test and the test result when no fault is encountered.

6.2.2 Performance Evaluation

This thesis has presented our knowledge about the machinery and technology involved in the most common vending machines present all over the world. It helps increase efficiency by lowering dependence on manpower. The desired outcome is achieved as per the user's requirements in the form of a product dispensed by the machine. How easier it would make people obtain products from vending machines rather than waiting in queues for long hours. We also learned about the functioning of various instruments. This includes the functioning of RFID, Microcontroller AT89C51, Motor drivers, etc. All these have contributed greatly to improving our knowledge about the functioning and performance of a vending machine. The system was able to validate payment card data before dispensing can take place. Hence the performance of the system can be rated at 95%.

6.2.3 Training

For the new system to function effectively and efficiently, educating and training vending machine operators is necessary. Training is conducted for the person selected to do the job of registering new cards, printing the recharge codes/cards, and placing products on the vending machine. The selected person is trained for a period of time on how to manipulate and operate the system so as to be acquainted with the vending machine and the system design. The operator is also given procedural manuals to assist them in operating the system.

7. CONCLUSION

An automated Vending Machine for the sale of drinks has been designed and implemented in this thesis. An RFID payment system was also incorporated to make the Vending Machine cashless in operation. When this RFID-based Vending Machine is compared with the cash-based alternative, it is noted that the RFID-based has outperformed the cash-based one in terms of efficiency, security, and sales tracking and it is therefore a better machine used for the sale of drinks.

This thesis has presented to our knowledge the techniques used to develop an RFID technology-based Vending Machine for the sales of drinks. The realized product has the advantage of data flexibility and efficiency and has a better way to manage the financial returns of the business. The prepaid card must be funded before it can be used for transactions on the Vending Machine.

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