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Deployment of an IoT Storage Tank Gauge and Monitor

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Abstract

With an upsurge of data by global brands to interact/reach prospective clients, the birth of the Internet has today bridged the information gap. Virtualization techniques are today utilized as means to bridge the various lapses in our human processing endeavors. The adoption of tech to perform a variety of functions has since become imperative to ease our daily living as well as seamlessly allow transformations of various kinds to be impacted on our society. Study proposes a virtual key card access with cost-effective and cheap solution for managing access to areas within a facility. We have successfully integrated IoTs, virtual key card access, web-access control, solenoid lock integration, and ESP32-controller to create a comprehensive access control system. Its benefits over traditional key includes better security, user data privacy, system efficiency, and user convenience. The system also provides real-time monitor and control capabilities that will allow administrators to track and manage access to the facility remotely. And in turn, enhancing system's security and efficiency.

1. INTRODUCTION

The rapid development in technology in recent years has significantly contributed to improving daily living – creating a variety of applications in spheres such as environment, health, military, security, etc. These have and is currently, gradually becoming a sustainable alternative to traditional systems. All of this can be traced back to the development of microelectronics and integrated circuits, however, the appearance of several wireless communication standards such as Bluetooth Sigsbee, and Wi-Fi provide a compromise reliability of the system for long-term applications (Bengherbia et al., 2017)

Fuel asset has since become an integral part of today's society, and as such, it is one of the most expensive commodities any operation will incur. Whether it be keeping emergency generators ready to kick in or fuelling heavy-duty Earth moving equipment in mining operations, fuel is one of the most important resources in your inventory that you need to keep track of (Ojugo, Odiakaose, et al., 2023; Ojugo, Ugboh, et al., 2013)

1.1 Supervisory Control and Data Acquisition (SCADA)

Automation plays an important role in industrial systems. To speed up industrial processes, most industries now control their processes and operations remotely via their

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integration of the supervisory control and data acquisition (SCADA) systems. Cases of businesses where SCADA frameworks are utilized incorporate: Controlling the stream of gas and oil through channels within the oil industry, managing the flow of water in water and sewage systems, managing the power output from power plants to the grid, process controlling in chemical plants, transporting and distributing products during production. Management of railways and other transport infrastructure units and signal networks (Upadhyay & Sampalli, 2020).

SCADA systems typically include one or more topographically distributed field sites with control servers, communication links, and field devices located at a control centre. Field-site SCADA sensors and actuators continuously monitor various characteristics of electromechanical devices and provide feedback to field control devices such as programmable logic controllers (PLCs), remote terminal units (RTUs), or intelligent electronic devices (IEDs). Send a signal. Via communication links, the transfer of information transpires back and forth between field control devices and the control center. The field control devices will supply digital status information to the control center, where the software will process the status information and determine acceptable parameter ranges. This information will then be transmitted to the field device(s) where action may be taken to avoid various hazards or optimize the performance of the system. The control center will store the status information in a data historian and display it on an HMI (Human Machine Interface) which provides centralized monitoring of digital status information and system control. (Upadhyay & Sampalli, 2020).

SCADA protocols commonly used to cover large areas include Ethernet, Modbus, DNP3, Profinet, and DCOM. These help to disseminate data effectively over a wide area network via satellite, radio or microwave, cellular, switched network, telephone, or rented line communications media (Meixell & Forner, 2013). SCADA's objective is to proficiently handle execution at a single area, such as a fabricating office, instead of cantering on the security of organize data. Due to the increased interconnectivity of networks and the possibility of remote access to systems within SCADA networks, a variety of vulnerabilities and risks of cyber-attacks exist. To strengthen the security of your SCADA network, you need to incorporate appropriate security measures. Common protection measures include a restricted perimeter, patch management, strong encryption, and most importantly, separation of control and corporate networks via layered defences mechanisms. However, these security measures are difficult to apply because they have old vulnerabilities and the potential for exploitation during real-time communications is high. (Nazir et al., 2017)

1.2. The SCADA Architecture

A typical SCADA architecture consists of (Alade et al., 2017) as below:

1. Field location: Field service locations typically have remote access capabilities that allow field personnel to perform diagnostics and repairs remotely. Field location 1 (Figure 2.1) consists of a modem and a PLC that connect to sensors and other field devices via a field bus network. Fieldbus technology eliminates the need for point-to-point cable connections between the PC and field devices. Processed data from the PLC passes through a modem, where it is modulated and sent to the control center via a communication medium. "A modem is a device that converts serial digital data into signals suitable for transmission over telephone lines, allowing communication between devices." (Stouffer et al., 2015). At remote site 2, both the WAN card and the intelligent electronic device (IED) are connected directly to the modem. There is enough intelligence built in to

process some of the data, so no PLC is required. Field site 3 is similar to the field site except that the RTU is replaced by a PLC. Protocols are required for communication between sensors, other field devices, and RTU/PLC.

2. Communication Link: There is usually a long distance between the Field Sites and the Control Centre ranging from a few kilometers to hundreds of kilometers or at times thousands of kilometers. Effective communication is necessary for effective flow of data to/fro the MTU and other devices (Oliveira et al., 2016) as in figure 1. The link can be one of the following: We replaced the rental phone line. Power line-based communication. Wireless; Microwaves; Cellphones; Satellite and Wide Area Networks (WAN).
3. Control Centre: The main part of SCADA Server (or MTU), the HMI, Workstations, Data Historian, and Communication routers – all of which are linked to a LAN. Data collected by the field is via a control center, where it is recorded and displayed on the HMI to enable the operator to take appropriate actions needed based on detected events.
4. Trend analysis, alarms and central reporting are also the responsibility of the control center. (Stouffer et al., 2015).

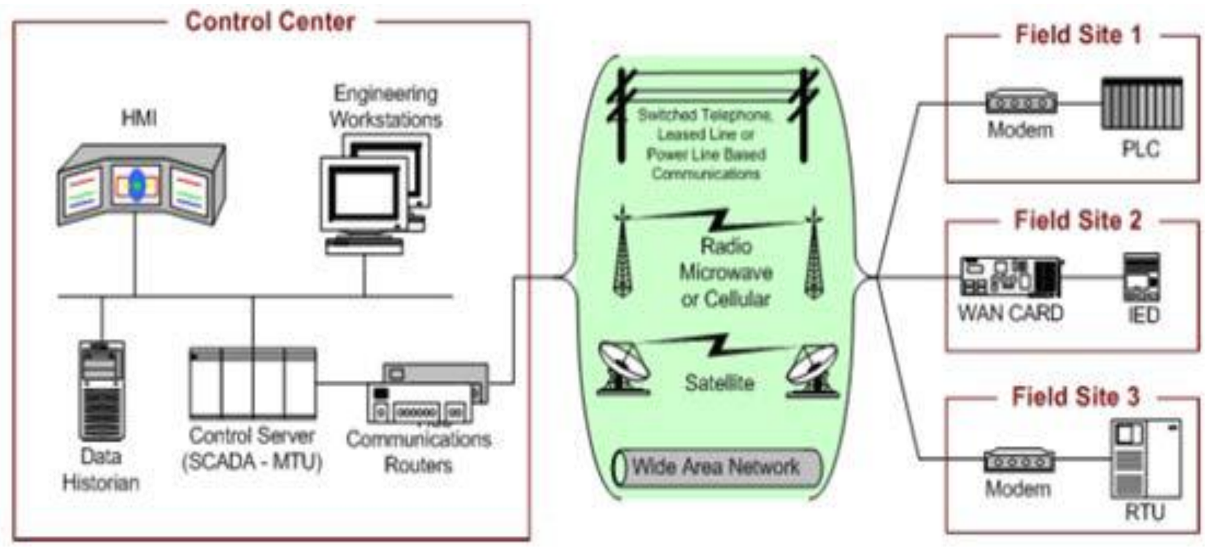

Figure 1. The schematic diagram of the SCADA Architecture (Ojugo et al., 2021a, 2021b)

1.3 Storage Tanks Gauging Technology

The various storage tanks gauging tech is explained as (Aghware et al., 2023a; Akazue et al., 2022, 2023; Oyemade et al., 2016; Oyemade & Ojugo, 2020, 2021):

1. **Dipstick** – uses a dip tape, user-operated manual measuring device consisting of a calibrated tape with a weight attached to the end. Units of measurement can be meters, feet, or yards. The weight (a bob) is lowered into the bucket by hand by the operator. The weight is continuously lowered into the barrel until the operator feels the weight touch the guard mounted at the bottom. At this point, the symbol on the tape is read. The strip is then retracted while an operator watches it become wet. The tape notation is then recorded again. The difference between both values are recorded. From known tank capacity and size, usage is then calculated. (Braddock & Chambers, 2011). The accuracy of this mode varies significantly depending on the skill and experience of the operator. Additionally, dip measurement accuracy can be affected by high winds and cold temperatures (Ojugo & Otakore, 2018a, 2018b).

2. **Automatic Gauging** is an electronic device that allows gas station operators to monitor fuel levels in tanks and issue warnings if fuel levels get low. ATG uses a probe consisting of a long rod with a float placed in the tank (Suleiman & Reza, 2019). The float position determines the fuel altitude and sends information to the fuel quantity display panel. Despite its advances, ATG is not widely used due to its high cost. (Nassar & Al-Hajri, 2013; Ojugo, Ugboh, et al., 2013).
3. **Float-Wire guided, inductively coupled systems** – the wire is fixed at both the top and bottom of the tank and is used as a guide for the float. The float contains an inductively coupled transducer where the wire is energized. During a short period, the primary coupling is interrupted and the secondary induction coupling from the transducer to the driver on the wire is achieved. It measures via conductors wires, which produces a grey-coded word. It is one of the cheaper level measurement systems available and is still commonly used (Braddock & Chambers, 2011). The material build-up hinders free movement of the float. Thus, cannot be used in dirty applications. In clean applications, the float mechanism can jam. Components of float-operated wire-guide wears off easily due to continuous movement of attached drive on the liquid surface. Thus, level of reliability is poor; This, in turn impacts on its accuracy and yield high maintenance demands the fuel storage (Chang & Lin, 2006; Charan et al., 2020).
4. **Servo-operated float** uses the movement of the fluid (i.e. fluid displacement) in the tank to continuously measure. They move to continuously measures the liquid in a tank by driving the float through the open space in the tank until it contacts with the liquid surface level. As the level changes, the system seeks to balance the float and measures its level (Gorawski et al., 2015; Ibrahim & Syed, 2018; P. Joshi et al., 2020; Zawislak et al., 2022).
5. **Radar Gauge** originally developed for use on crude oil carriers because there was a requirement to be able to measure the quantity of oil by non-invasive means. Radar tank gauging is currently one of the most popular level measurement methods used in fuel (gasoline) storage. This mode was originally used by crude oil carriers because there was a requirement to be able to measure the quantity of oil by non-invasive means. It uses a probe, known as waveguide located in a container delving below the liquid surface. The waveguide measures by transmitting a periodic pulse from below the surface, which is received in its attenuated form somewhere within the tank but not in contact with the liquid.
6. **Hydrostatic** is a continuous monitor that places 2-sensors within a known distance apart and measures the temperature at a point between them. It is popular since there is no moving parts inside the tank. Reasonably accurate level measurements can be obtained because the measurement is based on volume to provide a quantity in terms of mass. It also provides leak detection feat. However, its accuracy is highly dependent on a well-maintained and calibrated pressure sensor. Also, its accuracy decreases if measured material is stratified due to temperature or density. Therefore, the measurement of boiling materials and two-phase materials will be less accurate using HTG (Liptak, 1995).
7. **Ultrasonic** sensor is a non-contact mode that emit audio frequency waves between 20 kHz and 200 kHz, which are reflected from the liquid surface and detected by the transmitting transducer Ultrasonic level sensors detect changes in the speed of sound. Its speed changes

due to factors such as temperature and pressure. This is corrected via careful planning and design of the sound to ensure optimal response. Additionally, to maximize measurement accuracy, the relative tank should be free of unnecessary supports and scales as these act as obstructions to the ultrasonic signal and can lead to signal pick-up. Incorrect response signal (Yuan & Wu, 2021; Zardi & Alrajhi, 2023).

The study is motivated (Ojugo, Akazue, Ejeh, Odiakaose, et al., 2023; Ojugo, Eboka, et al., 2015a, 2015b) as thus:

1. **Ineffective measurement/monitor tools**: In Nigeria, fuel or petrol station does not have a monitoring system for fuel level storage in their tanks since most of them use dipping methods.
2. **Health Hazards**: Fuel is been measured manually by calling the employees to measure the level of petrol in a storage tank using a dipstick. When you open the gas cap, the gasoline evaporates into the air. This practice is dangerous for workers. If you are not protected, you will inhale the evaporated gasoline, and the gasoline on the level will come into direct contact with your skin. Inhaling vaporized gasoline in the air can be harmful to humans and can cause toxicity for people who constantly inhale vaporized gasoline.
3. **Fraud**: Fraudulent operators can skim from the tank and add water to mask the difference. A station manager might sell gas off the books and then either dilute the remaining inventory or change the settings on his console to make up the difference (Ojugo and Ekurume, 2021a, 2021b; Ojugo & Otakore, 2020).

Study proposes an IoT-based fuel storage tank gauge and monitors are the best way to monitor petrol levels as it does not require opening the tank cover and reaching in to make measurements that evaporate the petrol when the weather is hot, besides the petrol can be exposed to rainwater during rainy days.

2. MATERIALS AND METHODS

2.1. The Proposed IoT-Tank Gauge

The proposed system seeks to extend the work of Jaiharish et al, (2019) via an IoT-based fuel storage tank gauge and monitor. The monitoring system provides real-time measurements of fuel levels and temperatures and pressure within underground storage tanks captured by ultrasonic sensors and humidity sensor BME280 (K. W. Brown & Armstrong, 2023; W. Brown & Armstrong, 2015). The system will alert the user when fuel is low or high temperatures exceeding 35℃ as in figure 2. This IoT technology helps gas station operators remotely monitor the fuel in storage tanks. They can save time, and energy and reduce the health risks of performing manual dipping. Also, gas station operators can save monitoring maintenance costs as this is cheaper compared to ATG as in figure 3 (Alakbarov & Hashimov, 2018; Datta et al., 2021; C. Joshi et al., 2021; Ojugo & Yoro, 2020b; Pradeepa & Parveen, 2020). Its many benefits includes (Ojugo & Eboka, 2021):

1. **Interconnectivity** in IoT seeks to have all devices approximate interconnected with the worldwide records and conversation infrastructure.
2. **Things-related services** helps an IoT to effectively handle persistent-issue and fault-tolerance concerns even as system operates efficiently under constraints of factors, which include privacy safety and semantic consistency between physical matters and their related virtual things. To provide factor-associated services inside its constraints of factors, both tech inside and the data must be exchanged.
3. **Heterogeneity** ensures such IoT gadgets are based on extraordinary hardware and cross-cutting platform/network so they can interact effectively with other devices or system provider.

4. **Dynamic change in improved accuracy measurement:** A device state constantly changes (e.g. sleep, (dis)connect, speed, active, location, etc). These changes can result in faults. Number of devices can change flexibly. Thus, the system must be robust and adaptable so as learn these changes as well as measure accurately the products within the tank.
5. **Enormous scale:** The number of devices to be managed and communicated with will be an order of magnitude larger than the gadgets connected to the present-day Internet. Even more important may be the control of the information generated and its interpretation for software purposes. This relates to the semantics of data, as well as efficient data handling.
6. **Safety:** As benefits are gained from the IoT, safety must not be forgotten. As both the creators and recipients of the IoT, protection should be paramount inside the design. This consists of the safety of our records and the protection of our physical well-being. Securing endpoints, networks, and the data moving across all of it means creating a security model that will scale.
7. **Connectivity** permits community access and compatibility. Accessibility is getting into a community; And, compatibility seek to provide users with the unusual potentials of proposed system to consume and produce data.

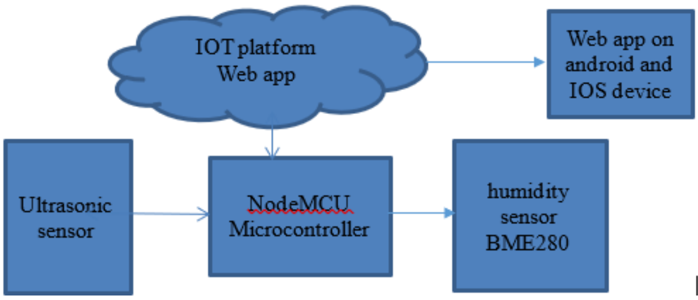

Figure 2. Block diagram of the proposed system

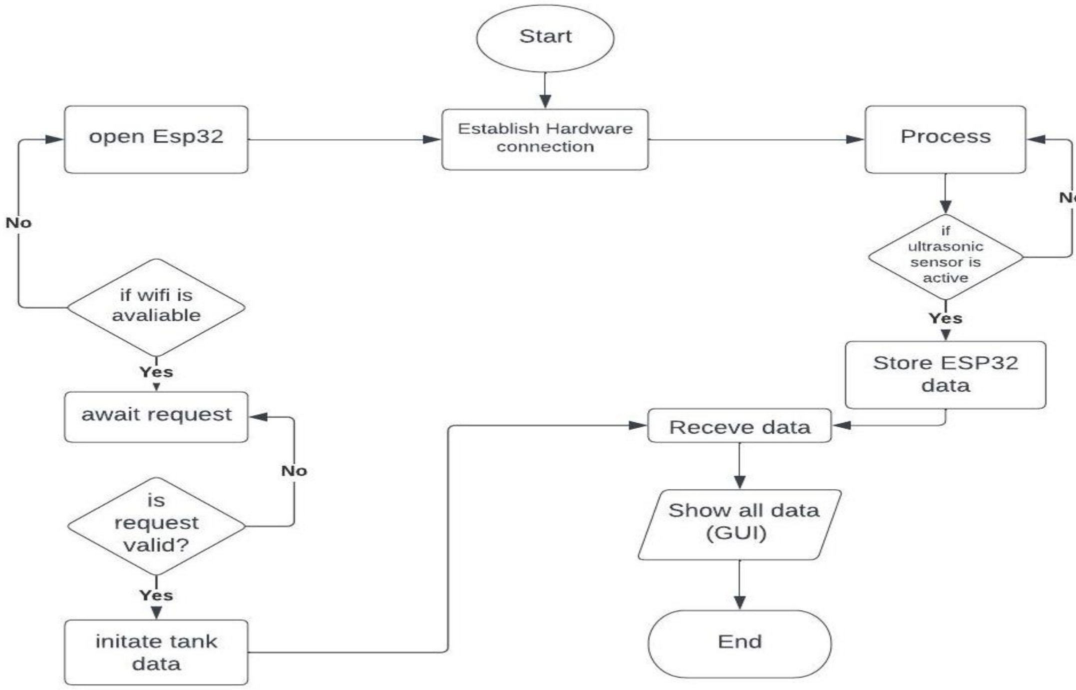

Figure 3. System flowchart of the proposed system

2.2. Technical Experimental Procedure

It involves both hardware and software parts (Chevalier et al., 2003; Ojugo, Aghware, et al., 2015; Ojugo & Eboka, 2014; Ojugo & Otakore, 2018a; Okobah & Ojugo, 2018; Tarafdar & Zhang, 2005):

1. **Input Design** acquires data via ultrasonic sensor, ESP32-microcontroller and other sensors. It then lets the user input via the web app interface to set threshold feats or parameters via the following:

- ✓ **Ultrasonic Sensor** as primary input device, measures the depth of the fuel and provides real-time data on fuel level.
- ✓ **ESP32** microcontroller is responsible for interfacing with ultrasonic sensor and processing acquired data.
- ✓ **BME280** measures temperature and pressures of the tank as supplementary data.
- ✓ **Web App** interfaces with users to collect input parameters or set thresholds via the web app interface.

2. **Output Design** provide meaningful data to the users via the web app (Ojugo, Yoro, et al., 2013; Ojugo & Yoro, 2020a, 2020c). Its output is as follows:

- ✓ **Fuel Level Display**: The web app displays the real-time fuel level in the storage tank, indicating how full or empty it is. This is derived from the data received from the ultrasonic sensor. It renders: (a) real-time updates of fuel level as it changes to reflect the recent measurements from the ultrasonic sensor, and (b) visual display graphically and numerically displays the fuel level, depending on the design preferences and requirements.
- ✓ **Volume:** system computes fuel based on the depth measurements obtained from the sensor that measures the tank dimensions used.
- ✓ **Alerts and Notifications:** If the fuel level reaches critical levels or if any anomalies are detected, the system may generate alerts or notifications to inform users. To achieve notification, we set various feats: (a) threshold values for low fuel levels, this triggers an alerts if the threshold is exceeded, and (b) alert is delivered via the web app, email and SMS as channels.

3. **Algorithm** is crucial for converting all measurements from the sensor into useful data (i.e. fuel level and volume data). Its steps are as thus, with the listing 1 below :

- ✓ **Step-1: Data Acquisition** is measure of the raw distance as retrieved from the ultrasonic sensor(s).
- ✓ **Step-2: Calibration** accounts for any calibration requirements or sensor-specific adjustments to ensure accurate distance measurements.
- ✓ **Step-3: Fuel Level Conversion** – uses the known tank dimensions to convert the measured distance to the actual fuel level in the storage tank.
- ✓ **Step-4: Volume** is based on the fuel level and tank's geometry, the system computes using the appropriate form (i.e. cylindrical tank volume etc).
- ✓ **Step-5: Unit Conversion** converts the calculated volume into the desired units, such as litres or gallons.
- ✓ **Step-6: Output** provides volume and level information to the web app for display and further processing.

Algorithm 1: Listing of IoT-Tank Guage

```
INPUT: get tank_geometry (height, radius, length, width)
OUTPUT: display fuel_log, fuel_level, fuel_volume
START
Calibrate factors to adjust raw read_values (distance,
    fuel_level, fuel_volume, units)
For while: Do
get distance reading from ultrasonic sensor
distance == raw reading * calibration_factors
if (distance < 0 or distance > tank_height) then
  | continue loop
  | fuel_level = tank_height - distance
endif
if tank ← cylindrical then
  | volume = π * radius^2 * fuel_level else
elseif tank ← rectangular then
  | volume = lenght * width * fuel_level
endif
```

```
if unit ← gallons then
    display ← log fuel_level else
    display ← log fuel_volume
endif
```

2.3. Rationale for Proposed System

The system rationale and significance lies in its access control via the integration of advanced secured and user-friendly features – all of which improves user experiences and task efficiency with these feats (Allenotor et al., 2015; Allenotor & Ojugo, 2017; Ibor et al., 2023; Ojugo & Eboka, 2018):

1. **More data means better decisions** With added sensors, these devices can collect a large amount of data in many different areas. For example, in addition to the practical elements of being able to know when the fuel level is low to restock.
2. **Ability to track/monitor:** Tracking data for use greatly benefits a user. IoTs have the ability to capture current quantity of fuel. Knowing the state of your fuel will allow an operator know when to restock without having to consistently check it themselves (Aghware et al., 2023b).
3. **Lighten the workload with automation** Having a device doing most of the work for you means that you can save more time and cost. This greatly reduces human efforts. It also results in devices being created that need little to no human intervention, allowing them to operate entirely on their own.
4. **Better Life** Having your devices track and order things, turn light switches off for you, and help manage important tasks that you may not have the time to do yourself certainly takes away a lot of stress (Malasowe et al., 2023; Ojugo, Akazue, Ejeh, Ashioba, et al., 2023; Ojugo, Ejeh, et al., 2023; Yoro, Aghware, Akazue, et al., 2023; Yoro, Aghware, Malasowe, et al., 2023).

3. RESULT AND DISCUSSION

3.1. Result Findings and Discussion

Figure 4a shows the generated system test results from the Blynk platform. The Blynk software was used to test the metrics for the proposed system.

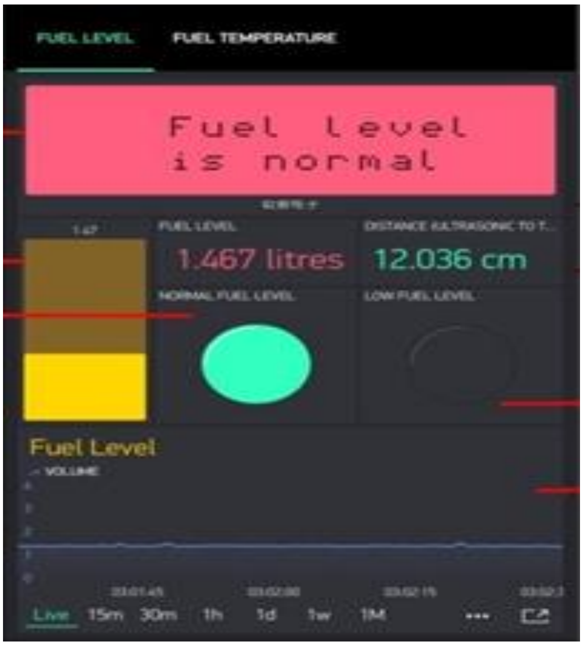

Figure 4. Test results from the Blynk software

In developing the IoT-fuel storage tank gauge and monitor system – several findings were made that shed light on various aspects of the system's functionality and performance. Firstly, it was found that the ultrasonic sensor provided accurate measurements of the fuel level in the storage tank (Ojugo, Allenotor, et al., 2015; Ojugo & Eboka, 2019; Yoro & Ojugo, 2019). By comparing these with the actual values, the system demonstrated a high level of accuracy and precision in determining the fuel level. This finding instils confidence in the reliability of system's core functionality (Ojugo & Yoro, 2020b).

System observed that real-time updates were consistently responsive as the system efficiently captured and reflected changes in the fuel level, providing users with up-to-date information through the web app interface. This ensured that users could monitor the fuel level in real-time and take timely actions as needed (Brown and Armstrong, 2019).

The threshold alerts implemented in the system were found to be effective. When the fuel level reached critical levels or anomalies were detected, the system promptly triggered alerts. This feature prevents fuel shortages or overflows, enhancing the overall safety and management of storage tanks (Cerf, 2020; Charan et al., 2020; Manickam et al., 2022; Ojugo, Abere, et al., 2013; Ojugo, Yoro, et al., 2013).

The interface of the web app was found to be intuitive and user-friendly. Users could easily navigate the interface and access the required information without confusion. The clear presentation of fuel level and volume data facilitated a positive user experience, enabling efficient monitor and management of the fuel storage tanks (Ferrari et al., 2012; Hurt, 2019; Kakhi et al., 2022).

With system integration, the components worked seamlessly together, ensuring compatibility and smooth operation. The microcontroller effectively communicated with the ultrasonic sensor and transmitted the data to the web app and database. This integration created a robust and cohesive system that functioned as intended(Sreejith et al., 2019a).

Overall, findings highlight the successful development of the " IOT-Based fuel storage tank gauge and Monitoring System " system. The system demonstrated accurate fuel level measurements, real-time updates, effective threshold alerts, a user-friendly interface, and seamless integration. These findings validate the system's capabilities in providing reliable and efficient fuel monitoring and management, making it a valuable tool for various industries and applications (Sreejith et al., 2019b).

4. CONCLUSION

The virtual key card access system has demonstrated a practical, cost-effective and cheap solution for managing access to areas within a facility. We have successfully also integrated IoTs, virtual key card access, web-access control, solenoid lock integration, and ESP32-controller to create a comprehensive access control system. Its many benefits over traditional key includes better security, user data privacy, system efficiency, and user convenience. The system also provides real-time monitor and control capabilities that will allow administrators to track and manage access to the facility remotely. And in turn, enhancing system's security and efficiency.

Conflict of Interest

The authors declare that there is no conflict of interest.

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