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Smart FuelGuard RFID-Based Wrong Fueling Prevention System

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Abstract: The Smart FuelGuard system will be created to ensure safe, automated, and error-free fuel dispensing through a combination of RFID authentication, PIN verification, and sensor-based fuel monitoring. All the parts are connected to an Arduino microcontroller as the primary control unit. The RFID reader checks with users, and a keypad enables entry via PIN and the amount of fuel to use. An I2C LCD displays the status, instructions, and error messages of the system. A relay module powers the DC pump to imitate fuel dispensing, and a buzzer has been used to give feedback on unauthorized cards, wrong PIN inputs, or any problems within the system. A controlled power supply will make all modules operate consistently. It also has a color sensor to identify the type of fuel using the optical properties; it is used to check whether the fuel dispensed is of the correct type as assigned, and determines whether there is a mismatch or abnormal color, and the pump is automatically switched off, and an alarm is activated to avoid misfueling. With legitimate authentication, PIN check, and a kind of fuel check, the Arduino will switch on the pump and run it for a predetermined time period according to the amount of fuel chosen. The prototype has a proven, intelligent, and simple fueling system that can boost the safety and eliminate expensive engine damage caused by improper fueling.

Keywords: RFID, Smart Fuel, Arduino Mega, Colour Sensor, Wrong Fueling Prevention.

1 INTRODUCTION

Fuel dispensing systems are an essential component of modern transportation infrastructure and play a significant role in ensuring safe and efficient vehicle operation. However, conventional petrol pump systems are still largely dependent on manual supervision, which increases the probability of operational errors such as dispensing the wrong type of fuel into vehicles. Wrong-fueling incidents, such as filling petrol in diesel vehicles or vice versa, can lead to serious engine damage, increased maintenance costs, operational downtime, and safety risks. With the rapid growth in the number of vehicles and fuel stations, the need for intelligent, automated, and secure fuel dispensing systems has become increasingly important.

Recent developments in embedded systems and identification technologies such as Radio Frequency Identification (RFID) have enabled the implementation of automated authentication mechanisms in fuel dispensing applications. RFID technology allows secure identification of vehicles and users without physical contact and supports fast and reliable authorization before dispensing fuel. Similarly, keypad-based Personal Identification Number (PIN) verification enhances system security by introducing an additional layer of authentication that prevents unauthorized access and misuse of fuel resources. These technologies together improve transparency, reliability, and operational safety in fuel station environments.

Despite the availability of RFID-based automation systems in existing research, most conventional approaches focus primarily on user authentication and transaction monitoring, while limited attention has been given to detecting mismatches between the assigned fuel type and the fuel actually being dispensed. Wrong fueling continues to remain a major concern due to the absence of real-time validation mechanisms in traditional and semi-automated fuel dispensing systems. Therefore, there is a clear requirement for an intelligent solution capable of verifying fuel type before dispensing and automatically preventing incorrect fueling operations.

To address these limitations, the proposed Smart FuelGuard system introduces a multi-layered security architecture that integrates RFID authentication, PIN verification, and sensor-based fuel identification within a single embedded platform. The Arduino Mega microcontroller acts as the central processing unit, coordinating all system components, including the RFID reader, keypad module, color sensor, LCD display unit, relay-controlled pump, and buzzer alert mechanism. The color sensor plays a critical role in detecting the optical characteristics of fuel and verifying whether the selected fuel matches the authorized fuel type associated with the registered vehicle. If a mismatch is detected, the system immediately disables the fuel dispensing process and activates an alert notification to prevent possible damage.

The proposed system aims to reduce human intervention, improve operational accuracy, enhance fueling safety, and minimize the possibility of unauthorized or incorrect fuel dispensing. By combining authentication, verification, monitoring, and automated control mechanisms within a unified embedded framework, the Smart FuelGuard model provides a reliable and scalable solution suitable for modern fuel stations, fleet management systems, and smart transportation infrastructure. The implementation of such intelligent automation systems can significantly contribute toward improving fuel station efficiency while ensuring safe and error-free fueling operations.

2 LITERATURE SURVEY

Recent advancements in intelligent fuel management systems have focused on improving fuel security, automation, monitoring accuracy, and prevention of unauthorized usage through the integration of embedded systems, Internet of Things (IoT), artificial intelligence, and Radio Frequency Identification (RFID) technologies. Yamini *et al.* proposed a smart IoT-based fuel monitoring system capable of detecting fuel theft and providing real-time indications for refilling operations using connected sensing infrastructure and cloud-supported monitoring platforms. Their system significantly improves fuel usage transparency and remote supervision capabilities; however, it does not address the prevention of wrong fuel dispensing at the source level [1]. Similarly, Thangasankaran *et al.* developed a sustainable fuel management system for two-wheelers aimed at ensuring measurement accuracy and preventing fuel theft through embedded monitoring mechanisms. Although the system enhances fuel utilization efficiency, it lacks mechanisms for authentication-based fuel dispensing control [2].

Artificial intelligence techniques have also been explored for monitoring vehicle fuel consumption and emissions. Valido *et al.* introduced an AI camera-based monitoring system combined with a gas emission estimator model to evaluate fuel consumption patterns and environmental impacts. While the approach provides intelligent analytics for fuel usage monitoring, it does not focus on secure fuel dispensing infrastructure [3]. In another study, Yan and Li proposed a hydrogen leakage diagnosis system for fuel cell vehicles using a dual-channel neural network-based recognition approach to improve safety monitoring in fuel systems. Although effective for safety diagnostics, the method is limited to leakage detection rather than dispensing validation [4].

RFID technology has emerged as a reliable solution for secure identification and automation in fuel dispensing environments. Mankal *et al.* developed an RFID-enhanced pump automation framework that improves fueling efficiency by enabling automatic authentication and controlled dispensing operations. However, their system does not incorporate fuel-type validation mechanisms to prevent incorrect fueling events [5]. Similarly, Rautela proposed an RFID and ESP8266-based smart fuel dispensing system that integrates wireless communication for monitoring and automation, improving transaction transparency and operational efficiency, but lacking multi-level verification features [6]. Cyber-physical system architectures and machine intelligence frameworks also support the development of secure embedded monitoring platforms. Shaikh *et al.* presented a taxonomy of intelligent cyber-physical architectures highlighting opportunities for integrating sensing, automation, and intelligent decision-making in embedded infrastructures.

These architectures provide conceptual support for designing secure automated fueling environments, but do not directly address fueling mismatch prevention [7]. RFID identification technologies have been extensively studied for secure object tracking and automation applications. Ilie-Zudor *et al.* presented a comprehensive survey on RFID-based identification systems and their industrial applications, demonstrating the effectiveness of RFID in enabling secure and reliable automated access control systems suitable for fuel station automation environments [8]. Recent research has further explored RFID-enabled fuel dispensing architectures for improving operational safety. Muthusamy *et al.* designed an RFID-based fuel dispenser system that provides automated authorization prior to fuel delivery, improving transaction accuracy and reducing manual intervention. However, the system does not include sensor-based fuel-type verification [9]. A. Shanmugapriya et al. proposed an intelligent fuel pump system integrating RFID with IoT monitoring for enhanced automation and transaction transparency in fuel stations, yet their work does not address real-time mismatch detection between vehicle fuel type and dispensed fuel [10].

Raj *et al.* introduced a Smart FuelGuard system that applies RFID-based protection mechanisms to prevent wrong-fueling incidents by enabling vehicle-specific authentication before dispensing operations. Their work demonstrates the importance of integrating identification mechanisms with fueling infrastructure; however, the system lacks additional sensor-based verification layers for improved reliability [11]. Chandana *et al.* proposed a smart fuel dispenser architecture combining RFID technology with IoT-based monitoring platforms to enable automated authorization and remote supervision of fueling activities. Although the system enhances automation and operational monitoring, fuel-type validation using physical sensing techniques remains unaddressed [12].

From the literature review, it is observed that existing systems primarily focus on authentication, monitoring, fuel theft detection, and automation of dispensing operations. However, limited research has addressed the integration of multi-layer authentication with real-time sensor-based fuel-type verification for preventing wrong-fueling incidents. To overcome these limitations, the proposed Smart FuelGuard system integrates RFID authentication, PIN-based verification, and color sensor-based fuel identification within a unified embedded platform to ensure secure, automated, and error-free fuel dispensing operations.

3 Problem Identification

The conventional fuel dispensing networks at the petrol stations are mostly operated manually and under the supervision of humans, leading to errors, inefficiencies, and safety problems. In the current system, the pump operator determines what type of fuel to use and how the dispensing process is done, which may cause the filling of the wrong fuel because of laxity, misunderstanding, or the absence of proper checking systems. This may lead to serious damage to their engines, higher maintenance expenses, and possible safety risks for the owners of the vehicles. In addition, normal fuel stations do not have proper verification of the vehicles with their vehicles; this leads to more fuel theft and misuse. Lack of electronic verification and monitoring systems makes it hard to monitor the fueling operations accurately, and the records are not transparent. The manual billing and logging systems are slow, prone to errors, and inefficient, particularly when the business is at its highest point. Current systems also lack real-time monitoring or automatic control of the dispensing of fuels. The fueling process does not have an intelligent system to detect incorrect fuel flow and terminate it in case of abnormalities. Also, the absence of automation, customer reliability, and consistency of the system in the traditional methods of fuel dispensing, the fact that the accuracy of operations depends on the level of attention and experience of the operators, and the level of safety can be improved with a more intelligent automated method of fuel dispensing that will remove human errors, improve safety, and guarantee accurate fuel dispensing.

4 Proposed System

Conventional fuel dispensing systems at petrol stations are highly susceptible to error, inefficiencies, and safety hazards due to the fact that most of them are manual and require human oversight. Under the current approach, the pump operator determines the type of fuel to be dispensed and the dispensing process; hence, wrong filling of fuel can occur either through negligence, misunderstanding, or failure of mechanisms. These types of accidents may result in serious harm to engines, higher costs of maintenance, and even safety risks to the owners of vehicles. Moreover, the traditional fuel stations do not have sufficient vehicle validation, unauthorized vehicles or persons can tap into the fuel, and as such, the probability of fuel theft and misuse is high. Lack of electronic verification and monitoring systems ensures that it is hard to monitor fueling activities as accurately as possible or to maintain transparent records. Paper-based billing and recording processes are slow, inaccurate, and ineffective, particularly when there is high traffic. The current systems do not even offer real-time monitoring or automatic control when fuel dispensing happens. As soon as fueling commences, it is not smart enough to identify the wrong flow of fuel and halt it in case of abnormalities. Moreover, the reliance of people on human operators decreases the reliability and consistency of the system, since the accuracy of operations depends on personal experience and attentiveness level, which complicates the use of conventional fuel dispensing systems, as they do not completely exclude human error and lead to the lack of value in human life and the misuse of fuel. On the whole, the absence of automation, security, fuel-type validation, and real-time safety monitoring of fuel dispensing confirms the necessity of using a more intelligent, automated system, which can avoid the errors of people and improve the safety of operations.

4.1. Existing System and Limitations

The current fuel dispensing system is very manual in nature and highly relies on human control. In the traditional petrol pumps, the attendants will identify the car, choose the type of fuel, and run the dispensing nozzle. It does not have an automatic system to check whether the type of fuel that is being used is suitable for the vehicle or not. User authentication is not highly enforced, and fueling is usually done after verbal confirmation or a visual judgment. Also, the system does not provide any digital security protection (user authentication, transactional log, or real-time tracking). Dispensing of fuel commences as soon as the nozzle is switched on, and there are no electronic checks to verify authorization or correctness. Mostly, there are no alerts or warning systems, and the mistakes are only detected after fueling has been done, which may cause severe outcomes. The fuel dispensing system is based mostly on manual control and suffers a number of serious limitations that impact the safety, reliability, and efficiency of the system.

4.2. Proposed System Overview

Conventional fuel dispensing systems at petrol stations are highly susceptible to error, inefficiencies, and safety hazards due to the fact that most of them are manual and require human oversight. Under the current approach, the pump operator determines the type of fuel to be dispensed and the dispensing process; hence, wrong filling of fuel can occur either through negligence, misunderstanding, or failure of mechanisms. These types of accidents may result in serious harm to engines, higher costs of maintenance, and even safety risks to the owners of vehicles. Moreover, the traditional fuel stations do not have sufficient vehicle validation, unauthorized vehicles or persons can tap into the fuel, and as such, the probability of fuel theft and misuse is high. Lack of electronic verification and monitoring systems ensures that it is hard to monitor fueling activities as accurately as possible or to maintain transparent records. Paper-based billing and recording processes are slow, inaccurate, and ineffective, particularly when there is high traffic. The current systems do not even offer real-time monitoring or automatic control when fuel dispensing happens. As soon as fueling commences, it is not smart enough to identify the wrong flow of fuel and halt it in case of abnormalities.

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Moreover, the reliance of people on human operators decreases the reliability and consistency of the system, since the accuracy of operations depends on personal experience and attentiveness level, which complicates the use of conventional fuel dispensing systems, as they do not completely exclude human error and lead to the lack of value in human life and the misuse of fuel. On the whole, the absence of automation, security, fuel-type validation, and real-time safety monitoring of fuel dispensing confirms the necessity of using a more intelligent, automated system, which can avoid the errors of people and improve the safety of operations.

4.3. Block Diagram of Proposed System

The block diagram of the Smart FuelGuard-RFID-Based Wrong Fueling Prevention System depicts the general form of the system and the interrelation between the hardware modules that will be needed to attain the safe and automatic dispensing of fuel. The Arduino Mega is the heart of the system, the central control unit, and coordinates all the operations. The power supply block supplies regulated DC power to all the components to ensure a stable and reliable operation of the system. On activation of the system, the RFID reader waits to scan an RFID card. The RFID cards have different identification numbers that are associated with an authorized user and a type of fuel that is defined. After scanning the card, the RFID reader will transmit the card information to the Arduino Mega, where it is compared against the stored databases. Once the RFID authentication has been completed, the user is prompted to enter a selectable amount and a PIN using the keypad. This is an extra security measure and enables interaction with the user.

The Arduino receives the entered information, and the system messages like instructions, updates of status, or error notifications are shown on the LCD (Liquid Crystal Display). The color sensor is very important before the pump is activated, and this is because it identifies the type of fuel depending on the optical properties of the fuel. The sensor transmits the color information read by the sensor to the Arduino Mega, which makes comparisons with the authorized fuel type stored with that RFID card. When the type of fuel is not the same, the Arduino will instantly terminate the process and run the buzzer, which will give a sound notification, and a warning message will appear on the LCD to avoid using the wrong fuel. When all requirements are met, i.e., a valid RFID card, a correct PIN, and a matching fuel type, then the relay module is triggered by the Arduino. The relay is an electrical switch that operates the DC pump so that the fuel is dispensed for a specific period, depending on the amount of fuel that is chosen. When dispensing is done, the pump is stopped automatically, and the system is reconfigured to be used by the next user. Generally, the block diagram depicts a closed-loop, automated fuel dispensing system that combines authentication, verification, monitoring, and control. The blocks collaborate with one another under the control of the Arduino Mega to increase the safety level, eliminate improper fuel filling, and decrease the possibility of human error, as well as to make the fuel station work more efficiently. Fig. 1 shows the block diagram of the proposed method.

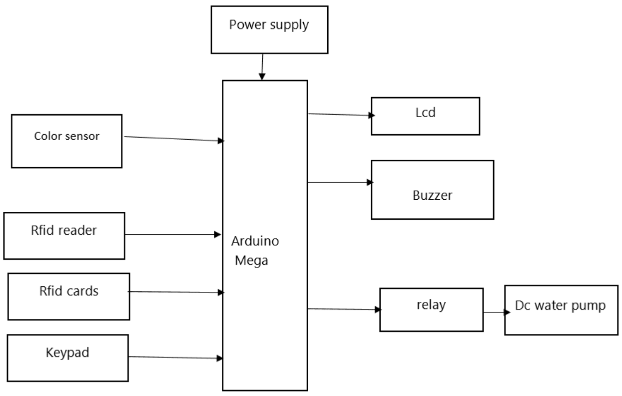

Fig. 1. Block Diagram of the Proposed Method

4.4. Methodology of Smart FuelGuard RFID-Based Wrong Fueling Prevention System

The proposed Smart FuelGuard system methodology is based on the idea of the combination of RFID authentication, multi-level security, sensor-based fuel inspection, and automatic control to avoid wrong fueling and improve the safety of fuel stations. The system architecture is to run a minimal human action system and guarantee safe, accurate fuel dispensing. First, in the system database, a unique RFID tag with all the required information (vehicle identification number and the authorised type of fuel) is registered against each vehicle. As the vehicle nears the fuel pump, the RFID reader reads the tag and sends the information to the microcontroller, which is used to verify the tag. In case the RFID authentication has been effective, the system will pass through to the next security level. To enhance security and reduce misuse of RFID tags, a PIN-based authentication program is used. A valid PIN is required by the user using an I2C LCD display. Then, only after the point of PIN verification, the system opens access to an option of fuel selection and dispensing, which guarantees multi-layer authentication.

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Upon the achievement of the authentication, the system enables the fuel-type verification module to use a color sensor. The color sensor identifies the physical properties of the chosen fuel and checks against the approved type of fuel in the database. This check is done prior to the dispensing process and throughout the fuel flow, with real-time checking of the pump to be stopped or started depending on the outcome of the validation process. The control of the fuel dispensing is by a pump control mechanism that is a relay-based motor control, which is turned on or off depending on the validation results. When the fuel type found is identical to the allowed fuel type, the relay is switched on, and the fuel dispensing is launched. To reduce the risk of a disconnect or anomaly, the system will switch off the fuel supply instantly, display warning messages on the LCD, and issue alerts to avoid additional harm.

4.5. Future scope

The Smart FuelGuard system offers an excellent platform to conduct the safe and automated fuel dispensing process; nevertheless, it has a number of growth prospects and the possibility of massive implementation. The implementation of IoT connectivity is one of the major improvements that can be made in the future to facilitate real-time transmission of data to cloud platforms. It can be further improved by adding advanced fuel identification methods, like spectroscopes or machine-learning-based fuel classification, so that the owners and fleet operators of fuel stations can monitor the fueling process, fuel consumption, and alarms even when the conditions are not exactly the same (with regard to the environment or to lighting conditions). This would make it more reliable when used in actual fuel station settings, such as cashless payment information like UPI, RFID-linked wallets, or mobile application payment services. This would facilitate complete self-service gas pumps, lower the waiting line, and benefit the client. It can also be integrated with GPS and vehicle telematics systems to track the fueling locations, mileage, and fuel efficiency, particularly in applications serving fleet ownership.

5 Results And Discussion

The Smart FuelGuard system was put into practice and was tested in different conditions to check its functionality, reliability, and the effectiveness of the system in dispensing the wrong fuel. The experiment outcomes support the fact that RFID authentication, PIN verification, color-based fuel identification, and automated pump control are the means of a secure and intelligent fuel dispensing solution. In the course of testing, the RFID module was able to identify authorized cards all the time with a small response time, which facilitated the process of user authentication. The RFID cards that were not authorized were automatically denied, and the system was kept in a locked condition. After RFID authentication, user credentials were correctly verified by the keypad-based PIN authentication process. Any erroneous PIN entry sounded an alarm with the help of the buzzer and barred further work of the system, which guaranteed greater security. The color sensor was also extremely important in determining the type of fuel before dispensing. The system was able to access the optical properties of the fuel and match it against the known type of fuel that is linked to the verified RFID card.

The relay-controlled pump was switched on when the detected fuel was the same as the assigned fuel. By contrast, in the case of any mismatch detected within the system, the pump was automatically shut off, and an alert was generated, effectively avoiding the wrong fuel. The time-based method was used to control the fuel dispensing process by turning the pump on during a specified time based on the quantity of fuel that had been selected. This strategy led to standard and repeatable fuel delivery for all the test cycles. The LCD display also offered real-time feedback such as authentication status, fuel validation messages, and error notifications, as well as dispensing progress, and users interacted with the system more, and system transparency was improved. Fig. 2 shows the hardware kit.

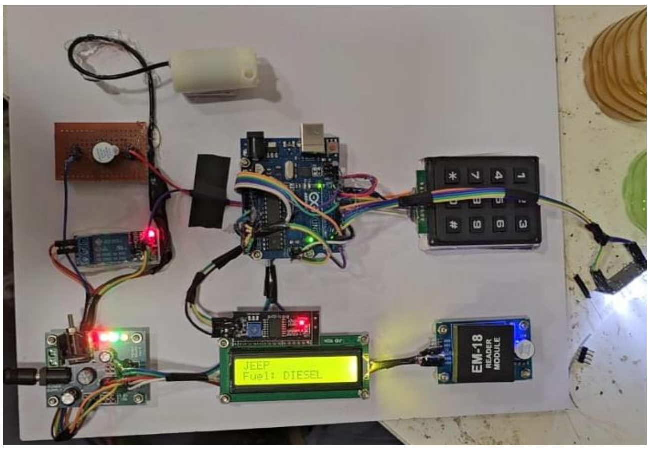

Fig. 2. Hardware Kit

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The Arduino Mega microcontroller proved to be a good coordinator to the various peripherals, including the RFID reader, keypad, LCD, color sensor, relay, and buzzer, without causing much delay or failure. Power supply was consistent during extended power operation, and therefore, the performance was reliable without any sudden resets. The consistency of the results was achieved due to repeated trials, which proved that the system is robust and repeatable. Fig. 3 shows the result of the hardware kit.

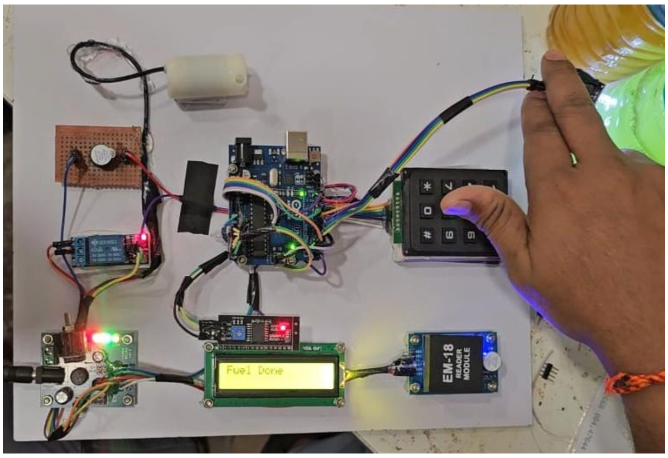

Fig. 3. Result of the Hardware Kit

6 Conclusion

The Smart FuelGuard RFID-Based Wrong Fueling Prevention System is a viable and smart solution to the problem of conventional fuel dispensing systems. The proposed system can help avoid any human errors, eliminate unauthorized access, and provide accurate fuel delivery by combining RFID authentication, PIN-based security, and detection of real-time fuel type by using a color sensor. The control architecture based on the Arduino allows the easy coordination of the authentication, sensing, and actuation modules, hence leading to a fully automated fueling process that is easy to operate. Experimental findings indicate that the system is reliable in determining the identification of authorized users, has a good ability to verify that the fuel is compatible, and that the process halts immediately when the system senses that the fuel dispensing is under the wrong condition. On the whole, the Smart FuelGuard system enhances the accuracy of fueling, increases the security, decreases the possibility of engine damage, and offers a convenient and scalable option to the current fuel stations as well as fleet management systems. The suggested model provides a solid foundation for prospective smart, secure, and automated fuel management systems.

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Ethics Statement

This study did not involve human or animal subjects and, therefore, did not require ethical approval.

Statement Of Conflict Of Interests

The authors declare that they have no conflicts of interest related to this study.

Licensing

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