AUTOMATED SYSTEM FOR MONITORING FUELING OPERATIONS ON TELECOMMUNICATION TOWER SITES

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Abstract

Telecommunication tower companies with sites in isolated zones often use generator sets as their main source of energy. Fueling a generator is one of the crucial activities of such companies and there is a need for it to be carried out excellently. A lot of supervision is done on the volume of fuel purchased and filled into the generators in zones which are accessible. For isolated zones, the company relies on the data collected; volume of fuel added, volume of oil added, rate of consumption of generator etc.

Data collection has become an integral part of many growing industries. One may ask why this information needs to be collected and how it will be handled. In this work, we study the context of Telecommunication tower companies who use manual data collection strategy on fueling operations. These data when collected is kept till the end of the month when they are analyzed. On analysis, there seem to be a large volume of fuel which was never filled into a generator and this causes the company to incur financial loss. Real time notification on the fueling activities in these isolated zones is required. Site supervisors and engineers want to be informed about the true quantity of fuel each generator receives and at the time the fueling is done. Therefore, collection of sensitive information which drives the financial strength of a company should be done with a secured technology.

Thus, we present different methodologies used by researchers to solve this problem in industries. The first methodology uses Ultrasound sensor to collect information on the volume in the tank and notify a site engineer of fuel theft. The second methodology measures the flow of fuel between a fixed tank and the generator's tank using a flow sensor and displays on a panel. The third methodology designs a monitoring system to detect fuel theft in vehicles using flow sensor and GSM (Global System for Mobile communications) to notify owner using the SMS service. We also looked into a few IoT (Internet of Things) solutions developed to solve fuel theft and fraud in tower companies.

Finally, we have designed a methodology to solve the problem of theft and fraud in tower companies by monitoring fueling operations; this can be summarized as follows: **Data Collection** (using digital form, ultrasonic and flow sensors), **Data Storage and Processing** (using distant server and expert system respectively) and **Data Visualisation** (web application to dispatch result). In this work, we also provide a notification system for the information collected on these tower sites. A prototype was designed with ultrasonic sensor, Arduino Uno, and Internet for communication network. We tested this prototype on a 10 l container using water to simulate fuel. We viewed simulations on fueling operations of different sites on the web app. In addition, we obtained a response time of averagely 1 minute for emails sent by the notification system. This automated system for fueling operations is used to replace the manual collection of information and report them to the tower authorities with stronger security.

Key words: fuel operation, fuel theft, fraud, data, generator set.

Declaration

I, the undersigned, hereby declare that the work contained in this essay is my original work, and that any work done by others or by myself previously has been acknowledged and referenced accordingly.

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French Version

Les pylônes de télécommunication dont les sites sont situés dans des zones isolées utilisent souvent des groupes électrogènes comme principale source d'énergie. L'alimentation en carburant est l'une des activités cruciales et elle doit être menée à bien. Les principes de supervision accordent plus d'attention au volume du caburant lors du remplissage des groupes électrogènes dans les sites accessibles. Pour les zones isolées, l'entreprise s'appuie sur les données collectées; volume du carburant ajouté, volume d'huile ajouté, taux de consommation du générateur, etc.

La collecte de données fait désormais partie intégrante de nombreuses industries en croissance. On pourrait donc se demander pourquoi cette information doit être collectée et comment elle sera traitée. Dans ce travail, nous procédons dans le contexte des entreprises possèdant des pylônes de télécommunication qui utilisent une stratégie de collecte des données manuelles sur les opérations de ravitaillement de leurs sites. Une fois collectées, ces données sont conservées jusqu'à la fin du mois où elles seront analysées. Selons les resultats des analyses, il semble qu'il y ait une quantité importante de carburant figurant dans les donnés mais qui n'a pas été consommée par les générateurs, ceci entraîne une perte financière pour l'entreprise. Une notification en temps réel des activités de ravitaillement dans ces zones isolées est donc requise. Les ingénieurs et les superviseurs des sites souhaiterons être informés de la quantité exacte de carburant que chaque générateur reçoit au moment du remplissage. La collecte des données qui impact financièrement l'entreprise devrait se faire avec une technologie plus sécurisée.

Toutefois, nous présentons différentes méthodologies utilisées par les chercheurs pour résoudre ces types de problèmes dans les industries. La première méthodologie utilise un capteur à ultrasons pour collecter les données du volume de carburant dans le réservoir et informer les ingénieurs d'éventuels vol de carburant. La seconde méthodologie mesure le débit du carburant entre un réservoir fixe et le réservoir du générateur à l'aide d'un capteur de débit et l'affiche sur un panneau de visualisation. La troisième méthodologie consiste à concevoir un système de surveillance permettant de détecter le vol de carburant dans les véhicules à l'aide d'un capteur de débit et du GSM (Global System for Mobile communications), afin d'avertir le propriétaire du véhicule par SMS. Nous avons également exploré quelques solutions IoT (Internet of Things) développées pour résoudre le problème de la fraude et du vol de carburant dans les entreprises possédant des tours de télécommunication.

Enfin, nous avons établi une méthodologie permettant de résoudre le problème de fraude et du vol de carburant en surveillant les opérations de ravitaillement dans les entreprises possédant des pylônes de télécommunication; résumée comme suit: **Collecte de données** (utilisant des capteurs à ultrasons, capteur de débit, formulaires numériques), **Stockage et traitement de données** (utilisant un serveur distant et un système expert respectivement) et **Visualisant les données** (application Web permettant d'afficher les résultats du traitement). Dans ce travail, nous fournissons également un système de notification des informations collectées dans les sites de pylônes. Un prototype a été conçu avec un capteur à ultrason, Arduino Uno et l'Internet pour le réseau de communication. Nous avons simulé ce prototype dans un réservoir de 10 litres utilisant de l'eau comme carburant. Nous avons visualisé les simulations des opérations de ravitaillement dans les différentes sites sur l'application Web. De plus, nous avons obtenu un temps de réponse d'environ 1 minute pour les courriers électroniques envoyés par le système de notification. Ce système automatique d'achat et de ravitaillement en carburant permettra de remplacer la procédure de collecte manuelle et la transmission d'informations aux autorités concernées avec plus de sécurité.

Mots clés: exploitation de carburant, vol de carburant, fraude, données, groupe électrogène.

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1. Introduction

Telecommunication Towers sites carry antenna, transmitters and receivers (Base Transmitter Station (BTS)) for mobile communications. With an increase in mobile communication in Africa [35], mobile service providers such as MTN, Orange and Airtel need to improve their telecommunication coverage by proper maintenance of towers. In Africa, most mobile service providers share a common tower, therefore towers are owned by Tower companies such as IHS, Towerco and Helios. These tower companies carry out maintenance and fueling operations in their respective sites with the help of field agents.

Fueling operations on telecommunication tower sites by field agents have encountered problems with loss of volumes of fuel and inconsistency with figures [7, 22]. Tracking consumption and being informed of fueling in real time has become a necessity for sites with serious losses. As the field agents record information on consumption and fueling manually, this process is becoming less trustworthy. For predictive analysis to be carried out on these sites, true data is to be collected and saved [5]. An administrator working at a distance of 60 km or more from the tower wants to be notified each time fueling is carried out. He/she wants to have a constant view of the different fueling operations carried out in a month without going to the sites to supervise. Most especially, to receive notification of theft or fraud at real time.

In this work, we will elaborate on the different methods by which researchers have approached analogous or similar problems and explain the method chosen for collection of data and the device required for this process. We will discuss the various security measures to ensure the data transfer is authentic, integral and not intercepted by an eavesdropper (unauthorized person), then describe the process of real time notification.

1.1 Brief Description of Fueling Operations in a Telecommunication Tower Sites

Telecommunication tower sites are classified into 2 types; **sites in accessible zones** and **sites in isolated zones** [37]. Sites in accessible zones are usually powered by national grid and use either diesel generator sets or solar panels or batteries as secondary source. Whereas sites in isolated zones depend on diesel generator as primary source and solar panels or batteries as secondary source. A study by Intelligent Energy in India, showed the irregular provision of electricity from the national grid to telecommunication tower sites in accessible zones in India which is a similar situation in Cameroon and most African countries [18]. This gives rise to the need for diesel fuel to power the sites as standby source.

1.1.1 Classical Telecommunication Tower Site Power Supply. Telecommunication tower sites are made up of antenna which belong to different mobile service providers and their control units. Equipment such as computers, UPS (Uninterrupted Power Supply) and air conditioners found in these control units contribute to the power consumption. Power supply can be provided by national grid, solar PV, diesel generator set and battery. The zone where the tower is found and the power demanded by the equipment on that site determines the power supply on that tower.

Tower sites in accessible zones can also be used as backbone sites (a site which has the capability to substitute for other sites during shortage of electricity in the latter). These sites are more sophisticated, carry many antenna, control units and auxiliary units. Therefore, they need constant control and monitoring. Figure 1.1 shows the power supply connection for most sites in accessible zones. Diesel generator sets are mainly used to top up the power needed by the equipment or during power interruptions of national grid when they become the main source. Fueling operations may not take place very often but when this process occurs; it consumes large volumes of fuel.

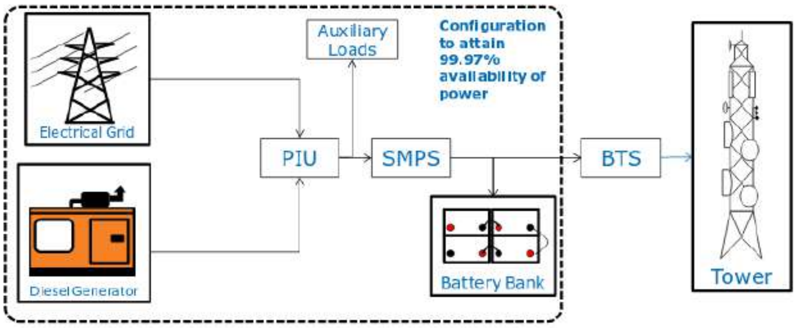


Figure 1.1: Power supply for a tower in accessible zone. [18]

During insufficient supply or interruption of national grid, PIU (Power Input Unit) sends signal to start the generator set. The battery bank is used to keep loads connected during the transfer of supply from national grid to generator set.

Telecommunication tower sites in isolated zones are powered as shown below.

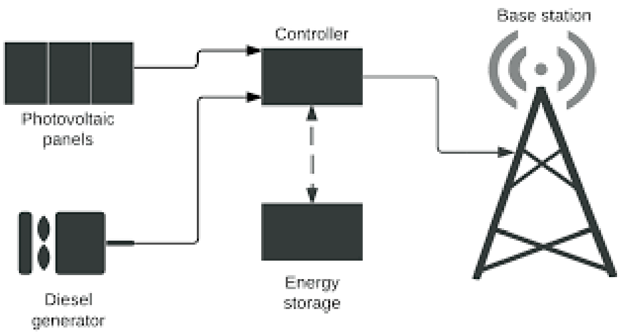


Figure 1.2: Power supply for a tower in isolated zone [6].

Tower sites could be powered by both as well as just one of the power supply in figure 1.2. Due to inconsistency in solar radiation as a result of climate change in some regions, diesel generators serve as the main power supply.

1.1.2 Fueling Operations. Fueling operation consist of purchase of fuel and provisioning into generator sets as well as maintenance of generators in order to limit excessive consumption of fuel due to generator failure. The presence of diesel generator sets in these sites make fueling operation a key activity in these sites; especially sites in isolated zones. A report from A.T. Kearney, demonstrated the influence of poor fueling operations on the tower business [7]. A glance at the world prices for fuel, shows a gradual increase in price in 2017 compared to the last 2 years as shown in figure 1.3. Therefore, poor management of fuel resource in telecommunication tower may lead to business failure.

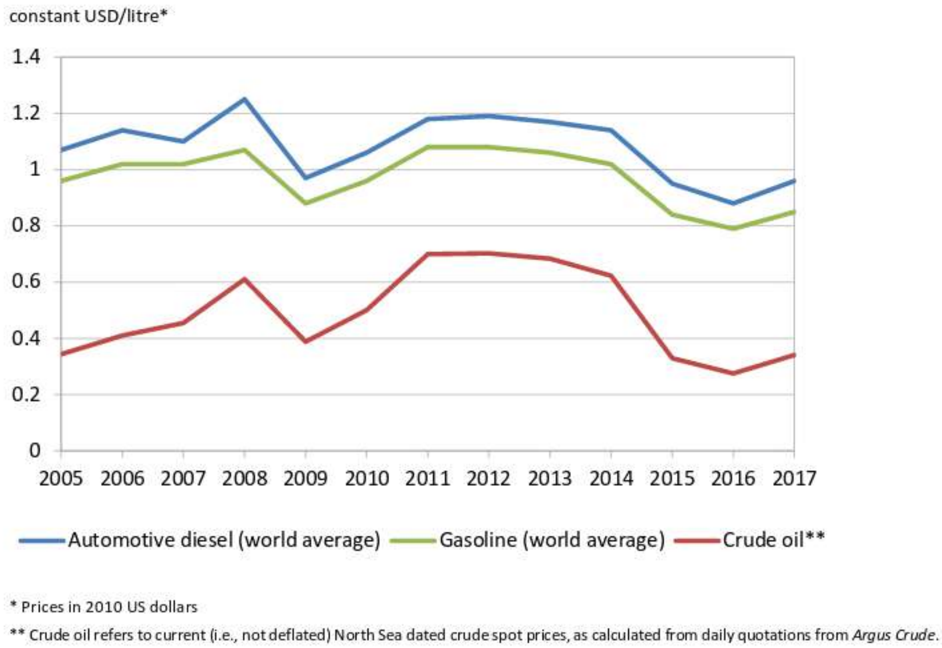


Figure 1.3: Global fuel price changes from 2005 to 2017. [3]

1.2 Problem Statement

Telecommunication tower companies invest huge capital on fuel since they want each site to have enough to power cells without interruption. A report submitted on a roundtable at TowerXchange, explained pertinent problems faced by Telecommunication Towers during fuel operations [31]. Two of these major problems are;

- **Theft**: This may occur during purchase of fuel at the station or during transportation to site or during provisioning of the generator on site. Most tower companies purchase fuel from stations a considerable distance from their sites, without supervision of the fuel truck, field agent may do as he/she wishes. On site, field agent can fill in whatever quantity to the tank since the tank is not being monitored. Other ways of theft include removal of volume of fuel by external members or field agent after fueling.
- **Fraud**: Replacing fuel with another liquid which in the long run destroys the generator. Modifying data collected on site in order to conceal theft. Some field agents partner with fuel station agents to falsify the quantity of fuel bought on the receipts. On the fueling report spreadsheet, they fill in a volume which may not correspond to the volume of fuel bought.

A study on 500 sites in Pakistan revealed up to 25 % of fuel stolen [29], a similar study was carried out in Cameroon on about 150 sites owned by IHS which approached the same value [32]. Telecommunication tower companies being willing to end such problems give rise to the main question of this study:

How can we monitor fueling operation and report in real time?

1.3 Contributions

We propose an automated system to monitor fueling operations in telecommunication tower sites. These are a few contributions we bring to the scientific community with interest in improving monitoring on fueling activities.

- We use two kinds of sensors (volumetric and flow) to design two electronic devices used for collecting information unlike other studies which used one. A simulation of each electronic device on a virtual platform is detailed out in this work.
- During Transmission, we encrypt the data collected and decrypt this coded information in the server. In addition, we propose security protocols such as *Datagram Transfer Layer Security Protocol (DTLS)* and *SSID (Service Set Identifiers) Hiding* to limit unauthorized people connecting to the wireless access point of both the electronic devices and server (in the case of physical server).
- We designed an Expert system for processing collected information using expert knowledge acquired during field work.
- We embed into this system a notification system which sends emails and SMS to alert tower authorities within 1 minute after purchase is done and 1 minute after the tank has been fueled.

1.4 Structure of study

The context of this study can be described as solving the problem of fuel theft and fraud in telecommunication towers in Africa, with more emphasis laid on the towers in isolated sites or towers with large consumption of diesel fuel. These tower sites require real time notification to improve supervision and control on these sites. This system was designed during a research internship for a company which wants to commercialize this solution to such problems in tower companies, we proceeded as follows;

- Field work: This was a period of collecting information on the problem faced by telecommunication tower companies, analyze them and research on existing solutions. We had access to IHS tower informations from one of their subcontracted company.
- Design Work: Proposing and modelling a new solution to these problems which suits the context of our study.

To answer the question in section 1.2, we partition the essay into three major parts:

1. Explain the methodology used by previous researchers and engineers. Mathematical model of the components involve in the fuel operation and explanation of key sciences involved in our chosen methodology.
2. Define the methodology suitable for the context of this study. Detail explanation of scientific simulations used in this study.
3. Demonstrate effectiveness of methodology by modelling a prototype.

2. Literature Review

2.1 Previous Study and Results

In the following we describe some methods researchers and engineers have used to solve the problems raised in chapter 1. A description of each method is given alongside its limitations in our context of study.

2.1.1 Context Aware Fuel Monitoring System for Cellular Sites. This study was carried out in Pakistan by Mohammad et al. [29].

a. **Context:** For almost fifteen years, Pakistan has faced energy supply shortages. This is the major reason why cellular network use diesel generator to power cellular sites. Due to the use of manual fueling and supervision of these sites, theft of fuel began to increase significantly to over 25 % of fuel purchased.

b. **Methodology:** The authors assumed fuel theft could be perpetrated by field agent or security guard or any individual who gains access to site. They tackled the major point of weakness of the manual system which created liberty for theft that is; after fueling, field agent could tap out the fuel and cover the theft by reporting a falsified generator runtime. The fuel detection procedure is summarized below using a flow diagram in figure 2.1 :

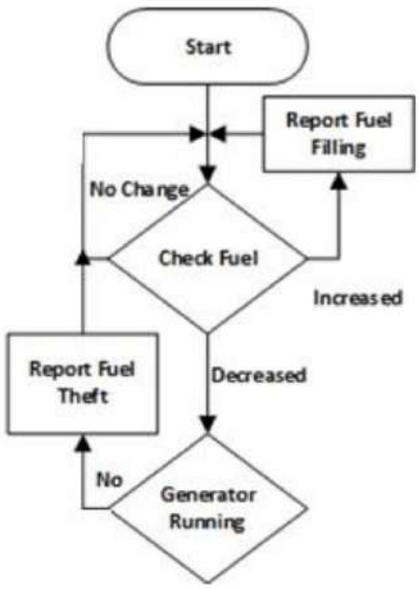


Figure 2.1: Flow diagram of fuel theft detection.[29]

During fueling a report on the fuel quantity is generated. When the generator is off, the system continues to check the fuel volume:

- If the value increases, then a fueling report is generated.
- If the value decreases, the system checks if the generator is on or off by checking for a valid runtime value. In the absent of a runtime value, a fuel theft report is generated.

c. **Result:** The proposed system is based on a microcontroller such that the site engineer can check the status of the fuel in the tank as well as control the generator runtime remotely.

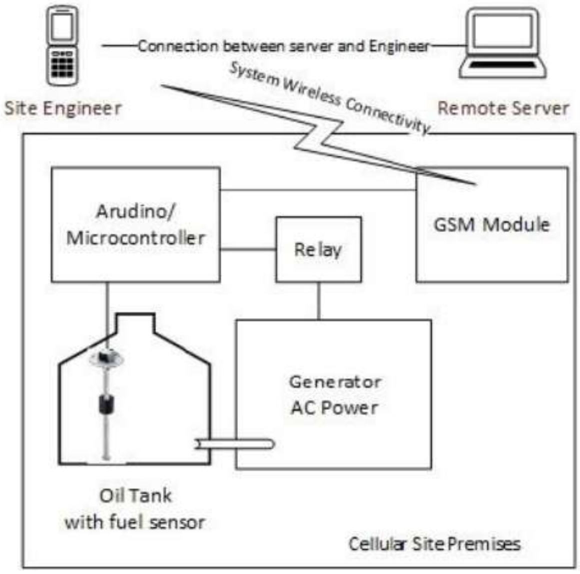


Figure 2.2: Diagrammatic view of the connectivity of the system. [29]

The prototype of this system was built using Arduino Mega 2560 (microcontroller), Ultrasonic sensor (volumetric sensor), Relays (start and stop generator remotely) and GSM SIM900 module (used to communicate with site engineer). This prototype was tested on a 12 KVA generator set for period of 5 days and the following result was obtained during one day's monitoring.

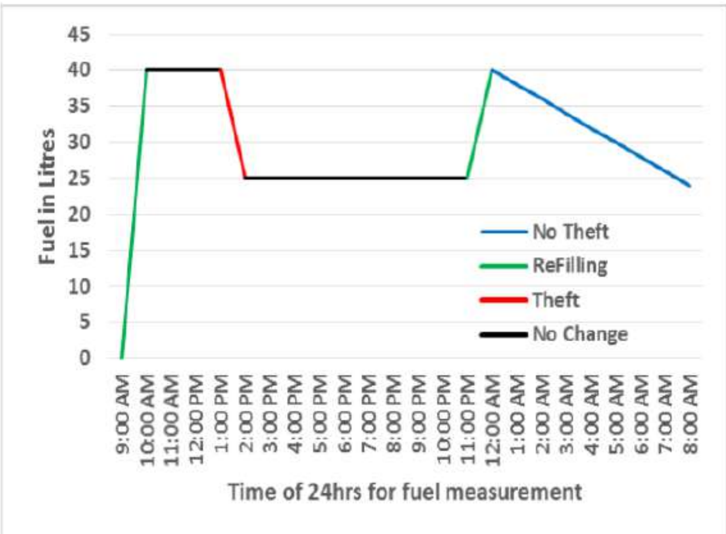


Figure 2.3: Statistics on fueling and theft for a day by the prototype.[29]

This graph maps out the period of the day when theft of fuel was perpetuated. This result helps the field engineer to question the field agent on the site with such a report.

d. **Limitations:** Though this system adds value such as the prevention of malfunctioning of the generator because of the ability to control remotely, there are still some drawbacks if used in our context of study.

- Theft detection can only take place if the fuel was previously introduced into the tank. System does not detect theft of fuel during fuel purchase or transportation to tower site.
- Volume of fuel can be falsified (example a mixture of fuel with another liquid) since the system relies on a volumetric sensor.

2.1.2 Monitoring Diesel Engine Fuel Consumption. This study was carried out by a product company called FLOWMETER [21]. It introduces another methodology adopted by several engineers due to its ease on adapting to tanks in industries.

a. **Context:** Diesel engines are used in most vehicles and generator sets. Monitoring the consumption of fuel is required due to excessive theft and fraud on the quality of diesel used. This study was carried out to benefit every machine using diesel engine especially those which are mobile. Another concern was preventing the use of different liquids other than diesel in the engine.

b. **Methodology:** Flow measurement is used to identify quantity of fuel consumed and ensure this fuel is diesel. The volume of fuel from the tank to the generator is measured and displayed. They compared the value of the runtime to how much has flown through the flow meter to detect if there have been theft or not. The device for monitoring ensures that another substance apart from diesel cannot be used in this engine.

c. **Result:** The authors proposed two systems with the use of flow sensors. One system uses only one flow sensor at the entrance of the generator tank while the other system uses two sensors; one at the entrance and the other at the outlet of the generator tank. The latter system exhibits a higher efficiency so has been adopted by many industries. It consist of two flow sensors as mentioned and a display screen. One sensor placed at the inlet to the engine, in order to measure the flow into the generator tank. When the generator is not running the same amount of fuel is expected to return through the other sensor back to the tank. Figure 2.4 below is the setup of this solution.

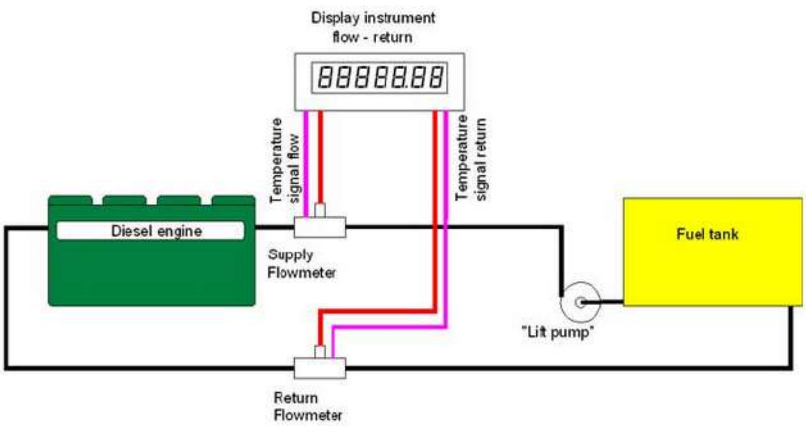


Figure 2.4: A setup of the solution to fuel theft using two flow sensors. [21]

To check the quantity of fuel in the tank, we look at the values displayed by the Liquid crystal (LCD). Therefore, monitoring is done where the system is installed and no values exported or saved.

d. **Limitations**

- This system does not take into consideration that the information can be stored for future use. Also the values displayed can only be reported to an administrator at a distance by the field agent (no real time reporting done).
- This system can detect theft which occurs after the fuel has been placed into the tank but does not detect theft during fuel purchase or during transportation to site.

2.1.3 Smart Fuel Theft Detection using Microcontroller ARM7. This is a study carried out on fuel theft in generator set due to global rise in fuel prices [24]. It uses GSM which is a technology for data transfer in areas where Internet is not available.

a. **Context:** A global increase in fuel prices in 2015 brought about a rampant pilferage of fuel in vehicle tanks. This study also sought to resolve problem of stolen vehicles alongside fuel pilferage.

b. **Methodology:** Flow sensor was used to collect information on the quantity of fuel used in the engine, GSM to report theft and GPS (Global Positioning System) to track the location of the vehicle. Figure 2.5 shows the flow diagram used in programing this system. At the start of this algorithm, the owner of the vehicle unlocks the device using a password during the installation of the device. The system checks the fuel in the tank:

- If above predefine level, then the system continues to monitor fuel.
- If less than predefine level, then the system sends information to the owner of the vehicle by GSM, with location information of the vehicle if the buzzer does not go off after 2 mins.

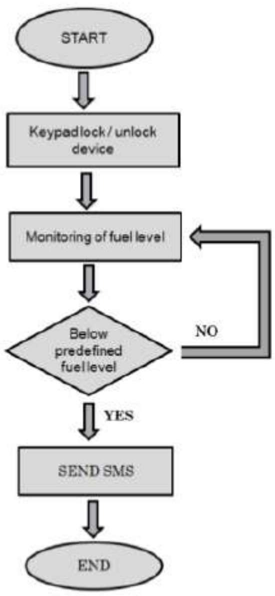


Figure 2.5: Flow diagram of smart fuel theft detection [24].

c. **Result:** Using the GSM and GPS technology, the user can monitor fuel level, receive notification for fuel and vehicle theft. A prototype was designed using SIM900A (GSM module), microcontroller ARM7, GPS module, LCD for display and keypad to enter password of the device. Figure 2.6 gives a view of these components.

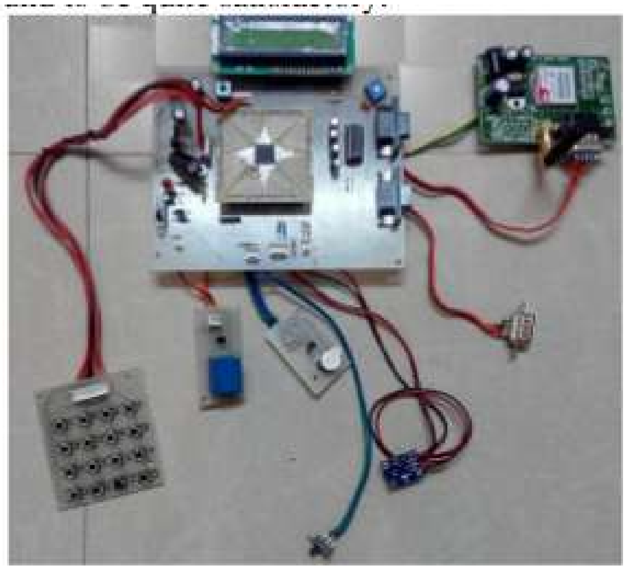


Figure 2.6: Components used to assemble prototype device [24].

d. **Limitation:** This system does collect information on the fuel level but this data is not stored for future use. It considers fuel pilferage only when the fuel has been provisioned into the tank and an attempt to remove fuel without the owner's permission (does not consider theft before or during fueling of the tank).

2.1.4 Fuel monitoring and management using IoT sensors. IoT (Internet of Things) is a network of devices such as sensors, actuators, computers, software in order for them to interact with each other. Ahmed et al. developed a Fuel Management System using IoT sensor [4]. They designed their IoT sensor using ultrasonic sensor, Rasberry-Pi as CPU (Central Processing Unit), Google Cloud as Database and a web application to visualize data collected. Edem et al. developed a system to monitor generator fuel and battery in Base Station Cell sites with SMS alert [17]. They designed the IoT monitoring system using an ultrasonic sensor, battery level sensor, ATmega328 as CPU, GSM module to interact with the other devices using telecommunication network and a display module.

Companies are using IoT technology to create systems for fuel management. LoRaWAN IoT sensors used by IOT Factory to measure fuel in the tank. This data network provides low rate data transmission on large scale distance of up to 15 km with low power consumption (*Source: iotfactory.eu*). Fuelics ltd owns an IoT Fuel Management Platform, with fuel sensor designed to collect data from stationary or mobile tanks and relay them to cloud (*Source: fuelics.com*).

2.2 Mathematical modelling of Fuel Volume Measurement device

Volume of fuel can only be known if a device is used to measure such information. The best method for measurement is using sensors [19]. When designing such device, there are five main steps to consider.

Figure 2.7: Structure of an instrument for measurement [19].

To measure the volume of a liquid in the tank, there are two key physical quantities; the height (level) and the velocity at which the liquid flows. These physical quantities determine the type of sensor to be used in the measuring device.

2.2.1 Sensors. They are used to detect changes in the physical quantity and respond to such stimulus [1]. There are many types of sensors but for this study, we give details of just two types; Ultrasonic sensor and flow sensor.

a. **Ultrasonic Sensor:** This sensor is most used in distant measurement [14, 28]. It uses time traveled by ultrasound waves to an object and back to calculate the distant between the sensor and object (called Time to fly or Time of Flight). Objects such as metals, glass and plastics deflect this wave 100 %, while liquid can deflect up to 80 %. Objects such as cotton and wool absorb these waves [30]. Figure 2.8 is a diagram to illustrate working principle:

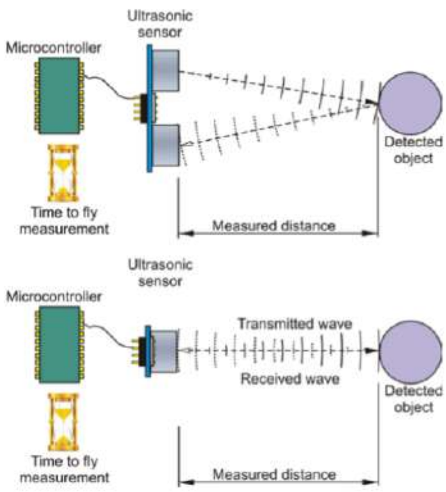


Figure 2.8: Working principle of an Ultrasonic sensor [28].

Shrivastava et al. demonstrated that using the ultrasonic sensor for measuring distance, as the distance increases the error of measurement reduces provided it is less than the maximum distance [2, 25].

Using the sensor to calculate the volume of fuel in a rectangular tank with height H_{max}, length L and width W. The sensor is connected to a timer which measures the time of flight $(\triangle T)$.

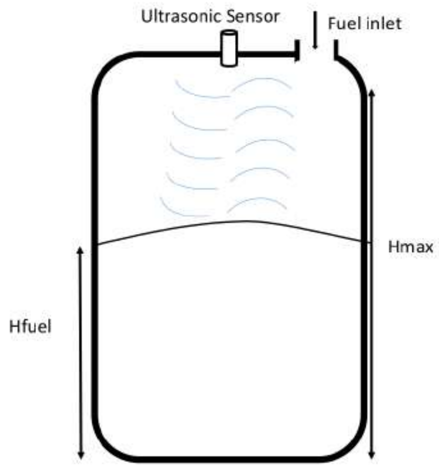


Figure 2.9: Representation of fuel tank with ultrasonic sensor for volume measurement.

To calculate the range R (distant between sensor and liquid surface);

$$R = \frac{v \triangle T}{2}, \tag{2.2.1}$$

where v is wave propagation velocity.

The level of water H_{fuel} is calculated; $H_{fuel} = H_{max} - R$. Finally, the volume of the fuel in the tank is given below;

$$V_{fuel} = H_{fuel} \times L \times W. \tag{2.2.2}$$

b. **Flow sensor:** It measures the amount of substance that flows at a specific time. There exists two major types; volume flow sensor and mass flow sensor [34, 40]. Ria et al. showed the importance of flow meter in fluid measurement in the case of irrigation of fields [38]. Sai et al. demonstrated that an accurate flow measurement using flow sensor is an important step for both qualitative and economical outcome [36].

A microprocessor is connected to the flow sensor and its timer used to get the interval between start and stop of fueling ($\triangle T$) in seconds. To calculate the volume of fuel passing through the flow meter;

$$V_{fuel} = A \times v \times \triangle T, \tag{2.2.3}$$

where A is the cross sectional area of the pipe, and v is the velocity of the fluid.

Since the fuel has a fixed density at constant temperature [13] and we assume a constant pressure change during flow in accordance to Bernoulli's equation;

$$P + \frac{1}{2}\rho V^2 + \rho g h = constant, \tag{2.2.4}$$

where P is pressure, ρ is density of the liquid, g is the gravitational acceleration, V is the velocity and h the height of the liquid in the tank.

2.2.2 Digital Signal Processing (DSP). DSP is a process to analyze signals and optimize performance. During measurement, the collected data will be affected by noise. Feher et al. analyzed the error during instrumentation and measurement in telecommunication and concluded that devices may record noise alongside values [20]. DSP is highly linear and ensures noise is easy to control. DSP programming is divided into three parts; *Assembly*, *compiler* and *application specific*. Microcontrollers are used in assembly (converting real values to binary digits) while compilation is done by microprocessors. Filtering signals is an important process in DSP. There are two kinds of filters; *Convolution-type* and *Fourier based* [10]. Equation 2.2.5 defines the FIR (Finite Impulse Response) filter.

$$y_i = \sum_j x_j f_{i-j}, \tag{2.2.5}$$

where y_i is the output, x_i is the input and f_{i-1} is the 'kernel' function.

The 'kernel' function is a low-pass filter (LPF) which reduces the noise, since the frequency of the noise is higher than that of the signal.

2.2.3 Digital Transmission. The digital signal which is the output of DSP needs to be sent from one computer to another. There are two kinds of transmission; *Parallel* and *Serial* [11]. In Parallel transmission, the sender sends all the bits at the same time while in Serial the sender sends a bit at a time.

Another name for transmission is digital communication. The normal-free error capacity of communication channel affected by addictive white Gaussian noise is calculated using Shannon's Principle [41];

$$\frac{C}{W} = \log_2\left(1 + \frac{P}{N_0 W}\right) = \log_2\left(1 + \frac{E_b}{N_0}\frac{R}{W}\right) \text{ bits}, \tag{2.2.6}$$

where,

- C is the channel capacity, bits/s
- W is the transmission band, hertz
- P signal power, watts
- N_0 Single-sided noise power spectral density, watts/hertz
- E_b is the energy per bit of the received signal, joules
- R data rate in bits.

Communication systems transmit information by means of coding techniques such as; *return-to-zero (RZ)*, *non-return-to-zero (NRZ)*, *Amplitude-Shift key (ASK)* and *4B/5B, 8B/10B* [9]. In RZ and NZ, signals alternate from positive voltage (+V) to negative voltage (-V). RZ assigns 1 to +V and 0 to -V while NRZ does the reverse. 4B/5B code translate 4 bits into 16 predetermined 5 bits while 8B/10B code translates 8 bits into 256 predetermined 10 bits. ASK assigns 1 to the maximum amplitude and 0 to the minimum or zero amplitude.

2.3 Encryption and Decryption of Information

Information transmitted over a long distance especially with an unsecure channel needs security measures. This is to ensure an eavesdropper does not have access to this information nor can illegitimately modify the message. Authenticated Encryption is an object security technique for channels used to turn information into secret code [39]. Its algorithm is used to secure information over several protocols. Encryption and decryption security strength lies in the secrecy of their keys and not their algorithms. Two kinds of keys exist; *secret key* and *public key*. Symmetric Encryption uses the same secret key for encryption and decryption while Asymmetric Encryption uses both keys (each person's public key is published and used for encryption, while the secret key is kept for decryption). Alice and Bob communication over a wireless channel can be described diagrammatically by figure 2.10.

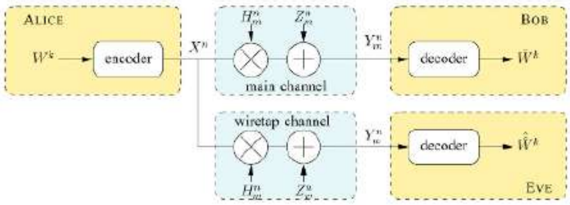


Figure 2.10: Wireless communication setup [12].

Alice sends a message, this message is encrypted to cyphertext and sent through the main channel. The secret key is communicated to Bob via the wiretap channel. Bloch et al. built an algorithm for secret key agreement protocol based on Multilevel codding and LDPC (low-density parity-check) codes [12]. In this study, the communication is Machine-to-Machine so the need for an automatic encryption style; symmetric encryption. A secret key is used to encrypt and decrypt the cyphertext to plaintext.

2.4 Complexity of an Algorithm

An algorithm is a procedure of computation which is carried out sequentially. Complexity of an algorithm is a measure of the amount of time and/or space required by an algorithm for an input of a given size n. It shows how fast the algorithm is and what amount of space it uses. This is denoted as *Big-O* which has as symbol $O(n)$ (where n is the size of the algorithm). Another notation is *theta* which has as symbol $\Theta(n)$ and is used throughout this study.

Definition: A function $f(x)$ is $O(g(x))$ if there are positive real constants c and x_0 such that $f(x) \leq cg(x)$ for all values of $x \geq x_0$.

In the next chapter, we describe the methodology suitable for the context of study. We propose a procedure to enhance fueling operation thereby reduces theft and fraud as well as improves supervision on site.

3. Design Methodology

In this chapter, we provide a methodology to reduce theft or fraud on these sites. This system collects information, process and displays it for both the field agents and the authorities in tower companies to access at anytime. It takes into consideration the limitations of the methodologies studied in chapter 2. The structure of fuel flow in this study is from a fixed tank (used for fuel storage) to the tank of the generator.

3.1 General Description

Our aim is to collect information on the volume of fuel in the tank and report real time on the fueling operations. This eliminates the field agent's opportunity to manipulate the numbers, in order to cover up theft. This system is designed on three important parts represented on figure 3.1;

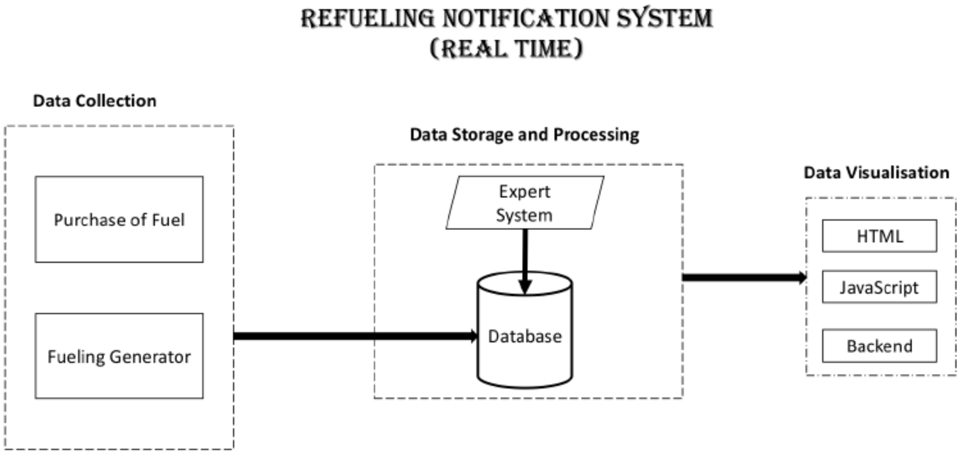


Figure 3.1: Overview of the chosen technology.

Data collection which is effectuated at the station and site, data storage and processing is done out of the site location and data visualization possible at all times.

3.1.1 Data Collection. This is the acquisition of useful information. There are two methods of collecting data:

- *Quantitative data collection*: Relies on random sampling and structured data collection instruments. Their results are easy to summarize, compare and generalize. An example of a domain where this method is used is clinical trials.
- *Qualitative data collection*: This is data collected to understand the process behind observed results. An example of a domain where this method is used is market survey.

In this study, we use the quantitative data collection approach. There are two major data collection points; during purchase and during fueling of a generator via a fixed tank.

a. **Purchase of Fuel**: It is important to know the quantity of fuel bought by the field agent. This is the starting point of fueling activity and fraud on the quantity of fuel bought and amount paid could occur [16]. Bates et al. invented a system that ensures only the vehicle meant for buying fuel can be connected to the tank [8]. It is our desire to ensure the field agent buys the right amount without the use of a sophisticated technology like that of Bates but with a simple digital form. This form is designed to create an alert to an authority in the tower company to verify the quantity of fuel. We use web-based form for zones with Internet access and USSD (Unstructured Supplementary Service Data) for zones without. USSD uses $*$ to start operation and $\#$ to end, only numbers are used between these two. For example, $*155\#$ used to verify recharge balance in MTN SIM cards.

b. **Fueling Generator**: The quantity of fuel provisioned into tank is collected. We use two sensors to design two devices; *ultrasonic sensor* to collect the volume added to the tank (**volumetric electronic device**)and *flow sensor* to collect the volume of fuel going into the generator (**flow electronic device**). The instrument for measurement in each electronic device comprises of; a sensor, microprocessor and WiFi shield or GSM (to access Internet). GSM can as well be used in areas with no Internet access. These devices are used per tank and generator with a code assigned to each to identify the tank or generator been monitored. Figure 3.2 describes the methodology to collect information from the tank using the volumetric electronic device.

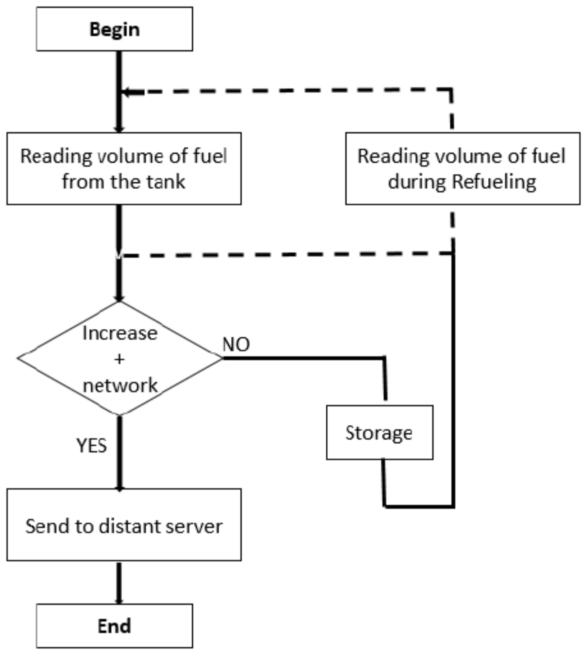


Figure 3.2: Collection of information on volume of fuel in tank using the volumetric electronic device.

When the volumetric electronic device is installed at the top section of the tank, it collects information on the volume of fuel in the tank every 5 minutes (in a day it collects 288 values of which there could be some values repeated in case the generator is shut down). During an increase in the level of fuel in the tank;

- The device searches if there is network available to send the information to a server.
- If network not available, the device stores the information and continues monitoring fuel level.

The storage in this device is a Buffer. A Buffer is a temporal storage area, usually in RAM. It uses FIFO (First In, First Out), therefore the data stored will still keep the order of arrival.

To collect the volume entering into the generator, we use this flow diagram;

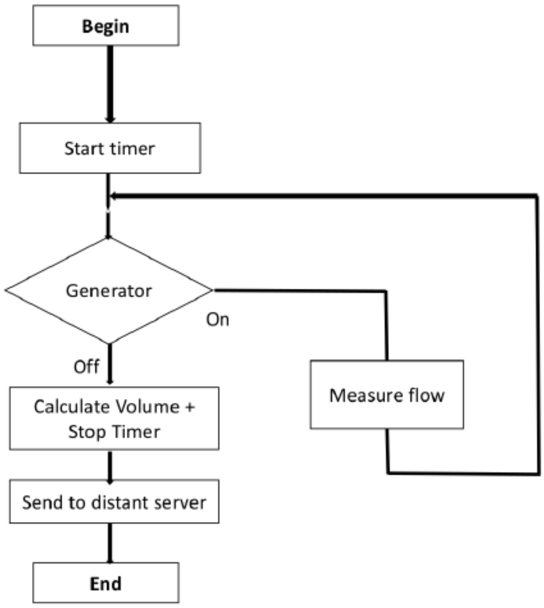


Figure 3.3: Collection of information on volume of fuel entering into the generator using the flow electronic device.

A timer is activated when the flow electronic device is installed on the pipe between the fixed tank and the generator tank. The device verifies the state of the generator set;

- If on, the device continues to measure the flow of the fuel into the generator tank.
- Else, the device calculates the volume of fuel used during the time interval and restarts the timer. This value is sent to a server.

Errors may arise during data collection due to

- incorrect measurement taken due to faulty device and
- inaccurate recording of data in the digital form due to misinterpretation of terms.

3.1.2 Data Storage and Processing. Data storage is the process of archiving data in storage devices. The capacity of the storage device enhances this process. On the other hand, data processing is the collection and manipulation of data to produce meaningful information. The information collected using the method above is organized into tables in a MySQL Database. MySQL Database is an open source relational database management system. This system makes use of a centralized database (a database which is stored in one location). The choice of this location is determined by the tower company but it is advisable not to be hosted in any of the sites. Cloud storage could also be used in this system.

Data processing has two major roles in this system: sorting data and expert system. The process of sorting data does the following;

- Delete abnormal measured values (this is to ensure that if the electronic device fails to do so; there is another level to control noise) and prepare values for expert system.
- Matching purchase information to fueling information. This is a very critical activity since information arrival may not be orderly. For Example, Site A,B,C and D have fuel purchased in the order Site A,C,B and D but during fueling this order of information is received from Site B,D,A and C.
- Moving data from one storage point to another.

Expert system is an Artificial Intelligence (AI) technique or program which uses database of expert knowledge to analyze and make decision on a set of data. It uses reasoning mechanism to execute instructions. It consists of two component; *knowledge base* (acquiring knowledge from experts in the domain) and *inference engine* (consist of algorithms to manipulate the result) [26]. Some typical task for expert system; interpretation of data, diagnosis of malfunctions and prediction. These are the processes the expert system does in this system;

- Compare the volume of fuel purchased to that placed in the tank. Verify that the volume entering the generator matches that of provisioned into the tank during the same time interval.
- Cross-check the price of the volume of fuel provision to that bought.
- Prepare a clean dataset which could be used by data scientist or predictive models.

The expert system takes an object and classify into two classes as shown in the figure 3.4.

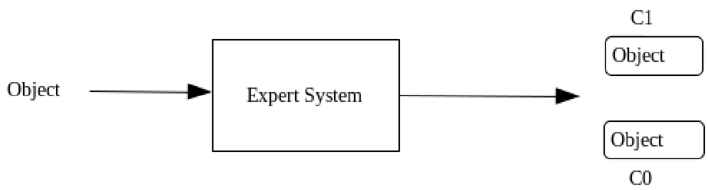


Figure 3.4: Expert System used to classify data collected.

$C0$ denotes the class zero; which is the class containing faulty fueling operation while $C1$ denotes class one; which contains fueling operation which were correctly executed.

Unlike other AI techniques, expert system is trained using knowledge acquired. Here below is a representation of the knowledge acquired during the field work;

Perfect	Acceptable	Faulty
$V_P = V_F$		$V_P < V_F, V_P > V_F$
$P_P = P_T$	$P_P < P_T$	$P_P > P_T$

Table 3.1: Knowledge Scheme used to train the Expert System.

Where, V_P is the volume of fuel purchased, V_F is the volume of fuel filled into the generator, P_P is the purchase price of the fuel, and P_T is the true price (actual price) of the fuel. This true price is based on the unit price of a fuel in the station the fuel is purchased.

The conditions in column 'Perfect' or 'Acceptable' being satisfied the Expert System will classify the data in $C1$. If any of the conditions in column 'Faulty' is found in the data; it classified to $C0$ by expert system.

3.1.3 Data visualisation. This is a visual communication of data using tables, graphs, charts and pictures. This process enhances understanding of fuel operation and decision making on fuel volume for each site. This module of the system entails presenting the information of the fueling operation to both the authorities and field agents. Placing the processed information at their disposal at anytime and anywhere. A web application is used in this system since local application (desktop app) may limit the visualization of these results in some workstations [27]. The structure of a web application can be summarized as;

- *Backend:* These are processes or functions running behind the scenes to produce a favorable outcome. Sourcing information from the database as well as navigation through web pages are some examples of such processes.
- *Frontend:* These are scripts used to project an appreciable design of the web page.
- *Database:* Used to store information collected from the web page, example login information.

3.2 Simulation of electronic device on virtual platform

Electronic devices are delicate components which get damage if wrongly powered [33]. It is of utmost necessity to model the device and test on a virtual platform before moving on to hardware assembling. In this study, we use Labcenter Electronics' PROTEUS 8 Design Suite as virtual platform since it contains both Schematic capture as well as PCB layout tools. ISIS which is the schematic capture tool of PROTEUS 8 is our main modeling tool.

3.2.1 Volumetric electronic device modelling and testing on ISIS. Our aim of this simulation is to demonstrate that the device can read the changes in volume of fuel in a tank. Unfortunately PROTEUS cannot model volume changes in tank using a virtual tank. Reason why we use three pushbuttons to demonstrate fueling and usage of fuel. The device reports on the activity going on in the tank, that is fueling or usage of fuel by the generator. Figure 3.5 presents the simulation of the electronic circuit carried out on PROTEUS. See figure A.1 for a zoomed image.

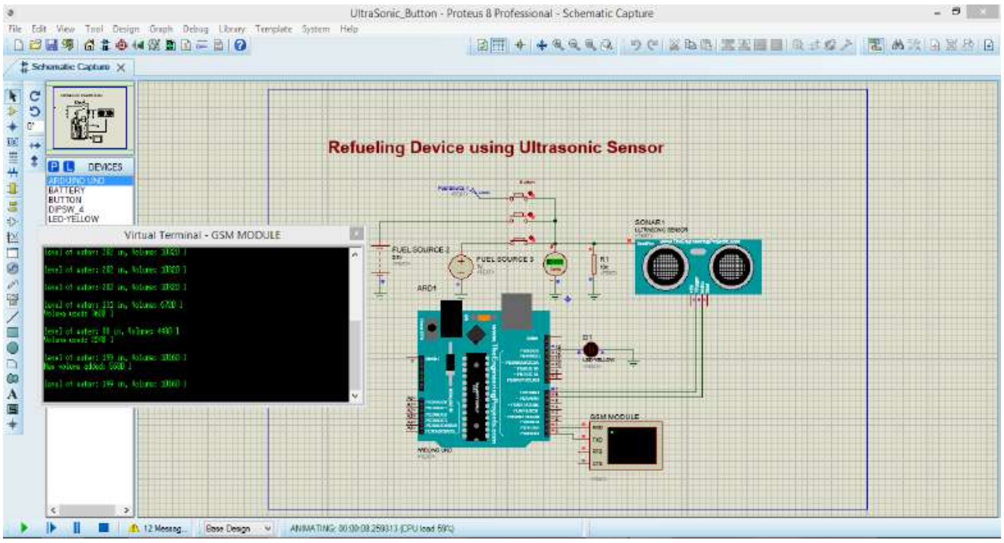


Figure 3.5: Simulation of the ultrasonic sensor device on PROTEUS.

The three pushbuttons are supplied with different voltages; one ac (alternative current) voltage of 1 V, another dc (direct current) voltage of 5 V and stake of battery to give 2.5 V. Pressing one or more of these buttons creates the different experience for testing. The ultrasonic sensor reads the voltage from these pushbuttons and interprets the value to time of flight. This time of flight value is then used by the microcontroller to calculate the volume of the fuel. Through out this simulation we assume a constant characteristic of the tank such as hieght H_{max}, length L and width W in cm. The virtual terminal which acts as the GSM module presents the result of the simulation.

Algorithm 1

Input: Voltage from the different sources when pushbuttons are activated.

Output: Display result of the volume of fuel and the activity in the tank.

1. Voltage is converted to time of flight (t_f in microseconds) by the ultrasonic sensor.

2. Distant covered by the wave (in cm) is calculated;

$$Distance = \frac{t_f \times v}{2}, \tag{3.2.1}$$

where v is the speed of the wave in air.

Initially, previous volume $(PrevV)$ is given the value 0.0 V, but this value changes as the new value is calculated.

3. Calculate new volume $(NewV)$;

$$NewV = \frac{(H_{max} - Distance) \times L \times W}{100} - PrevV. \tag{3.2.2}$$

4. Evaluate new volume;

   - If value is negative, then display "$|NewV|$ l used".
   - If value is positive, then display "$NewV$ l fueled".
   - if value is 0, then do not display.

5. $PrevV = NewV$.

Algorithm 1 was written in C++ on Arduino IDE (*explanation*: Appendix D) with a complexity of $\Theta(n)$.

3.2.2 Flow electronic device modelling and testing on ISIS. The aim of this simulation is to demonstrate that the device can calculate the volume of fuel which flowed into the generator tank during the time the generator set was running. Flow sensor measure flow of liquid with the help of the presure applied on this liquid by the device as seen in chapter 2. A pressure gauge is used to provide different values of pressure to the tube. With respect to a given value of pressure, the volume of fuel which flows in the tube during a period of 30 minutes is calculated. See figure A.2 for zoomed image of figure 3.6.

In this experiment, we provide pressure (P_1) values (whole numbers) from 0 to 150 N/m. The pipe carrying the flow electronic device is given a fixed characteristics; diameter (D_1 in m), D_2 in m is that of the flow sensor. The fluid flow (q in m^3/s) value is constant (Density ρ kg/m^3), therefore we can get the volume of the fluid flown into the generator tank during a period of 30 min (1800 sec).

$$q = C_D \frac{\pi}{4} D_2^2 \sqrt{\frac{2(P_1 - P_2)}{\rho(1 - d^4)}}, \tag{3.2.3}$$

where;

- C_D is the ratio of cross sectional area of the flow sensor (A_2) on that of the pipe (A_1), $C_D = \frac{A_2}{A_1}$.
- $P_2 = 0$, initial pressure.
- d is the ratio of diameter of flow sensor on that of the pipe, $d = \frac{D_2}{D_1}$.

$$V_{fuel} = q \times 1800. \tag{3.2.4}$$

The instructions for this simulation was written in C++ on Arduino IDE with a complexity of $\Theta(n)$.

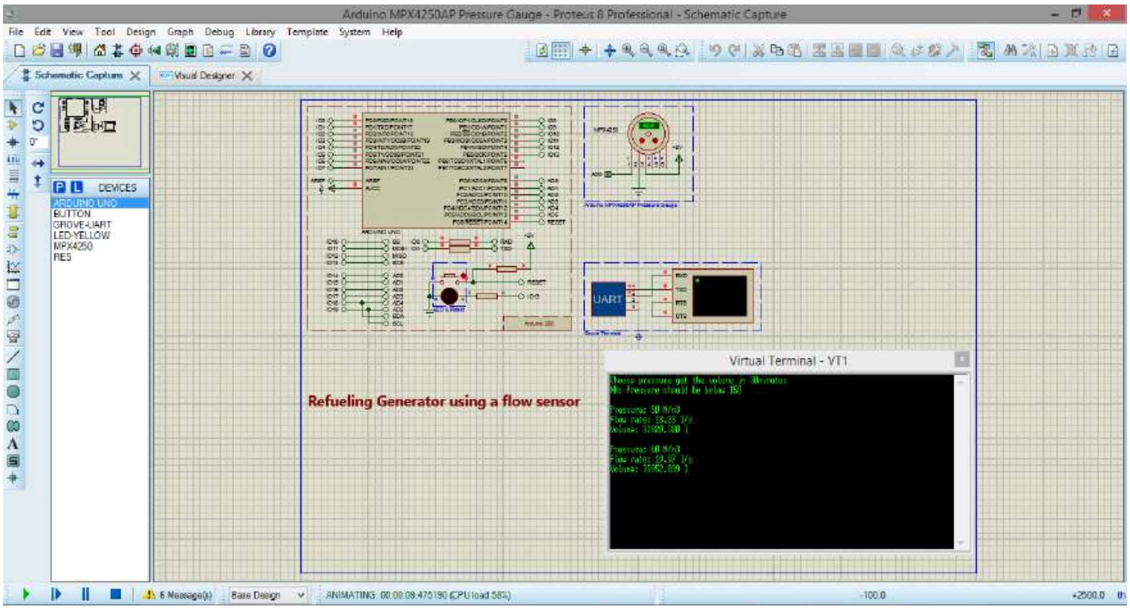


Figure 3.6: Presentation of the simulation on the flow measuring device on PROTEUS.

3.3 Real time Notification by Email/SMS

Instant notification of fueling operations is one of the key ways to supervise isolated sites. This system sends emails and SMSs when purchase is completed as well as when fueling process ends. Email and SMS APIs (Application Programming Interphase) are used to create notification system. This alert helps the tower company authorities to track exactly how the fueling operations is carried out on each site. In case of incoherent information, the field agent can be questioned immediately.

3.4 Security on Data Channels

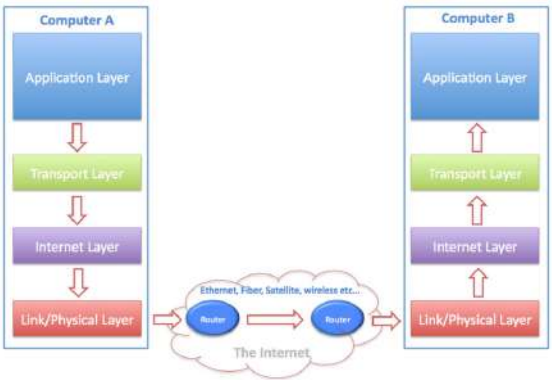


Figure 3.7: Data transmission using Internet as Wireless Communication. *Source:* www.cellbiol.com

Data Channels are routes used when transferring data from one device to another. Data transmission with Internet use TCP (Transmission Control Protocol)/IP (Internet Protocol). The data is divided into packets, then transmitted. Figure 3.7 shows the communication path of the electronic device (Computer A) and Server (Computer B) using TCP/IP.

The data from the electronic device (which is the volume of fuel filled) is broken into packets, sent through the internet layer. The physical link is a wireless network. The routers will find the correct route for the packets to get to the Server. When the server receives all the packets, it then travels to the transport layer where it is reassembled to the original data. There exist many Internet application protocol but for this system we recommend;

- *HyperText Transfer Protocol (HTTP)*: This is a simple request-response protocol layered on TCP. Its method uses basic words such as GET, POST and PUT. It is easy to integrate in web app using HTML. A secured version of this protocol is HTTPS (HyperText Transfer Protocol Secure) which is used by most browsers and websites.

- *Constrained Application Protocol (CoAP)*: This is a lightweight version of HTTP used in IoT applications. It operates over UDP (User Datagram Protocol), a less complex protocol than TCP [15].

- *Datagram Transfer Layer Security Protocol (DTLS)*: This is similar to TLS (Transfer Layer Security) but instead of relying on TCP, it relies on UDP. It deals with less reliable transmission and higher packet loss rates and for this reason it is suited to CoAP [23].

Wireless network is more open to attacks than wired network due to the easier access of unauthorized persons in coverage areas of wireless access points (WAP). The electronic device which is equipped with a WIFI/GSM module has a WAP. Therefore, SSID (Service Set Identifiers) Hiding is used to limit unauthorised people connecting to the WAP. The same technique is done to the Server and also IPsec (Internet Protocol Security) is used at the Internet layer. In addition, we encrypt the data before sending and decrypt before storing in the server. The encryption system is embedded in the processing of information by the electronic device before transmission while the decryption system in the process of cleaning data before storage.

3.5 Robustness of the system

This is the ability for a system to cope with errors during execution or erroneous input. The electronic devices ensure that the values sent are without errors but if they have any, they are detected and processed by the data processing module of the system.

The electronic devices are configured to a location, if any is taken out of the location it was configured; the server ceases to receive data from this device even if the device continues to read the volume in the tank or the volume flowed into the generator. This aspect of the system prevents the server from receiving information from a device which is stolen or used from a different location. These devices are mounted to be resistant to tampering, an acceleration sensor is embedded in them to detect vibrations and shocks. Vibrations and shocks above accepted threshold result to notification emails and SMS sent to tower authorities. When the battery level of the electronic device is below predefined value, the device sends notification emails and SMS to tower authorities. This is achieved by adding a battery level sensor to the electronic device.

4. Results and Prototype

We apply this methodology by designing a prototype of the system. This prototype is based on the idea summarized in the figure 4.1.

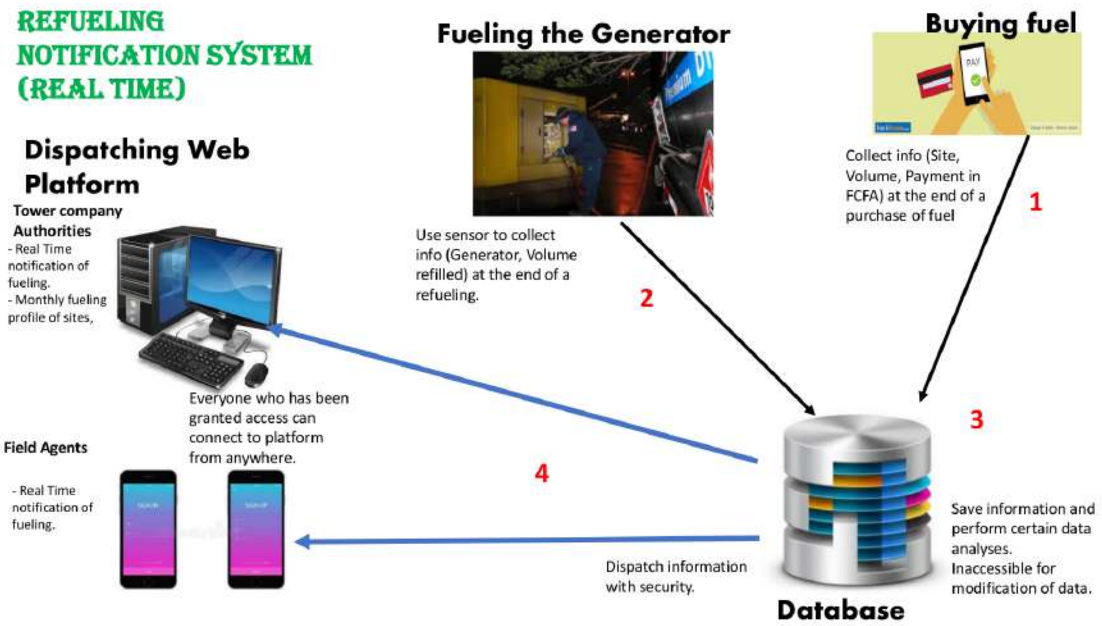


Figure 4.1: Overview of the prototype for the Refueling Notification System.

A field agent buys fuel at the station, fills a digital form. After fueling the generator via a fixed tank, the volumetric electronic device sends the value of the volume of fuel added to the server. The server processes the information and dispatches to both tower company authorities and field agents.

4.1 Phase 1: Digital Form

The ownership of smart phones in Africa increases every year [35]. Almost 90 % of field agents in tower companies have smart phones. The decision to use digital form hangs on this observation. This form is a web based form and simple to fill. Once the field agent is logged in, the site where the field agent works is assigned to the form automatically. Figure 4.2 shows the digital form of the field agent assigned to site Prototype. The field agent selects from a list the fuel station from which the fuel was bought. Inputs;

- The name of the station agent who sold the fuel. This is to avoid the station agent to connive with the field agent to fraud the receipts, since he/she will be called for questioning if there is any suspicion.
- The volume of fuel purchased in liters.
- The amount of money payed in CFA.

Then the field agent clicks on save to complete this process. If the form was not filled properly, after clicking save it will reappear.

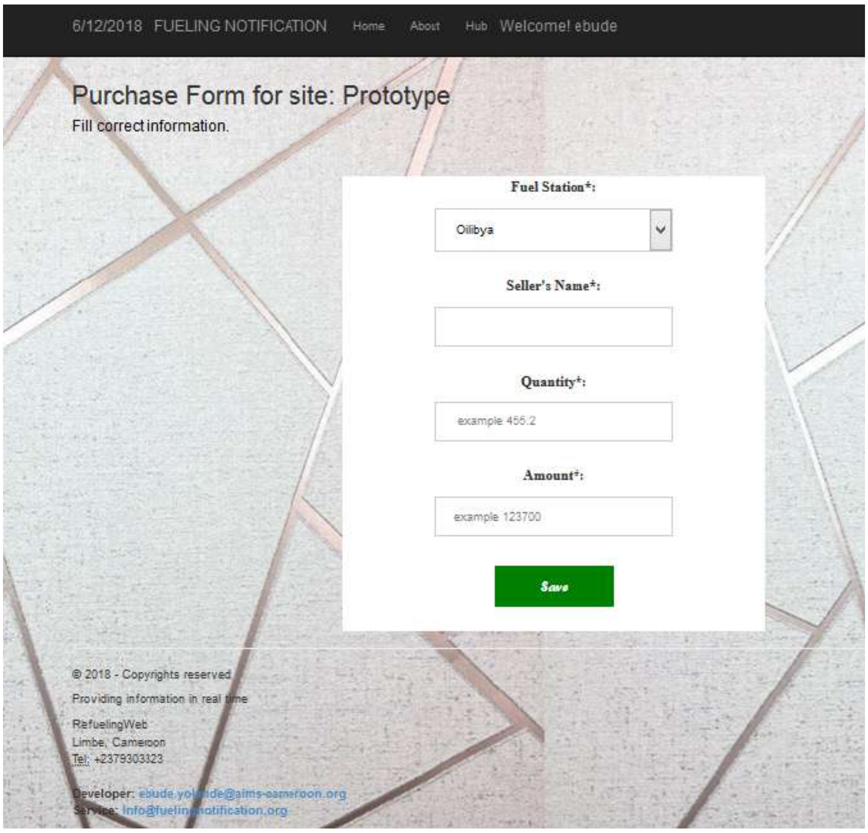


Figure 4.2: Digital form.

Once the save button is clicked with the correct information, assigned authorities in the tower company receive purchase notification by emails after 1 minute.

4.2 Phase 2: Fueling Generator

After purchase of fuel, the field agent carries to the site to fuel the fixed tank which connects to the generator tank. On each fixed tank is placed the volumetric electronic device for measuring volume of fuel. In this prototype, we use a plastic container of height 32 cm, length 16 cm and width 5 cm. This container can carry a maximum of 10 liters of fluid. Ultrasonic sensor was mounted on the Arduino UNO board (*explanation*: Appendix D) and programed to collect information in the plastic container every 3 mins.

Procedure repeated after 3 mins

- Ultrasonic sensor echo ping sents waves to hit the surface of the liquid and return to the trig ping. The time of flight is calculated.
- The time of flight is divided by two, then the distance is calculated.

- The volume of the liquid is calculated using the level of liquid detected.

This procedure is writing into instructions using C++ on the Arduino IDE with a complexity $\Theta(n^2)$.

Figure 4.3 shows how the electronic device is connected on the plastic container. The electronic device is powered by 5 V, through a connection by USB (Universal Serial Bus) port of a computer. This connection to the computer also serves as command interphase for the device. The CPU of the computer is used as a processor in the absence of a microprocessor. Figure 4.4 shows the command interphase used to control the electronic device during fueling. The 'Start' button is used to configure the device to commence the process of fueling while the 'Stop' button ends this process. Since this device uses Arduino Serial to communicate with the device, there are many ports by which this device can be connected; */dev/ttyACM0*, */dev/ttyACM1*, */dev/ttyACM2*, */dev/ttyACM3* and */dev/ttyACM4*. The dropdown menu 'choose a port' provide a possibility to select the port in which the electronic device is connected. When this port is selected, the computer operating system opens this port for communication between Arduino Serial and other programming software such as C++, Python.

Figure 4.3: Setup of the volumetric electronic device and the command interphase using a computer. *See more*: Appendix B

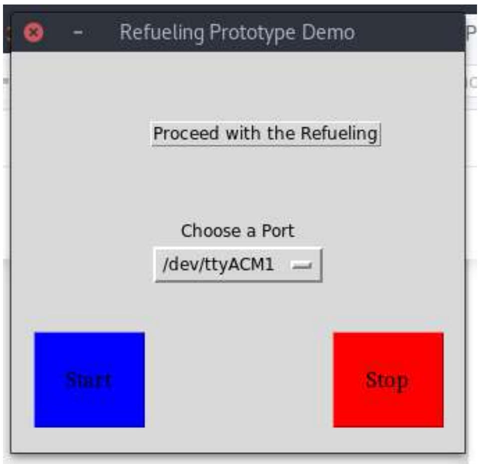


Figure 4.4: Command interphase to the electronic device.

Algorithm 2

Input: Volume of fuel.

Output: Value sent to a server, notification emails.

1. Select port using "Choose a port".
2. Start button activated.
3. Measures the volume of fuel in the tank.
   - If the measured value is valid, then display "Proceed with the Refueling".
   - Else (microcontroller detects presence of noise in the signal), display "Click again" and repeat step 2.
4. Wait for 3 mins (this is the time of complete cycle of measurement using this device).
5. Stop button activated.
6. Measures the volume of fuel in the tank.
   - If the measured value is valid, the previous measured value is subtracted from this new value. The devices sends the difference to the server and a fueling notification email is sent to an assigned tower company authority, then display "Refueling completed".
   - Else (microcontroller detects presence of noise in the signal), then display "Click again" and repeat step 5.

Algorithm 2 was written in Python 3 (*explanation*: Appendix D) with a complexity of $\Theta(n)$. At the end of every fueling process, the device continues the measurement every 3 minutes. Unlike in the real system, this prototype does not store these values read every 3 minutes due to insufficient processing capacity.

4.3 Phase 3: Data Storage and Processing

Storage and processing goes on simultaneously in this system. In this prototype, we use local disk of computer as final storage while Google drive is used as temporary storage device. SQlite Database is used due to its ease in manipulation. Processing is done by the CPU, this affects the runtime of the system.

Considering one fueling information, this is the process of storage and processing in four steps;

- Store purchase information.
- Store fueling information.
- Process information.
- Store both information after processing

We used two SQLite files for storage. Purchase and fueling information is stored in an SQlite file; *Purchase table* is the name of the table containing purchase information and *Fueling table* for fueling information. After processing, the new information is stored in *Complete table* in the second SQLite file.

4.3.1 Storage of purchase information. When field agent buys fuel, he/she fills a form. The data from that form is referred to as purchase information. This information is sent to Google drive, then picked from the drive to the local drive by the system. We describe below the algorithm for storage.

Algorithm 3

Input: Text file containing purchase information.

Output: A new row of information in the *Purchase table*.

1. Search Google drive for lastest information every 2 seconds. This is done by classifying the information by time of arrival.
2. Compare the latest information to that in the *Purchase table*.
   - If latest information is new (different from all the information in *Purchase table*), then continue to step 3.
   - Else, goto step 1.
3. Open SQLite file, then arrange information into *Purchase table*.

Algorithm 3 is coded using Python 3 with a complexity of $\Theta(n)$. Each column of the *Purchase table* is made for the information collected from the digital form, in addition to this information; site (this is assigned to a variable once the field agent logs in), date and time (this got from the timestamp of the digital form).

The same algorithm is used for **storage of fueling information** (replacing *Purchase table* by *Fueling table*). The columns on the table are; site, volume, date and time (all these information come from the Google drive).

4.3.2 Processing Information. More than one purchase could be done in a day as well as fueling. Sometimes fueling could be done two to three days after purchase. There is also a possibility that a field agent of site A purchase fuel before that of site B, but site B's tank gets fueled before site A's tank. The system must have the ability to match the right purchase information to fueling information. Analysis to determine whether the fueling was done properly is part of this processing. This process starts once a new fueling information is stored. The algorithm below describes the system's method of matching information as well performing analysis.

Algorithm 4

Input: Data from *Purchase table*, *Fueling table* and *Complete table*.

Output: Notification emails if theft or fraud is detected and a new row in the *Complete table*.

1. Open SQLite file, select all data in *Purchase table* and assign to a variable.

2. Append five last rows into a list.
3. Match information with the last row of *Fueling table*.
4. Create a list of the matched information.
5. Compare information in the list to that of the last row of the *Complete table*.
   - If similar, discard the list then restart the process.
   - Else, continue to 6.

The next three steps are those executed by the expert system.

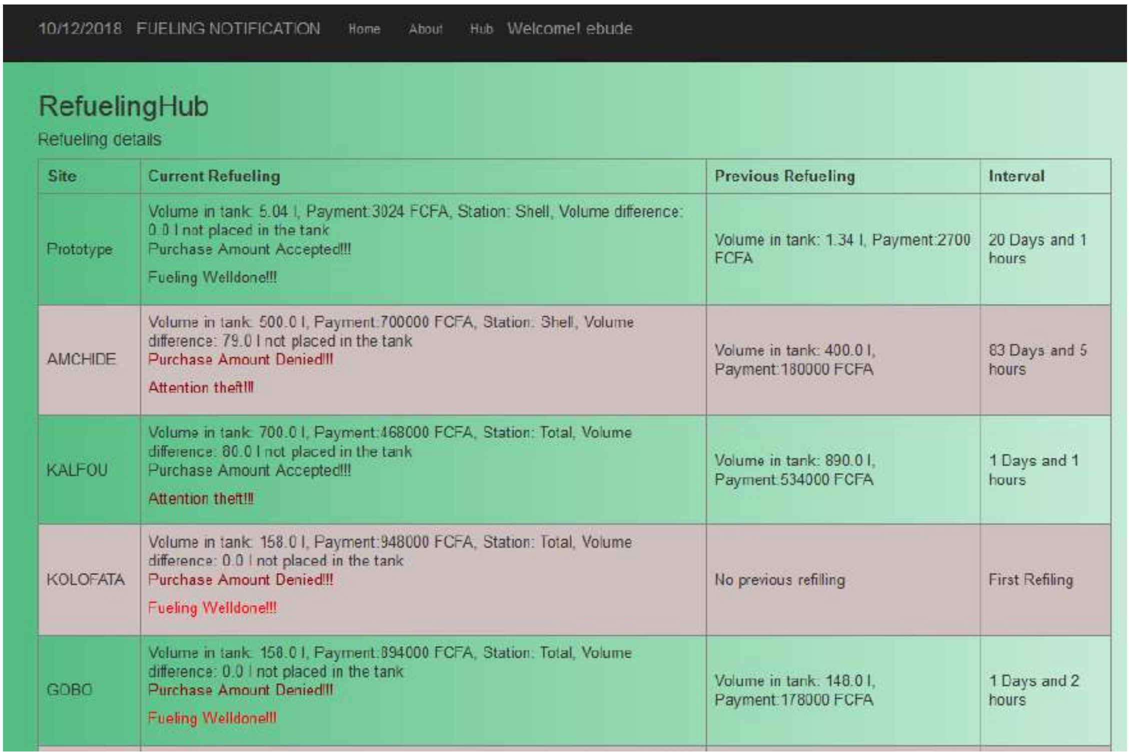
6. Compare the price of the fuel placed in the digital form (P_P) to *unit fuel price (depends on the station selected in the digital form)* $\times$ *quantity of fuel purchased* (P_T).
   - If $P_P > P_T$, then outcome is 'Purchase Denied'.
   - Else, then outcome is 'Purchase Well-done'.
7. Compare the volume of fuel purchased (V_P) to the volume fueled (V_F) into the tank.
   - If $V_P > V_F$ or $V_P < V_F$, then assign the logic number 0 to verify variable and outcome 'Attention Theft'.
   - Else, then assign the logic number 1 to verify variable and outcome 'Fueling Well-done'.
8. To the list created in 4. add the verify variable value to it. An email is sent out if the logic number is 0.
9. Create a new row in *Complete table* and save the information in 8.

Algorithm 4 was written in Python 3 with a complexity of $\Theta(n^2)$.

4.4 Phase 4: Data Visualisation

In this phase, we present the results of the fueling on a web application. This web application is programmed to use the outcome from phase 3 and transform it into visually suitable information. This app allows login into one of three categories; *field agent*, *tower company authority*, *system administrator*. A field agent can see the different fueling operations he carried out as well as what the other field agents have done. In addition to what the field agent can see, the tower company authority can also see the *Complete table* and download it for analysis, and the performance of each site in fueling operation monthly (*see* Appendix C.6). The system administrator can view all what the tower company authority can as well as create accounts for both field agents and authorities.

Figure 4.5 shows the display of the fueling operations carried out using the system from most recent fueling to the latter. The name of the site is written on the first column. The second column which is titled 'Current Refueling', presents the information of the fueling operation that has been recently executed while the next column is to remind the field agent of the quantity of fuel placed in the tank and how much it was bought during the previous fueling operation. The last column is the time interval between the fueling operations that is; current and previous refueling.



10/12/2018 FUELING NOTIFICATION Home About Hub Welcome! ebude

RefuelingHub

Refueling details

Site	Current Refueling	Previous Refueling	Interval
Prototype	Volume in tank: 5.04 l, Payment:3024 FCFA, Station: Shell, Volume difference: 0.0 l not placed in the tank Purchase Amount Accepted!!! Fueling Welldone!!!	Volume in tank: 1.34 l, Payment:2700 FCFA	20 Days and 1 hours
AMCHIDE	Volume in tank: 500.0 l, Payment:700000 FCFA, Station: Shell, Volume difference: 79.0 l not placed in the tank Purchase Amount Denied!!! Attention theft!!!	Volume in tank: 400.0 l, Payment:180000 FCFA	83 Days and 5 hours
KALFOU	Volume in tank: 700.0 l, Payment:468000 FCFA, Station: Total, Volume difference: 80.0 l not placed in the tank Purchase Amount Accepted!!! Attention theft!!!	Volume in tank: 890.0 l, Payment:534000 FCFA	1 Days and 1 hours
KOLOFATA	Volume in tank: 158.0 l, Payment:948000 FCFA, Station: Total, Volume difference: 0.0 l not placed in the tank Purchase Amount Denied!!! Fueling Welldone!!!	No previous refilling	First Refiling
GOBO	Volume in tank: 158.0 l, Payment:894000 FCFA, Station: Total, Volume difference: 0.0 l not placed in the tank Purchase Amount Denied!!! Fueling Welldone!!!	Volume in tank: 148.0 l, Payment:178000 FCFA	1 Days and 2 hours

Figure 4.5: Presentation view of fueling operations results.

The result of the 'Current Refueling' indicates the following;

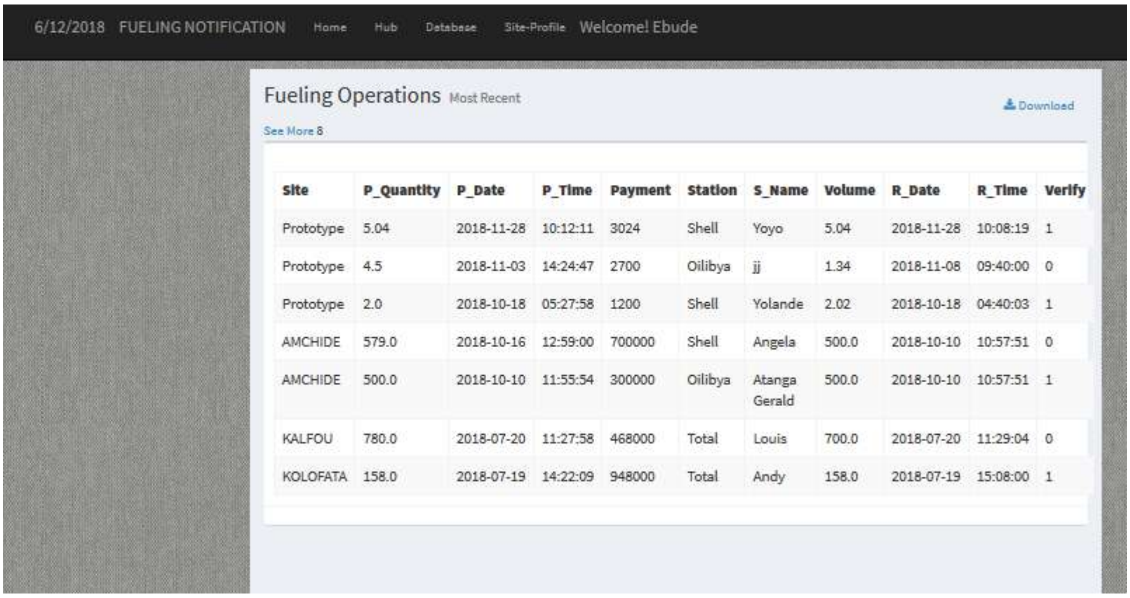
- If the volume and amount of fuel purchase was exactly what was required.
- If the quantity of fuel in the tank was the exact quantity bought.

The difference in colour of the output creates attention towards what fueling operation was not properly conducted. An important phrase in this column is the phrase 'Volume difference: [*number*] l not placed in the tank'. It gives an estimated quantity of fuel stolen by the field agent. The various fueling operations presented in figure 4.5, here are a few observations;

- Field agents of site Amchide and Kalfou stole 79 and 80 liters of fuel respectively.
- The field agents of sites Amchide and Kolofata frauded the purchase amount (price) of the fuel.
- Field agents of sites Kafou and Gobo have two fueling operations executed in less than two days.
- Site Kolofata is fueled for the first time using the system.

There can be not more than one row on this table containing the same site name. Once a site's fueling operation is completed, the previous row with this site information is deleted and a new row is created on the first row of the table.

When logged into the app as a tower company authority or system administrator, the *Complete table* is viewed as figure 4.6.



6/12/2018 FUELING NOTIFICATION Home Hub Database Site-Profile Welcome! Ebude

Fueling Operations Most Recent

See More 8

Download

Site	P_Quantity	P_Date	P_Time	Payment	Station	S_Name	Volume	R_Date	R_Time	Verify
Prototype	5.04	2018-11-28	10:12:11	3024	Shell	Yoyo	5.04	2018-11-28	10:08:19	1
Prototype	4.5	2018-11-03	14:24:47	2700	Oilibya	jj	1.34	2018-11-08	09:40:00	0
Prototype	2.0	2018-10-18	05:27:58	1200	Shell	Yolande	2.02	2018-10-18	04:40:03	1
AMCHIDE	579.0	2018-10-16	12:59:00	700000	Shell	Angela	500.0	2018-10-10	10:57:51	0
AMCHIDE	500.0	2018-10-10	11:55:54	300000	Oilibya	Atanga Gerald	500.0	2018-10-10	10:57:51	1
KALFOU	780.0	2018-07-20	11:27:58	468000	Total	Louis	700.0	2018-07-20	11:29:04	0
KOLOFATA	158.0	2018-07-19	14:22:09	948000	Total	Andy	158.0	2018-07-19	15:08:00	1

Figure 4.6: Web app view of the *Complete table*.

This section of the web app provides a clean database for analysis to the tower company. It can be downloaded by any authority and system administrator. The fueling operation information is arranged from latest fueling to earliest. The column named 'verify' shows the classification result of the expert system.

More explanation of the web app is given in Appendix C.

4.5 Notification by Email

A notification system which uses emails to alert tower authorities was designed for the prototype. It was less costly and more technically stable than the SMS notification system. We use Python 3 to access Gmail account, then use an algorithm to send email. This is made possible with the use of SMTP (Simple Mail Transfer Protocol) and IMAP (Internet Message Access Protocol) which are TCP/IP protocols.

4.6 Test of Robustness of the Prototype

This experiment demonstrates the behaviour of the system if there is an attempt to steal or trick the electronic device. The electronic device was taking to a new location, keeping the previous configuration. The server did not receive information from the device eventhough it continued to read the volume in the tank. The first time this experiment was carried out, the new location was 30 m from the configured location. More tests were executed with the aim to find the minimum distance from the configured location, whereby the server stops receiving the data from the device. We discovered that when the device is at a minimum distance of 18 m from the configured location, the server ceases to receive data from device.

4.7 Limitations of the Prototype system

Though we designed the prototype to be as close as possible to the real system, we must acknowledge that it is just a shadow of the real system. Due to time constrain, here are some modules described in the system not placed in the prototype system; *Encryption/Decryption system*, *Storage in electronic device* and *GSM module*. With the absence of these modules the prototype has the following limitations.

- In the absence of internet the prototype system cannot function.
- No data collected on fuel consumed by the generator due to absence of the second electronic device with flow sensor. Therefore, no clear conclusion on if the fuel was used by the generator or just slowly taped out.
- If fuel is mixed with any liquid the electronic device designed for the prototype cannot detect whereas the presence of the second device in the real system which assures the detection of this kind of fraud.
- SMSs which are more easily accessible than emails are not used in by notification system. This may cause a delay in supervision.

Conclusion and Future work

Tower companies face fuel pilferage and this affects the business. This theft could be carried out by field agents while fueling the tanks. Fraud of values from purchase receipts to consumption values to conceit theft has become rampant. Fuel operation, being a key activity in tower sites, need constant supervision. Since most of the tower sites are found in isolated zones, supervision by presence on site is very difficult.

In this work, we propose a solution to these three major problems; *theft*, *fraud* and *lack of supervision*. This solution exposes theft done by the field agent. It collects information automatically preventing the field agent from manipulating the values. The notification system embedded in this solution informs tower company authorities on the process of fueling. It also notifies them of fueling operation which were not properly done. This information can be visualized using a web app, making it easy for follow up by authority.

This work will help tower companies supervise their isolated tower sites without spending money on transportation and determine which field agent commits a fraud or theft. It will present an evidence to make the field agent pay for fuel stolen. Overall, it will improve the tower company's business by reducing operational expenditures (OPEX) .

There are three major aspects we would like to develop in the future work;

- **Improve prototype**: Present a prototype with both electronic devices for data collection with all its functionalities. Reduce the response time of the notification system to sending emails.
- **IoT sensor**: In this work, we used a simple sensor and transmitted the information to a server. This idea is closed to IoT sensors but we did not spend time to develop the network. We could build a better IoT sensor for this system and use WAN for communication.
- **Machine Learning (ML) model**: The AI technique used in this system is an Expert System. In two to three years period of usage of this device, the data collected will be sufficient to build a ML model which can act as a reinforcement to the expert system during data processing. Prediction of future fuel operation time and quantity of fuel needed could be done by the ML model. The data collected every 3 minutes in the tank is stored and preserved for analysis. A study on these data could predict the consumption characteristic of each site. Hence, this will improve prediction of fuel consumption per site.

Appendix A. Clear view of Simulations

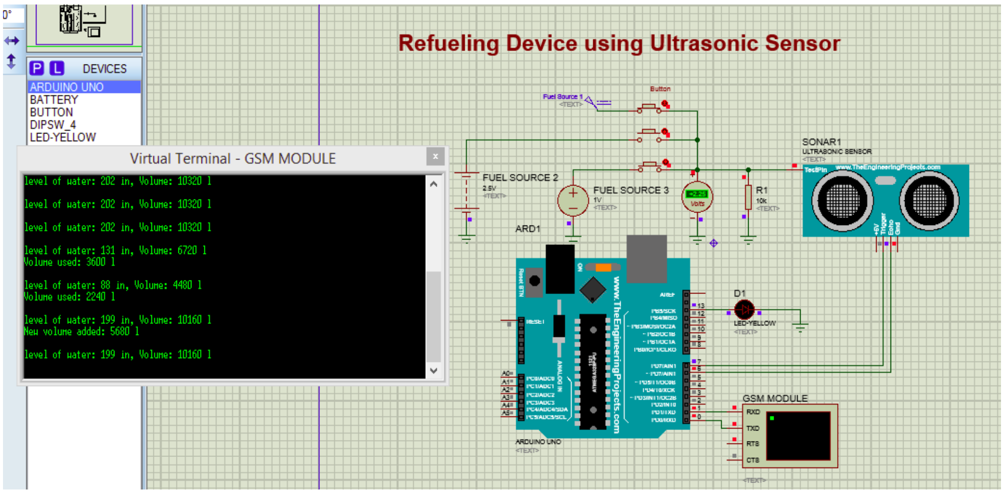


Figure A.1: Simulation of the volumetric electronic device on ISIS.

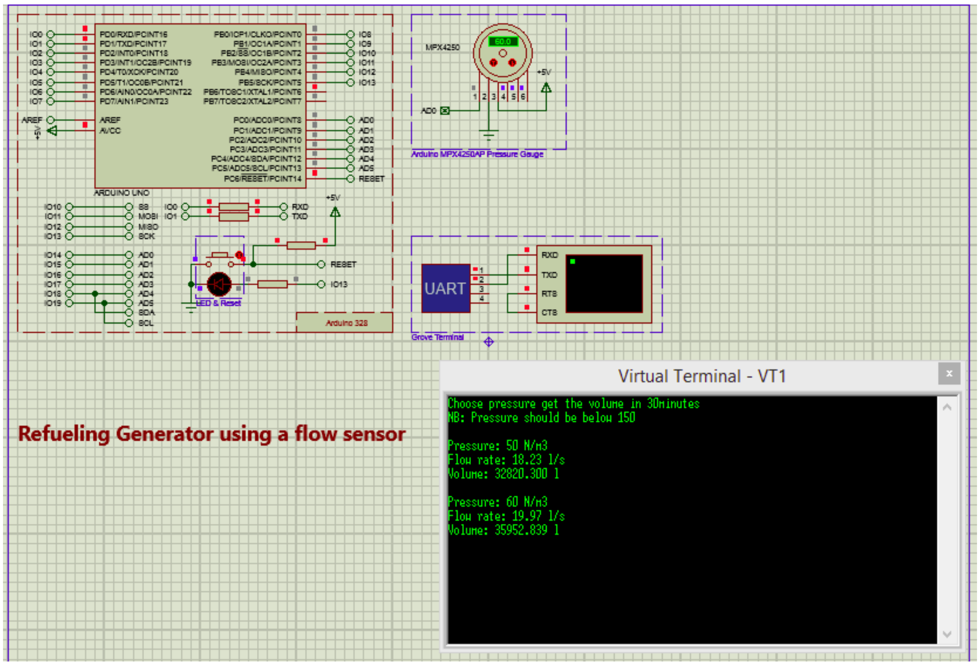


Figure A.2: Simulation of the flow electronic device on ISIS.

Appendix B. Electronic device of the prototype system

Figure B.1: Side View.

Figure B.2: View of the sensor and connections.

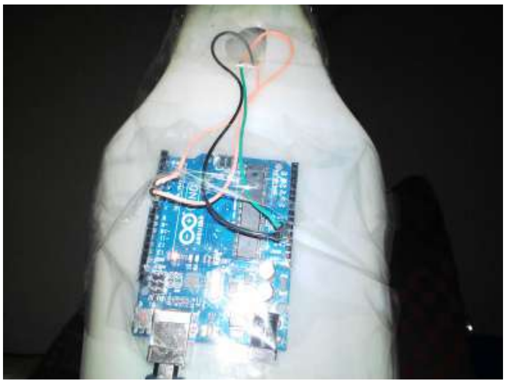


Figure B.3: View of the Microcontroller.

Appendix C. Web App presentation

1. **Home page before any login.**

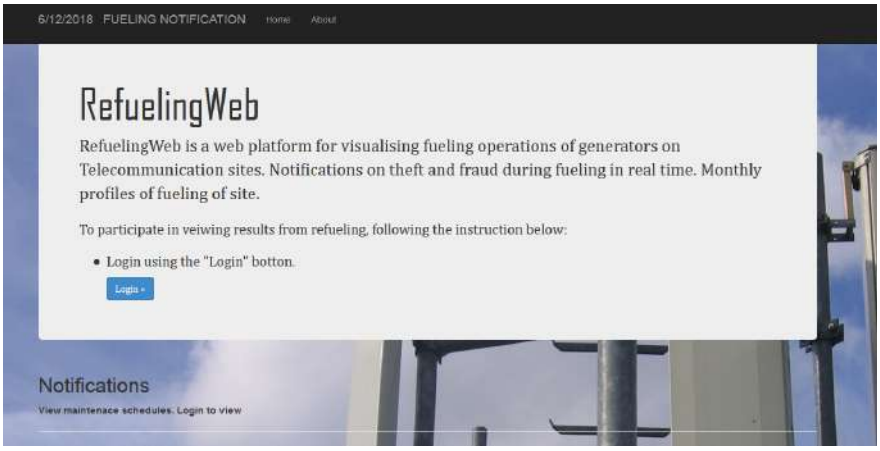


Figure C.1: Home page of the web app before login into various users.

This is the first page seen by everyone who types the URL.

2. **Home page when logged in as different users.** An individual can be logged into the web app as different categories. This depends on which category he/she was registered into. Here below are the things unique to each category;

   - *field agent*: Purchase form (digital form) is used only by this category.
   - *system administration*: Registration form is used only by this category. This creates accounts for different users of the system.

System administrator and authority share the same access to viewing information on the app. Field agent and authority receive the same notification on fueling operations to be carried out.

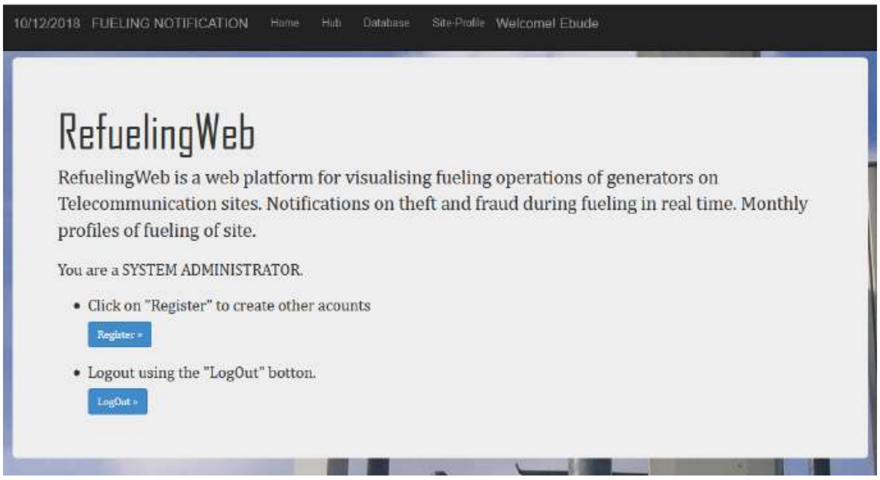


Figure C.2: Home page when logged in as a system administrator.

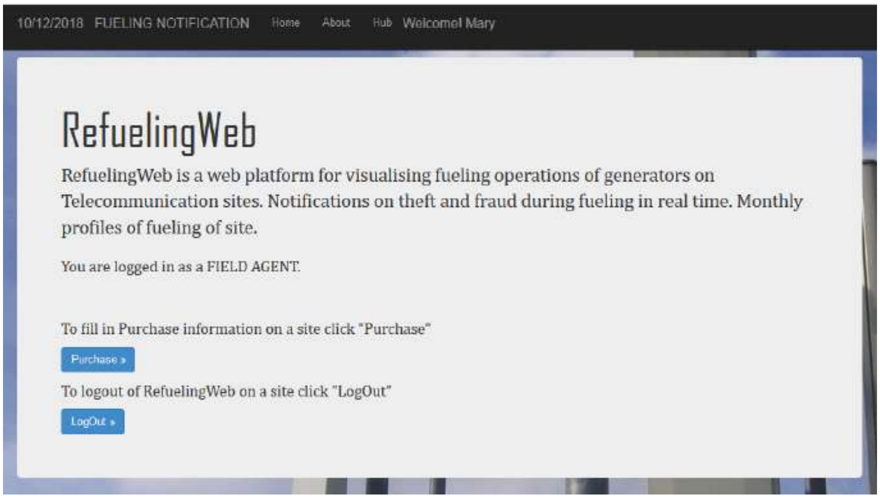


Figure C.3: Home page when logged in as a field agent.

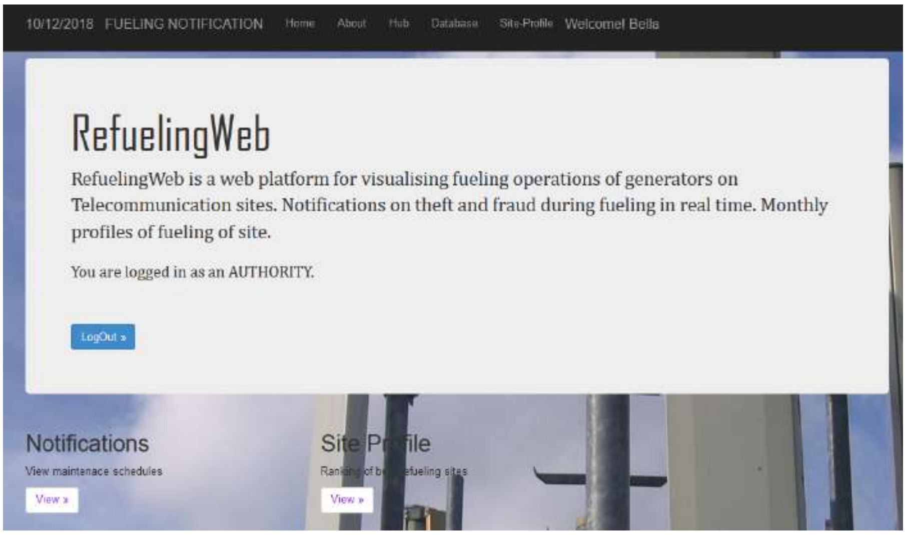


Figure C.4: Home page when logged in as an authority.

3. **Notification about fueling operation.** The instruction on what should be done on a site when the field agent has to perform fueling operation can be presented through a notice board titled 'Notification'. Figure C.5 is a presentation of the outlook of the notice board.

4. **Site profile.** This page presents fueling for each month. It presents a possibility to choose what month to view. This helps the authority compares the fuel volume carried out on different sites in just one glance. It will give an approximate price value of fueling operation done in each site. Figure C.6 show the fueling operations in the month of July 2018.

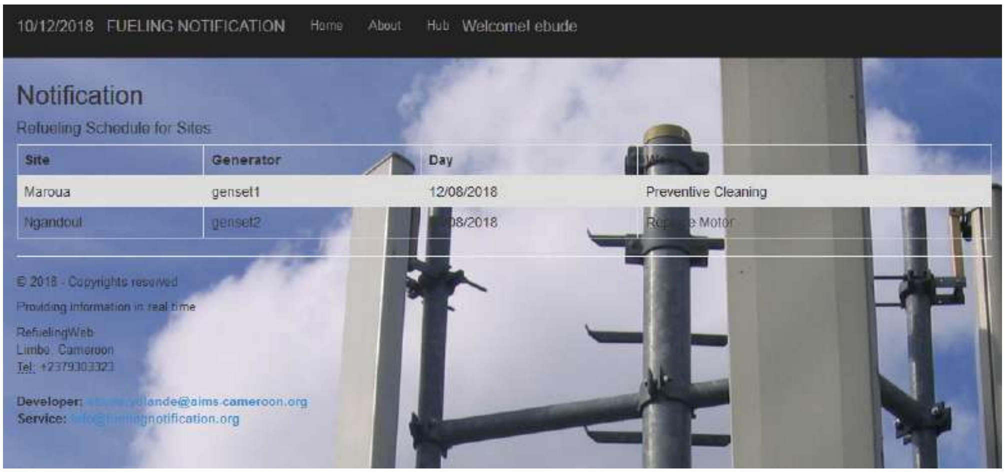


Figure C.5: Fueling operation notice board.

Figure C.6: Fueling operation carried out in the month of July 2018.

Appendix D. Programming Languages and Platform

1. **Python 3**: Python is a programing language that is known for its simplicity and a lot of advancement in AI and ML. Python 3 is the latest version of this language see www.python.org. Jupyter, Google Colab, Visual Studio and Spyder are some open-source softwares which use this language.

2. **C++**: This is a general-purpose programming language. It has imperative, object-oriented and generic programming features, while also providing facilities for low-level memory manipulation. Code::Blocks is one of the open-source softwares which use this language.

3. **Arduino IDE**: The Arduino integrated development environment is an open-source cross-platform application that is written in the programming language Java. It is used to write and upload programs to Arduino board using C/C++. The source code for the IDE is released under the GNU General Public License, version 2 see www.arduino.cc software.

4. **Arduino Board**: This is a microcontroller based board with different electronic component of which the prominent is a microchip. This board receives instructions from the Arduino IDE. There are different kinds of boards;

   - *Arduino Mega 2560*: It has 54 digital input/output pins (of which 14 can be used as PWM (Pulse-width Modulation) outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP (in-circuit serial programming) header, and a reset button.
   - *Arduino Uno*: It is the most used and documented board of the whole Arduino family. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button.

   To know more about other boards visit www.arduino.cc products.

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