IoT-Based Real-Time Diesel Fuel Monitoring and Fraud Mitigation in Stationary Facilities

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Received: 23-APR-2026; Reviewed: 26-MAY-2026; Accepted: 30-JUNE-2026
https://dx.doi.org/10.46792/fuoyejet.v11i2.1572

ORIGINAL RESEARCH

Abstract— The increase in diesel fuel theft and fraud remains a serious challenge for stationary diesel fuel storage facilities. In this study, an IoT-based real-time diesel fuel monitoring and fraud mitigation system was developed to address financial losses caused by fuel fraud. The developed system integrates dual-flow sensing, a cloud-hosted MySQL database, GPS-based location tracking, and mobile/web-based monitoring. The fuel level sensor was calibrated using known diesel volumes, and a polynomial calibration was developed by first taking sample measurements to accurately convert sensor readings into fuel volume. Experimental results obtained demonstrated a volumetric accuracy of 98.0%, with a linear correlation coefficient of 0.9998. WhatsApp notification latency was 1.25 seconds with a sudden fuel level drop, which was related to fraud. The results showed that flow sensor accuracy improved after polynomial calibration but remained sensitive to flow-rate variations. The main contribution of the developed system is its ability to monitor inflow and outflow, store data in the cloud, provide real-time alerts, support remote access, and assist in detecting irregular fuel movements, while also estimating the initial facility's fuel capacity via a calculator interface on both the web and the mobile applications. The integration of the GPS module makes it easier for facility managers to supervise stationary fuel storage facilities across multiple locations.

Keywords— Dual-Flow Sensors, GPS Tracking, Internet of Things (IoT), Polynomial Calibration, Stationary Fuel Facilities.

1 INTRODUCTION

Internet of Things (IoT) involves the inter-connection of physical objects for data exchange and remote supervision. In fuel management systems, IoT uses sensors and microcontrollers for real-time and remote monitoring of fuel (Mulenga & Halubanza, 2025). The increased use of IoT has improved resource management and operational control across various sectors (Sur et al., 2020). In modern institutional and industrial settings, stationary fuel storage facilities such as telecommunication base stations, power generator tanks, and industrial fuel storage are critical assets. As a result, the secure handling and accurate monitoring of fuel resources remain essential (Anand et al., 2024). However, many existing stationary fuel monitoring systems rely on manual inspection and analogue gauges. These methods are inherently imprecise and highly susceptible to human error (Rosaline et al., 2019; Mallieswaran et al., 2024). Although recent studies have explored the use of ultrasonic and vibration-based sensing techniques to improve measurement accuracy (Sur et al., 2020; Mulenga et al., 2025; Anand et al., 2024), these approaches often struggle to distinguish between real fuel consumption and fuel fraud. These limitations reduce their effectiveness in providing accurate consumption tracking and real-time fraud detection. To address these challenges, this study employs dual-flow sensing to continuously measure both the inflow and the outflow of diesel fuel within the storage system (Sur et al., 2020). The integration of IoT technology with flow sensors and GPS modules enables remote supervision and real-time monitoring of stationary fuel storage facilities. The developed system provides a scalable solution for accurate real-time fuel measurement, monitoring, supervision, and fraud detection (Mulenga et al., 2025; Anand et al., 2024).

2 RELATED WORK

The development of an IoT-based fuel management system has transitioned from manual fuel measurement and supervision to real-time remote fuel tracking and monitoring. Different studies have been carried out in the field of fuel measurement, which have established the fundamental basics for remote fuel level tracking using sensors and communication modules. Across existing studies, sensing technologies have been used to improve fuel monitoring accuracy and enhance fraud detection capability. For instance, fuel flow sensors are used to verify fuel volume during refueling, ultrasonic sensors are used for fuel level monitoring, and vibration sensors are used to detect physical vandalism (Fernandes et al., 2022). Similarly, IoT-based implementations combine ultrasonic sensors, flow sensors, and vibration sensors using platforms such as NodeMCU to monitor fuel levels, leakage, and fraud in real time (Sur et al., 2020). These approaches collectively show a shift toward the use of multi-sensors to improve fuel measurement. In parallel, data-driven approaches have been used to improve fuel consumption analysis and predictive capability, which include the use of big data such as Apache Spark to calculate fuel consumption with the application of machine learning prediction in fuel management systems (Ali et al., 2021). These developments highlight a growing transition from sensor-based monitoring to intelligent and predictive fuel management frameworks.

Furthermore, communication and connectivity of fuel data have also been used to extend facility supervision in different environments. IoT-based systems integrated with GSM/GPS modules and long-range antennas have been used to improve geographic coordinate acquisition

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Section B- ELECTRICAL/COMPUTER ENGINEERING & RELATED SCIENCES
Can be cited as:
Kolapo F. O. and Ogidan O. K. (2026). IoT-Based Real-Time Diesel Fuel Monitoring and Fraud Mitigation in Stationary Facilities. FUOYE Journal of Engineering and Technology (FUOYE**JET**), **11(2), 254-259.** https://dx.doi.org/10.46792/fuoyejet.v11i2.1572

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for stable tracking of fuel facilities (Mulenga et al., 2025). In a similar direction, fuel tracking systems used in areas with limited internet access rely on a GSM module to transmit fuel level and facility location data (Anand et al., 2024). Additionally, Telegram-based monitoring systems have been introduced to detect deviations between expected and actual fuel volumes during fueling operations, providing real-time error reporting for fraud detection (Nishith et al., 2025). These reviewed studies have shown a progressive evolution toward automated and connected fuel monitoring systems. However, the approaches differ in focus, with some leveraging on sensors, others focusing on predictive analytics, and others prioritising communication in low-connectivity environments.

This work differs from existing studies by developing an IoT-based fuel monitoring and tracking system for stationary diesel fuel storage facilities by using dual-flow sensors for fuel measurement. The fuel key data acquired with the help of the Arduino Uno (microcontroller) is transmitted to a cloud-hosted MySQL database. The GPS geographical coordinate of the diesel fuel facility is achieved through a GPS module, and the stationary fuel storage facility data are monitored remotely on both web and mobile applications. The applications contain a fuel estimate calculator that is used to determine the initial fuel capacity of the stationary diesel fuel storage facilities. The rest of the paper is arranged as follows. Section 3 is the methodology, section 4 is the results, section 5 is the discussion, and section 6 concludes the paper.

3 METHODOLOGY

3.1 SYSTEM DESIGN

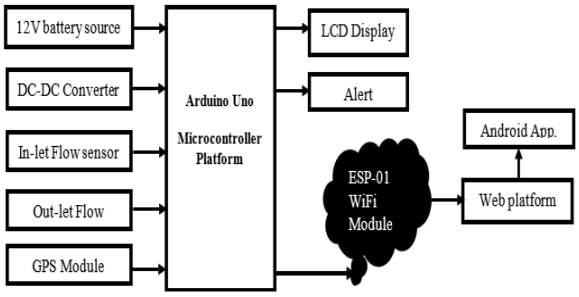
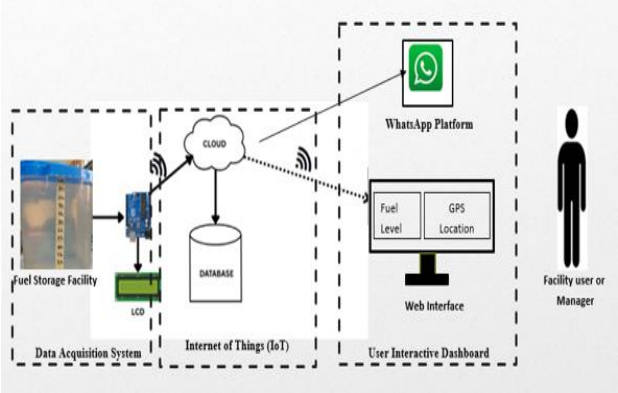


Fig. 1. Block diagram of the system model

The methodology, as presented in Figure 1, involved the use of a dual-flow sensor (YF-S201) to measure diesel fuel inflow and outflow across the storage facility. The microcontroller is the central processing unit, connected with a GPS module for location tracking and a Wi-Fi module (ESP-01) for data transmission to the web. The key fuel data and geolocation are communicated to the web and stored in the MySQL database for remote monitoring and supervision, while the use of the CallMeBot API allows prompt WhatsApp reports whenever there are abnormal fuel flows. The system model consists of the microcontroller (the brain of the system), which accepts electronic signals from sensors and modules and carries out predefined operations. The microcontroller input pins consist of a DC power source, flow sensor, GPS module, and DC-to-DC converter, while the output pins consist of the LCD, Wi-Fi module, and web app integrations. The main aim of the dual flow sensor is to continuously measure the diesel fuel volume entering the fuel facility during refueling and the volume of diesel fuel leaving the fuel facility during operation or usage. The LCD interfaced with the microcontroller displays the real-time data of diesel fuel levels and flow rates, providing remote access to facility managers. Furthermore, the GPS module communicates the facility's geographical coordinates in real time to distinguish one fuel facility from another when facilities are distributed. To keep facility managers entirely up-to-date, the system uses the Wi-Fi module (ESP-01) to transmit real-time fuel levels and GPS coordinates directly to the web.

Fig. 2. Architecture of diesel fuel storage facility



The overall system architecture in Figure 2 is divided into three major sections, namely, the data acquisition system, the Internet of Things (IoT), and the user interactive dashboard. The data acquisition system consists of the calibrated plastic diesel fuel storage, the Arduino microcontroller, and the liquid crystal display (LCD). The fuel storage is integrated with flow sensors and a GPS module. The flow sensors measure fuel movement (inflow and outflow) of the fuel storage, while the GPS module captures real-time geolocation data in latitude and longitude. The acquired data is processed by the microcontroller, and diesel fuel data is displayed on a liquid crystal display (LCD) for on-site monitoring. The IoT layer is implemented using the Wi-Fi module, which establishes a remote connection between the stationary fuel storage facility and the web. The Wi-Fi connected with the microcontroller transmits fuel level data (in litres) and location coordinates to the cloud server in real time for remote access, monitoring, and storage.

The User Interactive Dashboard shows how the stored data is accessed through a web interface and a mobile platform (WhatsApp integration). Facility managers can remotely monitor stationary fuel storage facilities and GPS positions in different geographical locations in real-time through the interactive, user-friendly dashboard. Furthermore, figure 2 demonstrates a complete end-to-end architecture that integrates sensing, wireless communication, cloud storage, and remote user interaction, ensuring real-time monitoring and management of fuel storage facilities.

3.2 HARDWARE IMPLEMENTATION

The system implementation wiring connections in figure 3 show the complete system implementation. This consists of the dual flow sensor and connections with the different stages involved in the development of a lab-scale prototype experimental setup in figure 7. The

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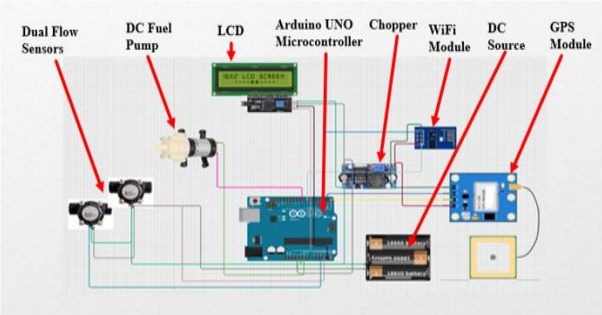
microcontroller is used for data acquisition, signal processing, and coordination. Pulse signals generated by the dual flow sensors are converted into fuel volume using calibrated pulse-to-volume relationships. The diesel DC pump transfers fuel from an external fuel container (diesel tanker) into the stationary fuel storage facility. For local visualisation, a 16×2 liquid crystal display is interfaced with the microcontroller through an I²C module to display key data such as fuel level, which enables on-site monitoring without reliance on an IoT remote platform. The Wi-Fi module transmits processed diesel fuel data wirelessly to the web through a configured network, and real-time data are obtained on the interactive web dashboard. The dual-flow sensor measurement enables an end-to-end fuel level measurement, which guarantees the detection of fuel fraud.

Fig. 3. Wiring diagram of the developed system



3.3 MATHEMATICAL MODELLING

The rate of flow of fuel volume is derived from the Hall effect frequency pulse produced by the dual-flow sensors. It is mathematically expressed as shown in equation (1).

$$Q = \frac{f}{K} \quad (1)$$

Where Q is flow rate (litres/min), K is the calibration constant (litres/pulse), and f is the frequency (pulses per second).

The calibration constant in (1) depends on the density of fuel and the flow sensor calibration. Diesel fuel has a kinematic viscosity in centistokes at a specific temperature around 40 °C and a density value in the range of about 820–845 kg/m³ under room conditions.

In a steady-state system, the net fuel status (V_{net}) is calculated by determining the difference in pulse counts between the supply and return lines, as shown in equation (2).

$$V_{net} = (k_{in} * N_{in}) - (k_{out} * N_{out}) \quad (2)$$

Where V_{net} is the net fuel status (liters), k_{in} is the calibration constant for the supply inflow (pulses per liter), k_{out} is the calibration constant for the outflow return (pulses per liter), N_{in} is the total accumulated inflow line pulse counts (pulses), and N_{out} is the total accumulated outflow lines pulse counts (pulses).

The total facility fuel level (Q_{net}) is the difference between inflow and outflow, as shown in equation 3.

$$Q_{net} = (Q_{in} * Q_{out}) \quad (3)$$

Where Q_{net} is the total volumetric flow rate (liters/minute), Q_{in} is the inflow volumetric flow rate (liters/minute), Q_{out} is the output volumetric flow rate(liters/minute), f is the sensor pulse frequency pulses/second), N is the total accumulated pulse count, and V is the total volume of fuel (litres) (Kwao-Boateng et al., 2024).

3.4 SENSOR CALIBRATION

The sensor calibration is based on the principle of conservation of mass (Sur et al., 2020). The sensors were observed to have a non-linear behavior which needed a software-based low-pass filter in the microcontroller firmware, coupled with polynomial calibration to correct the sensor's non-linearity (Brumand-Poor et al., 2025; Dias Pereira et al., 2009; and Jamil et al., 2023).

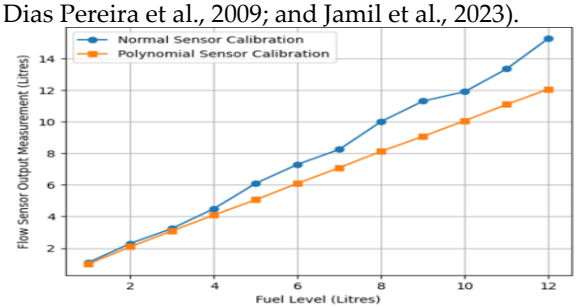


Fig. 4(a). Comparison of normal and polynomial sensor calibration at a slightly constant flow rate

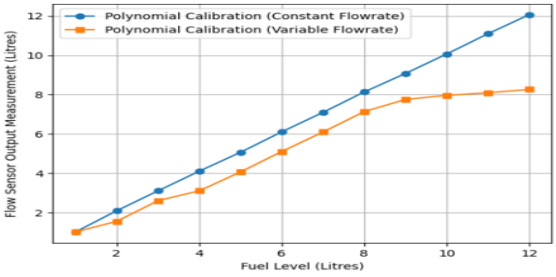


Fig. 4(b). Comparison of polynomial calibration under constant and variable flow rate conditions.

Figure 4(a) and Figure 4(b) show the flow sensor output response based on calibration and flow rate. Figure 4(a) used normal sensor calibration, and the measurement was taken against the standard measurement. The results were inaccurate in non-linear form against the standard measurement. The system was recalibrated using the polynomial calibration, which corrected the non-linearity. Though the flow sensor exhibits a linear response in figure 4 (a), the linear response output was affected by variations in the flow rate of the flow sensor as shown in figure 4 (b).

3.5 IOT AND CLOUD INTEGRATION

Figure 5 (a) shows the web interface (front-end) hosted environment, which contains the directories where the IoT fuel data is stored. The platform provides file management, hosting tools, and database connection, which are needed for a fuel facility remote monitoring system. To enable real-time communication between the hardware and the web interface, a local area network (LAN) hotspot network was used. The hotspot provided Internet connectivity for the Wi-Fi module.

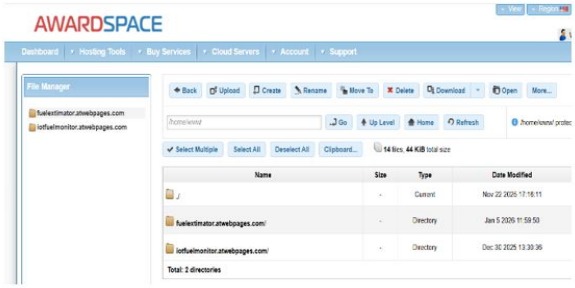


Fig. 5(a). Award web interface (Front-End)

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	id	flow_in	flow_out	total_in	total_out	tank	pump_status	timestamp
Edit Copy Delete	608	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:29:41
Edit Copy Delete	609	19.33	0.00	0.000	2305.151	0.000	0	2026-01-07 20:29:48
Edit Copy Delete	610	53.87	0.00	0.000	2305.151	0.000	0	2026-01-07 20:29:56
Edit Copy Delete	611	53.87	0.00	0.000	2305.151	0.000	0	2026-01-07 20:30:04
Edit Copy Delete	612	20.93	0.00	0.000	2305.151	0.000	0	2026-01-07 20:30:12
Edit Copy Delete	613	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:30:20
Edit Copy Delete	614	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:30:28
Edit Copy Delete	615	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:30:36
Edit Copy Delete	616	1.73	0.00	0.000	2305.151	0.000	0	2026-01-07 20:30:44
Edit Copy Delete	617	9.73	0.00	0.000	2305.151	0.000	0	2026-01-07 20:30:52
Edit Copy Delete	618	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:31:00
Edit Copy Delete	619	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:31:08
Edit Copy Delete	620	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:31:17
Edit Copy Delete	621	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:31:25
Edit Copy Delete	622	13.87	0.00	0.000	2305.151	0.000	0	2026-01-07 20:31:33
Edit Copy Delete	623	0.00	0.00	0.000	2305.151	0.000	0	2026-01-07 20:31:41

Fig. 5 (b). MySQL Database (Back-End)

The database figure 5 (b) consists of a fuel data row and a column logged with a time stamp. Each data point recorded in the row represents a real-time data entry generated by the system. The timestamp column data confirms continuous monitoring and logging of fuel data. The database enables accurate storage, auditing, and historical analysis of fuel consumption patterns. The mobile application connects directly to the web with the same configured credentials and provides the same information, ensuring that fuel level data and GPS location of the facility can be remotely monitored from any geographical location. As presented in figure 5 (a) and figure 5 (b), the integration of cloud hosting, structured MySQL database storage, and web and mobile visualisation provides a complete end-to-end IoT infrastructure.

3.6 ALERT MECHANISM

Fig. 6(b). WhatsApp platform fuel data notification, Google Sheet historical diesel fuel data, and correlation graph

Figure 6(b) shows the instant WhatsApp alert received when there was a sudden fuel level drop or irregular fuel usage pattern in the fuel storage facility. The fuel notification was received together with the geo-location of the fuel storage facility for immediate action.

3.7 EXPERIMENTAL VALIDATION

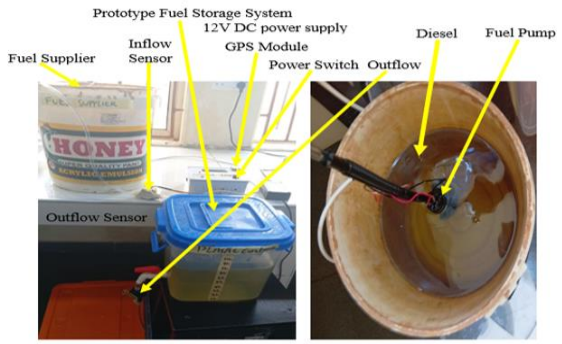

Fig. 7. The complete experimental setup of the developed system.

In the experimental setup shown in figure 7, fuel (Diesel) was pumped from the refueling tank into the storage tank by the DC pump while the inflow sensor was simultaneously being used to measure the fuel volume. The measured volume by the inflow sensor was displayed on the liquid crystal display (LCD), while the volume delivered to the storage tank was observed through the graduated storage tank with the system flow-chart shown in figure 8. Twelve measurement samples were obtained as recorded in Tables 1 (a) and 1 (b). The error and percentage error between the measured inflow sensor reading on the LCD and the volume observed in the graduated storage tank were computed. The measured fuel data, the facility's geo-location and the fuel usage pattern line graph were displayed on the web and also stored on the cloud-hosted MySQL database as shown in figure 9 (a).

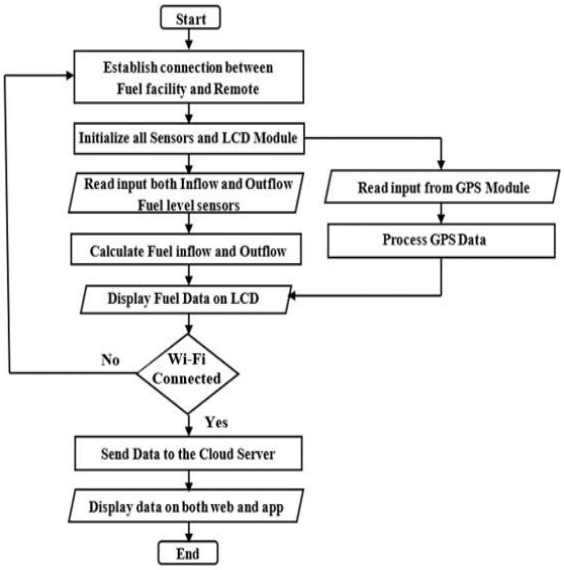

Fig. 8. System Flowchart

The system operation in figure 8 begins at the start point to establish a connection between the fuel facility and the web. Once established, sensors and modules are initialised to prepare the system for full operation. The system then reads input data from both the inflow and outflow fuel flow sensors while obtaining data from the GPS module. The system then calculates the fuel inflow and outflow, measured diesel fuel volume and displays the calculated fuel data on the LCD. A decision is then made to check if Wi-Fi is connected; if no connection is available, the system loops back to continue monitoring and acquire fuel data while ensuring that the Wi-Fi connection is established. However, if a Wi-Fi connection is established, the system proceeds to send the processed data to the web.

4 RESULTS

From the developed system setup (Fig. 7), the key fuel data is displayed on the LCD, communicated to the web interface and stored in the MySQL database. The developed storage facility is simulated using a calibrated plastic container of approximately 30 cm height and 15 cm diameter. The container is manually calibrated from 0 litres to 12 litres using a standard calibrated glass jar. An inlet flow sensor and an outlet flow sensor are fixed to the system, forming the dual-flow configuration described in figure 3. The embedded control unit is connected to the inflow sensor, the outflow sensor, and the NEO-6M GPS module.

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4.1 THE DEVELOPED LAB-SCALE SYSTEM EXPERIMENTAL RESULTS

The results of the IoT-enabled real-time diesel fuel monitoring and fraud mitigation in stationary facilities are presented in Tables 1(a) and 1(b), and figure 9(a) and 9(b), respectively.

Table 1(a). Fuel level correlation analysis between lab-scale prototype diesel fuel data communicated to the web.

Standard Fuel Level (Liters)	Measured Fuel Level on LCD (Liters)	Measured Fuel Level on Web (Liters)	Measurement Error (%)
1.00	1.01	1.01	0.01
2.00	2.09	2.09	0.09
3.00	3.10	3.10	0.10
4.00	4.10	4.10	0.10
5.00	5.06	5.06	0.06
6.00	6.10	6.10	0.10
7.00	7.09	7.09	0.09
8.00	8.13	8.13	0.13
9.00	9.07	9.07	0.07
10.00	10.06	10.06	0.06
11.00	11.09	11.09	0.09
12.00	12.06	12.06	0.06
Correlation: 0.9998			

Table 1(b). WhatsApp notification latency and delivery reliability test

Diesel Fuel Sample (Liters)	Latency (Seconds)	Delivery Status (Y / N)
1.000	1.00	Y
2.031	1.00	Y
3.009	1.00	Y
4.015	2.00	Y
5.042	1.00	Y
6.082	1.00	Y
7.082	1.00	Y
8.069	2.00	Y
9.046	2.00	Y
10.086	1.00	Y
11.009	1.00	Y
12.046	1.00	Y
Latency: 1.25 seconds		

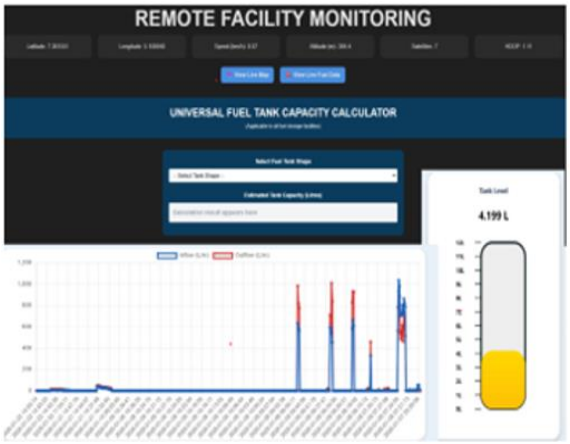

Fig. 9 (a). Internet of Things interactive web dashboard

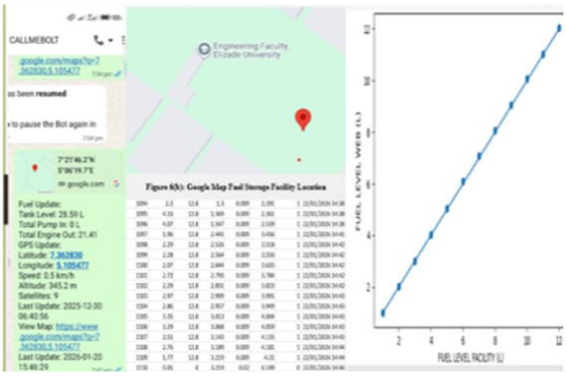

Fig. 9 (b). WhatsApp platform fuel data notification, Google Sheet historical diesel fuel data, and correlation.

From the results presented in Table 1(a), the percentage error obtained in the diesel fuel measurement in figure 7 remains very low across the diesel level (litres). Even at higher volumes, the absolute error remains minimal. The continuous inflow of diesel fuel gives a gradual rise to the diesel fuel level from 1 litre to 12 litres in the calibrated fuel container. The result confirms that the dual-flow sensor approach provides highly accurate real-time fuel level monitoring due to the polynomial calibration of the flow sensors that eliminates the sensors' nonlinear effects. The correlation results are presented in Table 1(a). From the table, the fuel level measured on the LCD, the web platform, and the physical lab-scale prototype fuel storage system exhibited no significant variance. The recorded correlation coefficient is 0.9998.

4.2 VOLUMETRIC MEASUREMENT ACCURACY

The experimental results presented in Table 1(b) show a near-perfect fuel measurement relationship between the actual delivery status of Y (success), confirming 100% delivery reliability during the experiment. The actual fuel volume and the fuel volume by the digital system are displayed on both the LCD and the web. Additionally, figure 9(a) and figure 9(b) demonstrate the real-time monitoring dashboard and geolocation display. figure 9(b) shows the Google Maps interface, which displays the exact location of the system setup. This confirms that the GPS module successfully transmitted accurate geographical coordinates to the web. The real-time geographical location displayed on the map confirms the actual location of the fuel storage facility.

4.3 WHATSAPP NOTIFICATION

Apart from displaying fuel data on the LCD, the web dashboard, mobile application, and WhatsApp notification are involved for continuous two-way real-time monitoring and fuel level monitoring as presented in figure 9(b). This ensures that even if there is a temporary delay in accessing the web dashboard, the facility manager still receives real-time updates directly on a mobile device. The WhatsApp SMS report presentation summary in Table 1(b) shows Y = 100% (success) message delivery success rate with a latency range of 1–2 seconds and an average latency of 1.25 seconds without any failure data delivery of "N" (failure). The close-to-real-time alert functionality meaningfully improves effective fuel security and quick response whenever there is an abnormal fuel event detected, such as leakage or theft.

Tables 1(a) & 1(b) and figure 9(a) & 9(b), respectively, clearly establish that the developed IoT-based fuel measurement, monitoring, and management system achieved high volumetric accuracy (correlation = 0.9998)

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with reliable cloud data synchronisation, accurate GPS tracking, and fast and dependable WhatsApp alert delivery. The results confirm the success of the dual-flow sensor architecture implementation, achieving intelligent fuel storage monitoring.

5 CONCLUSION

In this study, an IoT-enabled real-time diesel fuel monitoring and fraud mitigation system is developed to help stationary diesel fuel storage facility managers have an accurate measurement, monitoring and supervision of diesel fuel in the facility remotely to reduce or eradicate huge financial losses caused by fuel theft, operational inefficiencies and all other related fraud in both domestic and industrial settings. The developed system was able to successfully measure diesel fuel volume in and out of the fuel storage facility, display the results on the LCD, and also send key fuel data to the web and mobile App. The study used a diesel fuel pump to feed diesel fuel across the flow sensor for fuel measurement. With a polynomial calibration, the sensor non-linearity measurement was addressed. However, when the developed system was used for a long time, the DC power source voltage dropped, which affected the flow rate of the flow sensor and the system measurement performance.

Future system implementation should use an automated power management unit, comprising a voltage-regulated DC–DC buck–boost converter and real-time power monitoring circuitry, to ensure a stable operating voltage under varying power conditions. This improvement is expected to achieve measurement accuracy, operational reliability, and long-term system stability during continuous system usage.

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