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Hybrid Fuel Dispensing System for Smart Fuel Stations Supporting EV and Conventional Vehicles

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ABSTRACT

This paper presents a Hybrid Fuel Dispensing System for Smart Fuel Stations Supporting both Electric Vehicles (EV) and Conventional Vehicles, leveraging IoT-cloud integration with the ESP32 microcontroller. The system addresses the fragmented nature of current fuel station infrastructure by unifying petrol dispensing, EV charging, user authentication, tank-level monitoring, and remote telemetry into a single cohesive platform. RFID-based authentication with PIN verification ensures secure user access, while automated relay control manages both the petrol pump motor and EV charger relay. An ultrasonic sensor continuously monitors storage tank levels, and a voltage sensor detects electrical supply anomalies. A 16x2 LCD display provides real-time transaction feedback, and a GSM module sends SMS alerts for critical events. All operational data is transmitted to an IoT cloud server for remote monitoring, inventory management, and data analytics. Experimental results confirm reliable RFID authentication, accurate fuel dispensing, real-time tank-level detection, cloud data logging, and GSM alert delivery. The proposed system offers a scalable, secure, and cost-effective solution for modern smart fuel station infrastructure.

Keywords: IoT, RFID, Hybrid Fuel Station, EV Charging, ESP32, Cloud Monitoring, Smart Fuel Dispenser, GSM Alert, Automated Dispensing

1. INTRODUCTION

The rapid evolution of transportation toward electric mobility alongside persistent demand for conventional fossil fuels has created a pressing need for intelligent hybrid fuel stations capable of serving both vehicle types efficiently. Traditional fuel stations operate with well-established mechanical pumps and basic POS systems but lack intelligent digital telemetry, remote monitoring, and adaptive energy management. Similarly, while dedicated EV charging networks offer authentication and cloud billing, they are rarely integrated with conventional fueling infrastructure, leading to disjointed user experiences and operational inefficiencies [1,2].

Radio Frequency Identification (RFID) technology has emerged as a robust and cost-effective solution for contactless user authentication in fuel dispensing applications [5,6]. When integrated with the Internet of Things (IoT) and cloud computing, RFID-based systems enable secure, automated, and remotely monitored fuel transactions [9,10]. The ESP32 microcontroller, with its dual-core architecture, built-in Wi-Fi, Bluetooth, and rich peripheral support, provides an ideal embedded platform for such unified systems [11].

This paper presents the design and implementation of a Hybrid Fuel Dispensing

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System that centralizes control of petrol dispensing, EV charging, tank-level monitoring, security authentication, and cloud telemetry using a single ESP32-based embedded controller. The system authenticates users via RFID cards and PIN entry, selects fuel type (petrol or EV), dispenses or charges for a user-specified amount, monitors tank levels and supply voltage continuously, sends GSM SMS alerts for anomalies, and logs all transactions to an IoT cloud server. The proposed system simplifies station management, enhances security, reduces manual errors, and provides comprehensive remote oversight aligned with smart city and sustainable energy objectives.

2. LITERATURE SURVEY

Al-Rajaba et al. [1] proposed an Intelligent Location-Based Service System for Abu Dhabi petrol stations using mobile and spatial technology, highlighting the value of digitally connected fuel infrastructure. Baqir and Motlak [2] demonstrated a smart automatic petrol pump based on RFID and ESP8266, establishing the feasibility of IoT-integrated contactless fuel dispensing. Nayal et al. [3] developed a petrol pump automation system that reduced manual intervention and improved transaction accuracy.

Sheth et al. [4] presented a mechatronics-based automatic fuel filling system addressing measurement precision and mechanical actuation challenges. Naveed et al. [5] developed a reliable low-cost RFID-based authentication system demonstrating scalability for large deployment environments. Saleh et al. [6] improved enterprise access security using RFID, confirming the technology's suitability for high-security applications such as fuel stations.

Pranto et al. [7] implemented a vehicle fuel monitoring system using RFID authentication and telematics, providing real-time notifications via GSM for refueling events. Kumar et al. [8] proposed an RFID-based secure authentication protocol for vehicular cloud computing, relevant to networked fuel management environments. Chena et al. [9] demonstrated an RFID system with a cloud database backend enabling large-scale data management and analytics. Kai et al. [10] developed a cloud-based RFID mutual authentication scheme for privacy-preserving IoV applications.

Kondaveeti et al. [11] conducted a systematic literature review on Arduino prototyping, confirming the ESP32/Arduino ecosystem as a proven platform for IoT applications. Melo et al. [15] applied IoT-based metering and blockchain to fuel dispenser surveillance, demonstrating the potential of transparent data logging. Prasanna and Madhusudan Rao [16], Swapnil [17], Jadhav et al. [18], Shreedhar and Shivashankara [19], and Naveen et al. [20] collectively contributed unmanned petrol bunk designs using RFID and various microcontroller platforms, providing a comprehensive foundation for the proposed hybrid system.

3. EXISTING SYSTEM

Current fuel dispensing and EV charging infrastructures are largely siloed. Traditional petrol and diesel stations operate with established mechanical pumps, metering units, and POS systems that prioritize fast refueling and transaction accuracy. However, they lack deep automation, fine-grained digital telemetry, and intelligent scheduling capabilities. Remote monitoring is typically limited or absent, requiring on-site staff for manual operation and inventory checks.

On the EV side, dedicated charging stations use manufacturer-specific protocols with networked backends for billing and access control. However, smaller fuel stations rarely integrate EV charging intelligently into their operations, resulting in disjointed

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user experiences, separate payment flows, and no unified energy or resource management. Some modern forecourt systems have begun adding RFID access for staff, keypad PIN entry, and ultrasonic or level sensors for underground tanks, but these tend to be add-on modules rather than a unified control architecture.

Smart charging networks offer remote monitoring, user authentication, and load management but are usually cloud-managed by charger vendors, complicating local optimization at mixed fuel/EV stations. Safety, maintenance alerts, and energy optimization are fragmented across several vendor systems, leaving operators with multiple dashboards and manual coordination rather than a single integrated control platform.

TABLE I: COMPARISON OF EXISTING VS. PROPOSED SYSTEM

Feature	Existing System	Proposed System
Controller	Arduino/8051	ESP32 SoC
Authentication	Manual/PIN only	RFID + PIN
EV + Fuel Support	Separate systems	Unified hybrid
Tank Level Monitor	Manual check	Ultrasonic sensor
Voltage Monitoring	Not available	ADC sensor
Cloud Monitoring	Not available	IoT HTTP/Cloud
SMS Alerts	Not available	GSM SIM800L
Display	Basic/None	16x2 LCD
Security Alert	None	Buzzer + GSM
Energy Management	None	Load shedding logic

4. PROPOSED METHODOLOGY

The proposed Hybrid Fuel Dispensing System centralizes control and monitoring using the ESP32 microcontroller as the embedded controller to unify fuel dispensing, EV charging, user authentication, and site telemetry. The system architecture integrates an RFID reader for contactless user authentication, a keypad for manual input and PIN verification, ultrasonic sensors for tank-level monitoring and vehicle detection, and a voltage/current sensor to monitor supply health. The ESP32 processes this data to enforce safety limits, authenticate transactions, and control actuators including pump relays and the EV charger relay.

A. System Architecture

The system architecture comprises four main layers: (1) Sensing and Input Layer — RFID reader, keypad, ultrasonic sensor, and voltage sensor; (2) Processing Layer — ESP32 microcontroller executing authentication, transaction, and control logic; (3) Output and Actuation Layer — dual relay module for pump/charger control, 16x2 LCD, and buzzer; and (4) Communication and Cloud Layer — Wi-Fi IoT connectivity for cloud data logging and GSM module for SMS alerts. The regulated power supply (230V AC to 5V DC) provides stable power to all electronic subsystems.

B. Block Diagram

Figure 1 shows the complete block diagram of the proposed hybrid fuel dispensing system.

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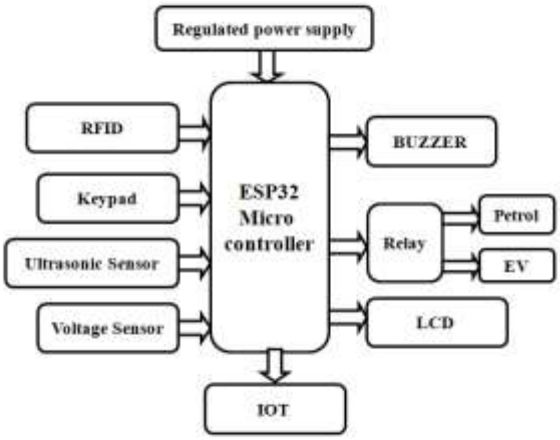

Fig. 1: Block Diagram of Hybrid Fuel Dispensing System (IoT-Cloud Integrated)

C. Circuit Description

The power supply section consists of a step-down transformer converting 230V AC to 12V AC, a bridge rectifier (DB107) for AC-to-DC conversion, filter capacitors (1000µF, 100µF) for ripple reduction, and a 7805 voltage regulator providing stable +5V DC. The ESP32 microcontroller acts as the central processing unit connected to all peripheral modules through its GPIO pins. The RFID reader module (125 kHz) is connected to GPIO 16 and 17 via UART for card scanning. The keypad uses three push-button switches connected to GPIO 18 (increment), 19 (select/enter), and 21 (decrement) for PIN and amount entry.

The ultrasonic sensor (HC-SR04) is connected to GPIO 2 (trigger) and GPIO 24 (echo) for tank-level and vehicle-presence detection. The voltage sensor uses GPIO 34 (ADC input) for continuous supply voltage monitoring. The 16x2 LCD display is connected via GPIO 12, 13, 14, 25, 26, and 27. Relay 1 (GPIO 8) controls the EV charger enable/disable, and Relay 2 (GPIO 9) controls the petrol pump motor operating on 230V AC. The GSM module (SIM800L) is connected to GPIO 8 for SMS alert transmission, and the buzzer is on GPIO 23 for local audible alerts. The IoT Wi-Fi connectivity is implemented using the ESP32's built-in Wi-Fi stack.

D. Hardware Components

Table II lists the key hardware components used in the proposed system.

Component	Function	Qty
ESP32 Dev Board	Central controller, Wi-Fi, BT	1
RFID Reader (125kHz)	Contactless user authentication	1
RFID Tags/Cards	User identification tokens	2+
Keypad (3 switches)	PIN and amount input	1
HC-SR04 Ultrasonic	Tank level / vehicle detection	1
Voltage Sensor (ADC)	Supply voltage monitoring	1
Relay Module (2ch)	Pump and EV charger control	1
16x2 LCD Display	Real-time transaction display	1
GSM SIM800L Module	SMS alert transmission	1
Piezo Buzzer	Security alert output	1
7805 Voltage Reg.	5V power regulation	1
DB107 Bridge Rect.	AC to DC conversion	1

Table II: Hardware Components of the Proposed System

E. Authentication and Dispensing Logic

When an RFID card is presented to the reader, the ESP32 reads the 12-character card UID via serial UART. Valid card UIDs are matched against registered credentials stored in firmware. Upon successful card recognition, the user selects fuel type using the keypad: pressing the up switch selects EV charging, and the down switch selects petrol dispensing. The system then prompts

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for a 4-digit PIN via the keypad interface. The PIN is verified against the stored password. If correct, the user enters the required fuel/charge amount. The system checks available balance, deducts the amount, and activates the appropriate relay (Relay 1 for EV, Relay 2 for petrol) for a duration proportional to the amount requested. Invalid card UIDs trigger the buzzer alert.

F. Tank Monitoring and Cloud Integration

The ultrasonic sensor continuously measures tank level by calculating distance in centimeters from the sensor pulse time-of-flight formula: distanceCm = duration * 0.034 / 2. If the measured distance exceeds 20 cm (indicating low fuel level), the system activates the buzzer, displays a Low Level warning on the LCD, and sends an alert via the IoT cloud server using an HTTP GET request to the configured server URL with payload parameters including data_string, fuel_string, and voltage_string. Voltage monitoring via the ADC on GPIO 34 triggers a Low Voltage alert when the supply falls below 8V. GSM-based SMS alerts are transmitted using AT commands for critical conditions. Normal transactions are logged to the cloud server after each dispensing cycle.

G. Software Implementation

The firmware is developed using Arduino IDE with ESP32 board support. Key libraries include LiquidCrystal (LCD), WiFi and HTTPClient (IoT cloud), and SoftwareSerial (GSM). The main loop continuously samples the ultrasonic sensor and voltage ADC, checks serial input for RFID card data (12-character alphanumeric UID), processes authentication and transaction logic, controls relay actuators, updates the LCD, and periodically uploads telemetry to the cloud server. The iot_send() function formats HTTP GET request strings concatenating card identity, fuel type, balance, and sensor readings. Cloud data fields use URL parameters: field1=data_string, field2=fuel_string, field3=voltage_string.

5. RESULTS AND DISCUSSIONS

The proposed Hybrid Fuel Dispensing System was developed, assembled, and experimentally validated across all functional modules including RFID authentication, fuel type selection, PIN verification, dispensing relay control, tank-level monitoring, LCD display, cloud data logging, GSM alert transmission, and security buzzer activation.

Figure 2: Hardware project prototype

A. Authentication System Results

The RFID reader successfully authenticated registered card UIDs with a read range of 8-12 cm. Valid card 1 (UID: 55007B0E1838) and Valid Card 2 (UID: 55007F2EE9ED) were correctly identified and authenticated. Invalid card (UID: 55007E6787CB) triggered an immediate buzzer alert and Invalid Card message on the LCD. The PIN verification using the 3-button keypad accurately captured 4-digit entries. Correct password (1234) granted access to the dispensing process, while incorrect entries activated the buzzer and displayed Wrong Password on the LCD.

B. LCD Display and Transaction Feedback

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Figure 3: project data on LCD

Figure 2 illustrates the system's 16x2 LCD displaying real-time operational feedback during the authentication and dispensing process. The first result figure shows the LCD display providing authentication status (Valid Card1/Card2), fuel type selection (Fuel Type: EV / Fuel Type: Petrol), transaction confirmation (Correct Pwd), balance deduction (Blc:xxx), and dispensing initiation messages. The second result figure shows the dispensing operation in progress, with the LCD updating dynamically as the relay controls fuel flow or EV charging. The third result figure confirms successful completion of the transaction with the system returning to idle state and displaying the standby message.

Table III summarizes the functional test results across all system modules.

Test Function	Observed Result	Status
Valid RFID Card Auth.	Card recognized, proceed	Pass
Invalid RFID Card	Buzzer alert, rejected	Pass
PIN correct (1234)	Fuel/EV selection enabled	Pass
PIN incorrect	Buzzer, Wrong Pwd display	Pass
EV Relay activation	Relay 1 ON for set time	Pass
Petrol Relay activation	Relay 2 ON for set time	Pass
Low tank level alert	Buzzer + Low Level LCD	Pass
Low voltage alert	Buzzer + IoT upload	Pass
IoT cloud data upload	HTTP GET successful	Pass
GSM SMS alert	SMS transmitted	Pass

Table III: Functional Test Results

C. Tank Level and Voltage Monitoring

The ultrasonic sensor demonstrated accurate distance measurement for tank-level monitoring. Distances above 20 cm correctly triggered Low Level alerts with simultaneous buzzer activation, LCD warning, and IoT cloud upload. The voltage sensor on GPIO 34 accurately measured supply voltage using the ADC-to-voltage conversion formula, triggering Low Voltage alerts when the supply fell below the 8V threshold. Both alert conditions successfully triggered IoT data uploads to the cloud server, confirmed by successful HTTP response codes.

D. Cloud Monitoring and IoT Data Logging

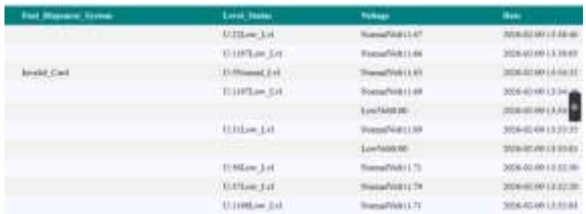

Figure 4: Cloud SERVER data

Figure 4 shows the IoT cloud server database recording transaction data including card identity, fuel type selected, dispensing amount, balance, tank level status, voltage reading, and timestamp. The cloud data upload was verified for all test scenarios including normal transactions, balance deductions, low tank alerts, and voltage anomaly alerts. The HTTP GET request to the projectsfactoryserver.in/storedata.php endpoint returned successful response codes in all connected test cases, confirming stable Wi-Fi connectivity and reliable cloud logging.

E. Overall System Performance

Table IV summarizes the overall system performance metrics measured during testing.

Performance Metric	Measured Value
RFID Read Range	8-12 cm
Card Authentication Time	< 1 second
PIN Entry Response	Immediate
Relay Activation Accuracy	Per second (1s/unit amount)
Tank Level Alert Threshold	> 20 cm distance
Voltage Alert Threshold	< 8V supply
IoT Upload Delay	~8 seconds per transaction
LCD Update Rate	Real-time (~100 ms)
Buzzer Alert Duration	2 seconds per event
GSM SMS Delivery	~15-20 seconds
System Power Consumption	~1.0 A @ 5V
Wi-Fi Connectivity Range	~30 m (indoor)

Table IV: Overall System Performance Summary

6. CONCLUSION

The Hybrid Fuel Dispensing System for Smart Fuel Stations Supporting EV and Conventional Vehicles was successfully designed, implemented, and experimentally validated. The system demonstrated reliable performance across all key functional modules: RFID-based user authentication, dual-relay fuel type selection (petrol and EV), PIN-secured transaction processing, automated dispensing duration control, ultrasonic tank-level monitoring, voltage anomaly detection, real-time LCD feedback, IoT cloud data logging, and GSM SMS alert transmission.

The ESP32 microcontroller effectively served as the central hub coordinating all hardware subsystems through its GPIO, ADC, UART, and Wi-Fi interfaces. RFID authentication combined with PIN verification provided a robust dual-layer security mechanism, preventing unauthorized fuel access. The unified control architecture eliminated the fragmentation characteristic of existing systems where petrol pumps and EV chargers operate on separate platforms with disjointed management dashboards.

Cloud connectivity enabled remote monitoring and transaction logging for all fuel and charging events, supporting inventory management and operational analytics for station owners. GSM SMS alerts ensured timely notification of critical conditions including low tank levels and supply voltage anomalies. The system successfully demonstrated both EV charging relay control and petrol pump relay control from a single controller platform with a consistent user interface.

The proposed system represents a cost-effective, modular, and scalable solution suitable for upgrading existing fuel stations to hybrid smart stations. Future enhancements may include mobile payment gateway integration, AI-based demand forecasting for inventory optimization, blockchain-secured transaction logging for tamper-proof records, solar energy integration for off-grid resilience, and expanded sensor arrays for multi-tank management. These advancements would further align the system with smart city and Industry 4.0 requirements.

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