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Design and Implementation of an RFID-Based Fuel Dispensing System

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A B S T R A C T

Current fuel dispensing systems rely heavily on manual payment processing and authorization steps, leading to long queues, revenue loss from errors, and vulnerability to internal fraud. This paper proposes integrating Radio Frequency Identification (RFID) technology to automate core aspects of the fueling process including user identification, metering fuel quantity, securely logging transactions, and accepting contactless payments. A functional prototype system was developed using an Arduino Uno microcontroller, MFRC522 RFID module, 16x2 LCD display, keypad, flow sensor, relay-controlled pump, and custom power supply. Key capabilities implemented include customer authentication via RFID cards, accurately metering dispensed fuel quantity based on flow sensor pulse feedback, securely mapping RFID profiles to accounts, and deducting amounts from user balances, all from the onboard memory. Rigorous testing demonstrated reliable user identification, metering accuracy within 8% error margin, an average error of 1.71% over 10 different trials, and robust system security. The prototype serves as a valuable proof-of-concept for enabling pervasive RFID integration in next-generation fuel dispensers. While limited in scale, it establishes the feasibility of using RFID technology to drive automation, enhance security, improve accuracy, and transform the gas station experience. Further work is proposed to evolve the system for real-world deployment through durability improvements, maintainability enhancements, and expanded feature scope.

Keywords: Radio Frequency Identification (RFID); Fuel dispenser; Metering; Automation; Contactless payment

1. Introduction

Fuel dispensing is an integral part of modern society, as we depend on gasoline, diesel, and other fuels to power vehicles, generators, machinery, and operations across industries. However, the fuel dispensing process still relies on outdated systems leading to major inefficiencies that negatively impact customers, the environment, and fuel stations (Čekerevac *et al.* 2006). Traditional fuel dispensers require customers to manually pay via cash or point-of-sale (POS) machines, receiving authorization for each transaction. This adds steps compared to fully automated payments (Fung et al. 2018). In times of high demand or fuel scarcity, manual payment and authorization requirements contribute to long queues at fuel stations. Customers can spend hours idling in their vehicles, leading to frustration as well as excess noise and air pollution.

Additionally, traditional dispensers are vulnerable to accidental errors and fraud due to reliance on manual processes. Beyond accidental errors, traditional dispensers are also susceptible to employee fraud through tactics like overcharging customers or under-reporting sales (Čekerevac *et al.* 2006). However, the dependence on manual data entry and lack of automated accounting opens substantial vulnerabilities to unintentional errors and deliberate fraud, resulting in reduced revenue, customer dissatisfaction, and compromised trust. RFID technology can help mitigate these issues through automated fuel quantity tracking and transaction processing with minimal human intervention (Patel *et al.* 2022). These limitations demonstrate the need for optimization through emerging technologies like radio frequency identification (RFID). This work holds practical significance in demonstrating the viability of RFID technology to enhance automation, security, and accuracy in fueling stations. Developing a proof-of-concept prototype that implements core RFID capabilities provides valuable insights into real-world components, programming techniques, and integration approaches needed to optimize fuel dispensing processes.

2. Literature Review

The work of (Li. 2010) showed that the emergence of radio frequency technology has changed the traditional methods of data collection. Compared to the traditional bar code, magnetic card and IC cards, RFID tags have the features of non-contact, reading speed, no wear, long life, user-friendly and the security function. RFID is replacing barcode technology and enjoying the major advantage of being independent of line-of-sight problems and scanning the objects from a distance. It offers the promise of reduced labour levels, enhanced visibility, and improved inventory management (Jaska *et al* 2010).

The application of RFID for vehicle identification, toll collection, traffic management, and parking lot management have already been experimented with extensively (Chaturvedula. 2012). Radio frequency identification (RFID) is a contactless technology that utilizes radio waves to digitally identify, track, and store information about objects or people (Bhuptani, M. and Moradpour. 2005). RFID tags can be read without direct visibility using radio waves, allowing for simultaneous scanning of multiple tags (Roberti. 2021). RFID systems are comprised of three key components: namely; (i) tags or transponders which contain identifying data, (ii) readers to wirelessly communicate with the tags, and (iii) middleware software to manage and process the RFID data into usable information (Chawla, and Ha. 2007). RFID systems utilize different radio frequencies offering various read ranges - from 125-134 kHz for short-range low frequency RFID to 860-960 MHz ultra-high frequency RFID allowing longer 10-meter reads (Bhuptani, M. and Moradpour. 2005).

Al-Naima and Hasan (2015) implemented an RFID-based fuel dispensing system at the Oil Products Distribution Company in Baghdad utilizing an ELA816B RFID reader with passive tags along with an Arduino microcontroller and VB.Net software application. However, their system lacked additional security mechanisms beyond card authentication, making it potentially vulnerable to threats like card skimming. The current project aims to address this limitation by incorporating PIN code authentication for each RFID card. Chandana *et al.* (2023) developed an automated RFID-enabled petrol pump system using an EM18 RFID reader interfaced with an Arduino via UART, and an AC pump actuator connected through a relay. While they enhanced security by adding PIN authentication and locking users after multiple failed attempts, their choice of AC pump introduced challenges in accurately metering fuel quantities. To overcome this limitation, the current project implements a DC pump to provide precise flow control.

Naveen and Rashmita (2019) showed how an IoT-based self-service petrol pump system can be developed using RFID cards and a Raspberry Pi controller. The system offers rechargeable cards and calculate dispense time based on user input to account for fuel amounts as well as monitor the fuel purity level. However, the design lacked a separate flow sensor to reconcile the computed dispense time with actual fuel dispensed. Krishna *et al.* (2022) designed an RFID based petrol pump automation system that allowed users to pay for fuel with RFID cards1. Users had to swipe their cards, enter a password, and specify the amount of fuel they wanted. The system then checks the card balance, dispensed the fuel, and deduct the amount from the card. The system also displayed the information on an LCD screen and used a buzzer for alerts. The system aimed to reduce human work, save time, and provide security. However, the system did not address the issues of card loss, password compromise, or network failure. A modern era petrol dispensing system using RFID technology to provide prepaid and secure fueling service was proposed by Tandon *et al.* (2022). It consists of an RFID reader, a microcontroller, a keypad, a motor driver, and a pump motor. The system verifies the RFID card details and PIN number entered by the customer, and dispense the desired amount of petrol. The system reduced human errors, time consumption, and man power, and also prevented unauthorized fueling.

Chaudhary *et al.* (2020) presented an RFID based automated petrol pump system that reduced human intervention and dispensed accurate fuel amounts. The system used a microcontroller to read RFID cards, verify PINs, and control a relay that activated an AC pump. The system also provided security features such as card rejection and alarm activation in case of unauthorized access. However, the paper did not discuss how the system measured the fuel flow or handled network failures. The current project improves upon this system by adding a flow sensor and a backup mechanism to ensure reliable and precise fuel dispensing. Gandha *et al.* (2020) developed an RFID-based fuel station automation system using Arduino Uno. The system used prepaid RFID cards to access fuel dispensers and deducted the amount of fuel dispensed from the user's account. The system also calculated the time and quantity of fuel to be dispensed based on the user's input and controlled a DC motor to pump the fuel. The system aimed to reduce human errors, malpractices, and time consumption at fuel stations. The work of Pooja *et al.* (2022) presented an RFID-based automated petrol pump using an Arduino Uno, RFID reader, LCD display, and relay-controlled pump. The system deducted amounts from RFID prepaid cards based on dispensed fuel. While providing automated self-service, their implementation was limited to a basic prototype without real-time metering or advanced features.

Murali *et al.* (2022) designed and implemented an RFID-based petrol pump automation system using an Arduino microcontroller, an EM-18 RFID reader, and an AC pump. Their system allowed users to swipe RFID cards, enter passwords, and select amounts to dispense fuel accordingly. The system also displayed the balance and deducted the amount from the RFID card. Their system improved customer service, reduced human errors, and enhanced security.

Due to the limitations in previous research works, this project is based on an RFID fueling system using flow sensor for accurate balance deduction based on dispensed fuel, allows users to add balances centrally, and employs PIN authentication for security. Also, the ability to store user data internally enhances reliability during power or network disruptions. The development addresses gaps in metering precision, security, balance management, and data resilience identified in prior work.

3. Block Diagram

The Block Diagram of the system, as shown in Figure 1, illustrates the basic functionality of the system. The Arduino Uno Microcontroller serves as the brain of the system which process the inputs and produce the required outputs.

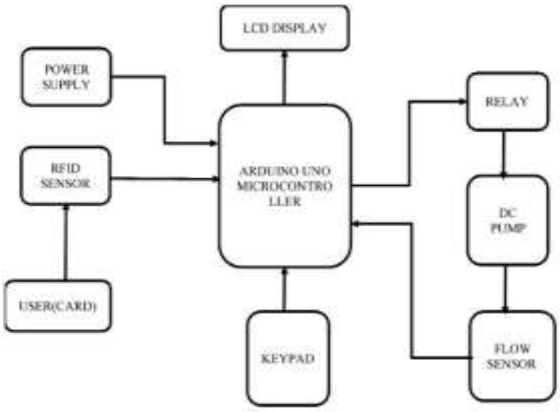

Figure 1: Block Diagram for the System

When the system is powered on, the LCD displays a welcome message, and asks for the User's card to be scanned. Upon scanning the card on the RFID sensor, the system prompts the user to enter a PIN using the Keypad, choose to dispense fuel, and after entering the amount, the system calculates the quantity, in liters, of fuel to be dispensed after which the relay is activated to connect the pump to the power supply and the pump delivers the fuel through the flow sensor. The system now listens for how many pulses have been generated, with four hundred and fifty (450) pulses corresponding to one (1) liter of fuel. When the required amount has been dispensed, the system deactivates the relay and the pump becomes inactive. The cost for the amount of fuel dispensed is then deducted from the User's card. During the dispensing process, the user can keep track of quantity of fuel dispensed by the pump through the LCD screen and when the system is done dispensing it shows a "THANK YOU" message and returns back to the "WELCOME" screen for another fuel dispensing cycle. The system was designed with two modes, an ADMIN MODE where an admin can add new Users and add the balance of Users cards, and a USER MODE, where the User can dispense fuel, check balance and change their PIN.

4. Circuit Diagram and Components

The circuit diagram used for the project is shown in Figure 2.

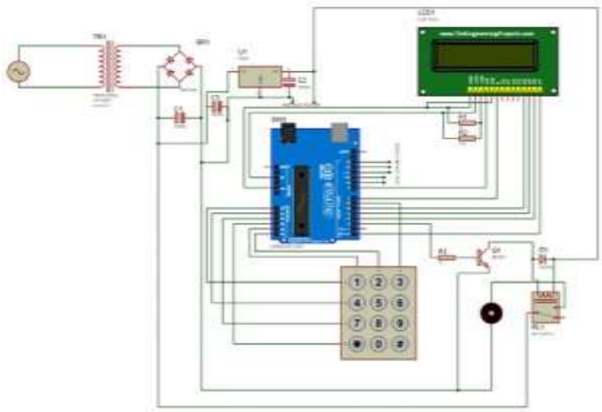

Figure 2: Circuit Diagram

The list of components used in this project are shown in Table 1. These components were selected based on their availability in the market, low power consumption, versatility and ability to meet the requirements for the project.

Table 1: List of Components

S/N	Type	Component
1	Arduino Uno	ATmega 328 microcontroller
2	RFID Module	MFRC 522
3	Display Device	16x2 LCD
4	Keypad	3x4 Membrane Keypad
5	Flow Sensor	YF-S201 Flow rate Sensor

6	Relay	6V 10A SPDT Relay
7	Transformer	230V/12V 1.5A Step-down Transformer
8	Transistor	BC547 NPN Transistor
9	Resistors	2*1KΩ, 10KΩ
10	Capacitors	25V 3300µF, 33µF 50V 10µF
11	Diode	5*IN4007

In the next section the results obtained during the simulation of the system along with the results of tests ran on the system after implementation are shown and discussed.

5. Results

In this section, results obtained from the simulation, prototyping and testing of the system were presented.

5.1 Simulation results

The simulation for the RFID Based Fuel Dispensing System was performed using the Proteus software, due to the unavailability of a way to scan an RFID card during simulation, card scanning simulation was not achieved. However, other functions of the system like User adding, balance checking, and dispensing were tested in the Proteus software environment. A screenshot of the simulation is shown in Figure 4

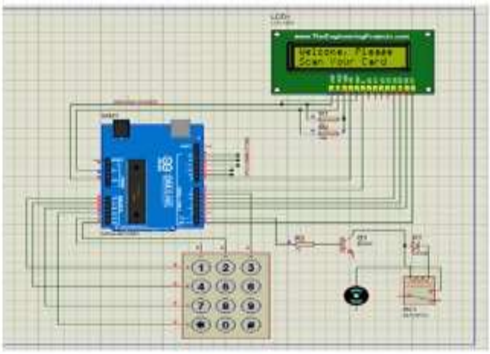

Figure 4: Simulation Result

As shown in Figure 4, the system displays the welcome message and asks the user to scan the RFID card when the system is turned on. This simulation correlates with the flow intended in the code, hence it is satisfactory.

5.2 Prototyping

The prototyping of this project passed through three key phases; the breadboarding, soldering and final assembling as shown in Figures 5, 6 and 7.

Figure 5: Breadboarding Stage

As shown in Figure 5, the prototype was first connected and tested using banana wires and a breadboard to create connections. This was done to ensure that the components were functional and the circuit function as it should both in simulation and the real world.

Figure 6: Soldering Stage

Figure 6 shows the prototype in the soldering stage. The circuit was soldered on a project board. In this stage, the power supply and the systems functions were tested.

Figure 7: Complete Assembled Prototype

In Figure 7, the image of the assembled prototype was shown. The wooden frame serves as the tank for the fuel dispenser and also adds more rigidity to the system. The plastic case serves as a housing for the electrical components to protect them from any fluid spillage during operations. The system performance tests presented were carried out and the results were outlined in the next subsection

5.3 Performance test

The testing of the system was performed to validate three key aspects; the dispensing accuracy, data persistence, and security robustness.

5.3.1 Dispensing accuracy test

This test was carried out to quantify the metering precision under varied dispensing volumes. Testing was done using graduated containers and the percentage error versus expected volume was measured. The results are presented in Table 2

Table 2: Dispensing Accuracy Test

S/N	Expected Volume (ml)	Dispensed Volume (ml)	Error (%)
1	500	461	7.80
2	600	587	2.16
3	700	685	2.14
4	800	790	1.25
5	900	889	1.22
6	1000	995	0.50
7	2000	1974	1.30

8	3000	2994	0.20
9	4000	3991	0.23
10	5000	4987	0.26

The system was discovered to have an average dispensing error of 1.71%. This was accounted for in the dispensing function where this percentage of the total sum the user requests for is added to the user's fuel.

5.3.2 Data persistence test

The aim of this test was to test the ability of the system to save user's data and only deduct the amount that was dispensed. The system saves the User card's Unique Identification (UID) along with the PIN and balance to the microcontroller's internal memory. This test was performed to ensure that the User's balance was only deducted of the amount dispensed. The system was asked to dispense one (1) litre when the tank was filled with only half (0.5) litre. The system performed well and only deducted the cost of the half (0.5) litre that was dispensed. This ensures that Users are not short changed at the event of pump failure or tank emptiness.

5.3.3 Security robustness test

This test was conducted to detect any potential vulnerabilities or loopholes in the system security mechanisms. These include

- Unauthorized access was attempted using 10 different unregistered RFID card
- 10 brute force attempts were made by inputting random PINs for a valid RFID card All unauthorized access trials were successfully blocked by the system security protocols. Only users with valid RFID and PIN could gain access to the system.

6. Conclusion

This paper involved designing and implementing an RFID-based fuel dispensing system to demonstrate automated, contactless payment and metering capabilities. A functional prototype was developed using an Arduino Uno microcontroller, MFRC522 RFID module, 16x2 LCD display, keypad, flow sensor, relay-controlled pump, and a regulated power supply. The system allows user authentication via RFID cards and PIN entry. It tracks fuel quantities dispensed using the flow sensor and only deducts the dispensed amount from a user's account. An administrative mode enables adding Users and adjusting balances. The prototype was tested for dispensing accuracy, data persistence, and security robustness. Results validated the core RFID automation functions for fuel stations. The developed prototype successfully demonstrated the integration of RFID technology to streamline payment, enhance security, reduce errors, and enable self-service in fuel dispensing systems. The project achieved its aim of designing and evaluating an initial RFID-enabled fuel dispenser. The prototype exhibits the underlying technological capabilities to optimize and transform fuel station infrastructure/

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