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Embedded IoT-based Monitoring Utility for Safety Management and Access Control

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Abstract – **In an industrial workplace, the safety of human lives and properties are key functions of the Health, Safety and Environment (HSE) department. In this work, an industrial automation monitoring system based on IoT was designed and implemented to assist in access control and safety management in a storage facility of an Industrial plant. The monitoring utility detects the alcohol levels of employees before they enter the facility. It further continuously checks the environment for Liquefied Petroleum Gas (LPG) leakage and any possibilities for a fire outbreak, then sends out real-time alert/alarm notifications to the HSE department, fire office, security units and other authorized personnel through the industry's website and a dedicated GSM line. The system's sensor modules, consisting of alcohol, LPG and fire sensors, measure the parameters and sends the relevant data to the microcontrollers for processing. The NodeMCU activates the IoT-based alert mode by sending the processed data to the ThingSpeak platform, SMS and website to be accessed by authorized employees. The system, while sending out the alert, also activates the fire suppression system via the sprinkler circuit. With this IoT-based monitoring system, the industrial storage facility urgently carried out necessary actions that prevented and minimized workplace hazards due to intoxicated employees showing up at work, potential LPG leakage and fire outbreaks.**

Keywords – **HSE, IoT Technology, Safety Management, Access Control, Node MCU, ThingSpeak.**

I. Introduction

Risk management policies and implementation are a means to reduce and/or eliminate fatal and non-fatal hazards in different environments. The clamour for zero number of Loss Time Injuries (LTI), fatalities and financial loss required for companies to attract and retain small to large scale contracts, via enhanced Health, Safety and Environment (HSE or EHS) procedures has now become more than ever before, a fundamental requirement to kick start any industrial small to large scale project and complete such. Due to the increasing accounts of preventable HSE fatalities across the globe, the need for the complete automation of monitoring facilities has become paramount [1]. Industrial monitoring and control combine electronics, architecture, machinery, procedures and people with algorithms and software to build a system to monitor and control the activities of industrial processes aimed at maximizing profits for an optimally safe working environment [2]. Recently, the outbreak of the COVID-19 pandemic gave rise to different means of communication and interaction for humans, machines and data to enhance health and security measures [1, 17].

The IoT technology provides opportunities for convergence of heterogeneous processes, devices and technologies. The term 'things' involve physical entities and non-physical entities such as devices, animal/ human body, as well as, data generated from sensors [4]. With automation, enabled by IoT engineered mechanisms and software systems, equipment failure, procedural flaws and human errors are maximally reduced and eliminated from the entire operation [5] – [8] [22]. Since 2001, there is progressive use of GSM in Nigeria, which gave way to the growth of wireless networks and technologies in the country, thus there are many opportunities for the implementation of IoT-based systems [9]. Such implemented systems have

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streamlined communication, effective industrial production and proactive safety and control are achievable in many parts of the country. Such that IoT-enabled applications are rapidly utilized in industries, transport, schools, health care and other endeavours.

In this research, IoT-based monitoring utility for LPG, fire and alcohol was designed and implemented in a storage facility owned by a private-owned Industrial Plant. The utility system is integrated with a status reporting mechanism. The system continuously monitored the parameters (i.e. alcohol, LPG, and fire) through a set of sensor modules and promptly sends alerts through a dedicated GSM module and webpage to the HSE department, the security department and the Emergency and fire control department. ThingSpeak IoT analytical platform is configured to visualize the reports from all the sensors. The live reports and control monitoring of the parameters are used to manage the safety of employees in case of fire outbreaks and LPG leakage. Also, the system performs initial access control functions such that it stops the entry of intoxicated employees into the facility. The industry used this utility mechanism to aid processes and procedures thus safety measures can take place before any accident and hazard escalate.

II. Literature Review

Worldwide, avoidable hazards due to human errors and equipment failures have claimed lives and properties in homes and workplaces [10]. The huge problem of poor working conditions brings about hazards due to human error or equipment failure that have led to fatalities, injuries and financial loss. According to International Labor Organization (ILO), an estimate of 340 million occupational accidents, 268 million non-fatal workplace accidents and 160 million victims of work-related illnesses occur worldwide every year, and increasingly more people are affected by accidents and ill health related to a place of work [1, 11]. Various businesses and industries in Nigeria possesses various liquefied petroleum gas (LPG) products and consequently are prone to LPG leakage and fire. According to [23], the lower explosive limit of LPG is around 2,000 ppm however LPG leakage can cause asphyxia even below this limit, which can lead to accidents, fire and death. In Abuja Nigeria, between 2013 and 2018, an estimate of 5 trillion Naira was lost to infernos thus there is decry in the lack of seriousness in applying HSE guidelines in offices and industry in various part of the country [11, 12]. Alcohol consumption during work hours is quite common. According to [14], 8 out of 10 serious workplace injuries and non-workplace accidents are caused by employees under the influence of alcohol or drugs or both. Even though the legal limit for blood/breathe alcohol concentrations (BAC) of 0.02 - 0.05 g/Dl (gram per decilitre) is deemed safe, there are no safe levels of alcohol consumption at work apart from zero [14]. Also, alcohol is commonly abused before and after work hours such that it contributes to road traffic accidents of high fatality estimated at 21.4% per 100,000 people in Nigeria [13]. The impact of alcohol consumption is not limited to during work hours, but also before and after work hours. Apart from accidents, other common effects of alcohol consumption include death, disability, impaired concentration, slow reaction time, slow decision making, reduced coordination, low productivity and worker performance etc. [13]. Therefore, it is the responsibility of employers to initiate physical and computerized measures that enhance employees' safety within and outside the workplace.

A. *IoT Technology*

Wireless networks and standards have continued to evolve to include the Internet of Things (IoT) technology

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that allows industrial processes to be automated and operated from anywhere in the world [3,4]. Light Fidelity (Li-Fi), Gi-Fi, and 5G network are some of the latest wireless networks that provide high-speed connectivity that can help promote IoT technology. The notion of ‘Things’ in IoT involves the “inextricable mixture of hardware, software, people, data and service” and are uniquely identified through IP address. IoT encompasses a plethora of connected smart devices and supports diverse applications, which consists of sensors, actuators and machinery, deployed for monitoring, data collection and analysis, asset management, maintenance planning, and plant control and optimization [2] – [7], [9, 15, 16]. IoT-based applications are beneficial now, and also in the future as seen in Fig 1(b). The positive benefits of IoT technology were seen in the efforts to execute its prevention measures of COVID-19. Many countries have reopened industries aided majorly by advanced IoT foundational systems aimed to safeguard the health and environment of employees in the workplace [17] – [19].

The concept of Industrial IoT (IIoT), as seen in Fig. 1(a), is such that an authorized person can get information and control one’s industrial ‘everything’ via the internet or other network technologies from anywhere in the world. IIoT technology applies to different hardware sets that work together to improve industrial processes. IIoT 4.0 is the recent framework for IIoT technology. IIoT systems indeed pose several challenges as they have to interoperate with existing infrastructures and integrate highly heterogeneous hardware and software platforms [5, 8, 20 – 22]. They have to be prepared to scale orders of magnitude in size, diameter, and/or density, as well as to enable management by different entities. Also, they have to be dependable, that is, reliable, safe, available, maintainable, and secure, all at the same time. Though it sounds good enough to have a smart business and/or industrial environment, soon, it will also have to face hurdles of handling big data as all the devices will communicate with each other and exchange their information over a common-platform. Despite these challenges, the focus of incorporating IIoT technology has proven to be a positive step and enables businesses to boost functionality, energy efficiency, streamline interaction, and maximize productivity and track events [5, 8, 20, 21]. Also, IIoT technology facilitates the use of advanced industrial hardware and technology for safety enhancement and access control management used by safety and security managers [5, 21].

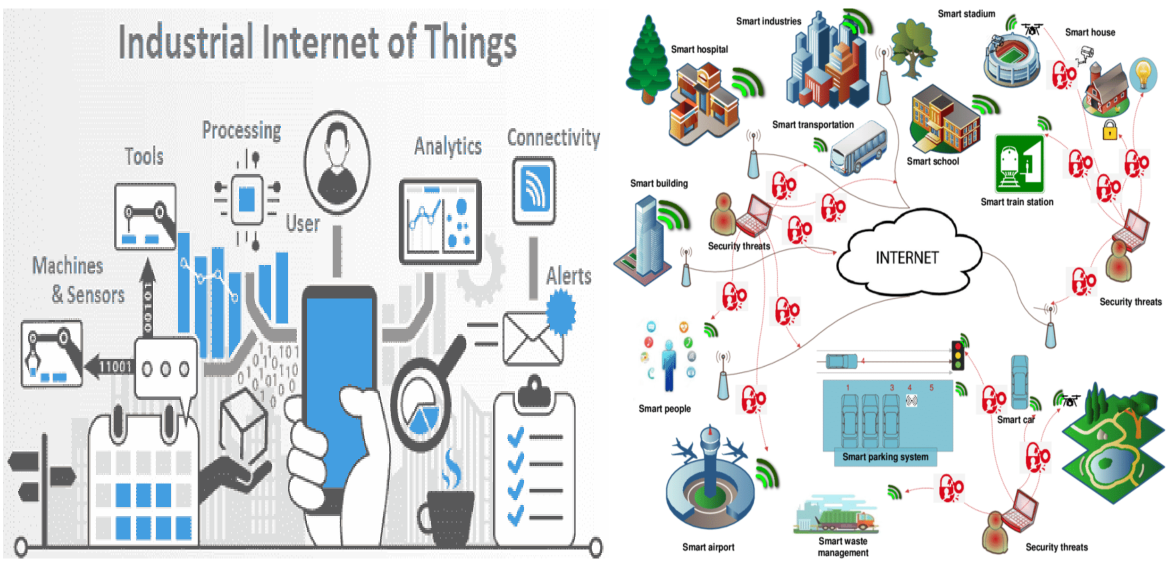

Fig. 1. (a) Concept of IIoT. (b) Smart city enabled by IoT technology.

B. *IoT Technology and HSE*

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The COVID-19 pandemic reduced physical interaction for humans, machine and information. HSE risks can still occur due to faulty machines and human errors. IoT technology enables multiple technologies and devices to converge for direct integration of the physical activities and processes into computer-based systems to increase efficiency, accuracy, productivity and economic benefits [22]. By using IIoT technology, industries enhance workplace protection and data accessibility. A system that can automatically monitor, process and promptly send alerts to personnel in any location via the internet and GSM can save human lives and properties [22].

The work in [2] used an accident reduction model for an IoT-based industrial safety monitoring system to determine the EHS risk and injury and to improve decision making. The research of [10] explores the weakness of IoT and proposed an IoT-based system that identifies real-time personal safety issues and saves data and records of 'near misses' for proactive measures and future EHS training. In [19], iWorkplace is proposed to facilitate a healthy environment for industrial workers. In [23] gave a comprehensive review of the use of IoT technology in high risk EHS workplace. In [24], an IoT-based system to detect LPG leakage in a home was done, and the warning alert was sent to the customer via a GSM module. In [25], a smart cylinder was designed to detect LPG leakage and to alert the customers via SMS for necessary safety actions. The research in [26] designed an IoT-based monitoring and booking system for gas usage to enhance the safety of consumers in a home. In [28], an embedded system for a smart residential fire protection system was implemented using flame sensors and triggered via an IoT interface. In [29], simulation of gas and fire detector and alarm system with water sprinkle was done to interface with an IoT monitoring system and a sprinkler. In this research, the monitoring system incorporates three parameters (LPG, fire, and alcohol) to interface with IoT and sprinkler system, and the data are sent to ThingSpeak for IoT analysis.

III. Materials and Method

A. *Materials*

The key materials used for the system are microcontrollers (MCU), sensors, and software. ATmega 2560 MCU, mounted on a 5V Arduino board, controls the entire system. NodeMCU, a Wi-Fi-based ESP8266 System-on-a-Chip (SoC) with TensilicaXtensa LX106 core/CPU, handles the IoT-based real-time notification/alert system via website or GSM. The GSM Modem used was SIM 900, while the ThingSpeak IoT analytic platform is for visualizing the system. Arduino IDE with C language for programming the microcontrollers. The 5V TTL MQ-2 Gas sensor detects and measures the LPG and other gases. A 5V MQ-3 alcohol sensor detects alcohol gases at concentrations from 0.05 mg/L to 10 mg/L. The LM35 Temperature Sensor detects fire/heat of output range between -50°C to 150°C with a sensitivity of 10mV/°C. The sensors continue to sense the key parameters (gas, flare, and alcohol) and send a signal to the microcontrollers (MCU) for update and notify/alert to the authorized personnel/system. Fig 2 shows the regions where the circuit systems for the monitoring utility are located within the storage facility.

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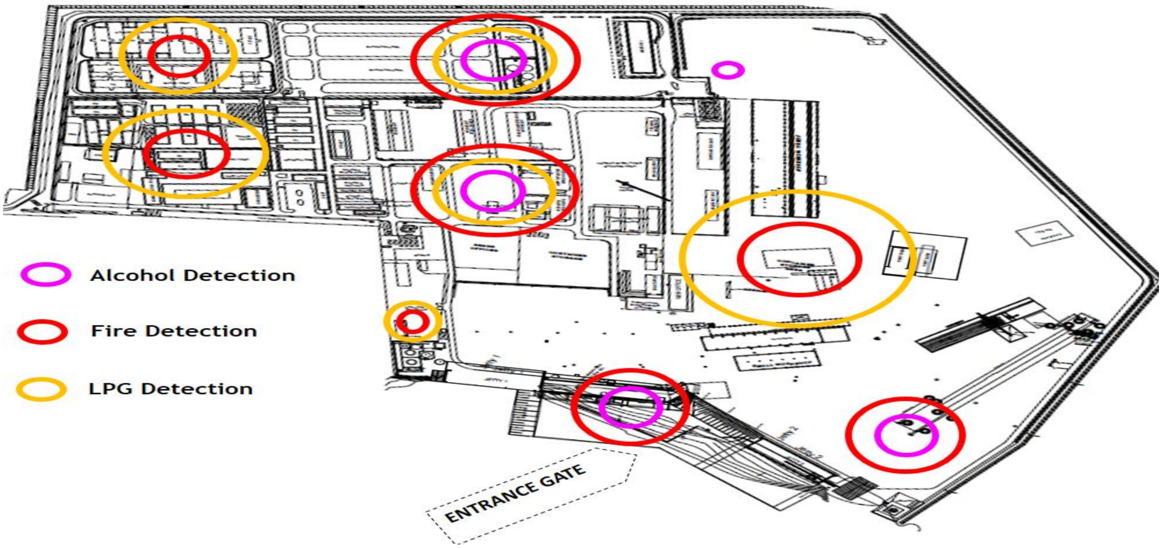

Fig. 2. The storage facility showing locations of the monitoring system.

B. *Description and Design of the Monitoring System*

Consider the block diagram shown in Fig 3(a). The monitoring system makes use of a set of sensors that constitutes a sensor module for safety management and access control in the storage facility. Three parameters, that is, LPG, fire and alcohol levels are measured. The industry's standard on the minimum threshold value for fire detection is 45℃, for alcohol is 0.03BAC and for LPG is 0.045% (4550 ppm). The system conducts safety management for protection against fire and LPG leakage within the facility, while access control is done by preventing entry of intoxicated employees at the main entrance. Break rooms and other smaller entrances in the facility also monitor employees' alcohol content as safety measures.

When an employee requires entry, a push-button is pressed to activate the MQ-3 alcohol sensor, which reads the breath of the employee. If a high alcohol level is detected, the system notifies the relevant departments, while it locks the entrance door via the servo motor until the incident is handled. When LPG leakage is detected by the MQ-2 sensors, the alarm buzzer turns on and warning alerts are sent to the relevant Departments and the employees. The LM-35 and MQ-2 sensors detect heat and smoke, which indicates fire, the system turns on the alarm and sprinkler systems, and also sends warning SMS/Email alert to the security department, the emergency and fire control department. In case of fire and LPG detection, all employees in the industry are notified via SMS to be aware of the situation and take necessary actions. The system is programmed using the Arduino C platform to integrate all data and commands from the sensors, push-button and other parts. The LM35, MQ-2 and MQ-3 sensors constantly monitor the parameters and send their data to the ATmega MCU for processing. Whenever the sensors' value reached their threshold values, the alarm mode (buzzer) activates and displayed values via Liquid Crystal Displays (LCDs). It sends all information over the internet to GSM and webpages via the GSM modules and NodeMCU, which are connected to the ATmega MCU to enable the IoT aspect of the system. Fig 3(b) shows the block diagram of NodeMCU connections. ThingSpeak IoT analytical platform is used to view the overall status of the parameters being monitored. The NodeMCU and GSM modules send status reports of the parameters to the ThingSpeak platform, to the dedicated industry's webpage, and the dedicated GSM lines of authorized employees. The live report notifies employees to take immediate safety measures from anywhere within and outside the industry premises.

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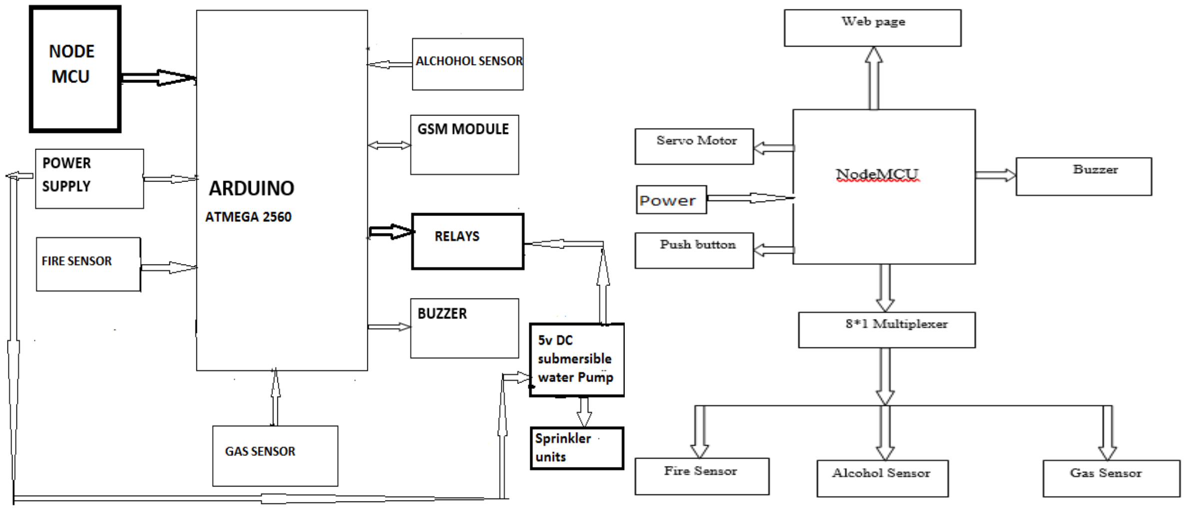

Fig. 3. Block diagram for (a) the monitoring system (b) connection to NodeMCU.

C. *Methods*

This research improved the work in [28] and [29]. The IoT adaptation was used in [28] and [29], where the authors had interfaced smaller modules consisting of only gas and/or flame sensors with associated sprinkler circuits, which was triggered via an IoT interface. However, this research used a holistic approach and implementation by embedding three sensing modules of flame, LPG and alcohol, together with the sprinkler circuit, into one integrated IoT-based system. Apart from GSM alert, this research also integrated the ThingSpeak platform and the industry's webpage for an online alert and report system, which aid safety management in the industry from any location. Also, the performance of the system was evaluated by the users for its usefulness before it was fully implemented. A statistical tool called Weighted Mean was also used to get the perception of the respondents/ employees on the system and how it monitors events. The method gives opportunities to the users to use the system and verify if the system works the way it is supposed to. The system was test-run multiple times to ensure its accuracy of event reporting and to test its efficiency in initiating the sprinkler system for fire mitigation. The equations for the MQ-2 and MQ-3 sensors are given by Equations (1) – (5). The output equations for LM35 are Equations (6)-(7), while the Weighted Mean formula is expressed in Equation (8). The pseudocode for the detection of the parameters for the monitoring system is presented in Table 1. Fig 4 shows the flowchart of the system's operation.

$$SV = SV + A_O \tag{1}$$

$$V_{out,MQ} = V_{in} \times \frac{SV}{SS} \tag{2}$$

$$R_S = \frac{V_{in} - V_{out,MQ}}{V_{out,MQ}} \tag{3}$$

$$\frac{R_S}{R_O} = \begin{cases} 9.8; & for\ MQ-2 \\ 60; & for\ MQ-3 \end{cases} \tag{4}$$

$$p = \frac{d-t}{9.48} \tag{5}$$

$$V_{out,LM35} = T \times 10\ mV/℃ \tag{6}$$

$$T = V_{out,LM35} \times 100\ ℃/V \tag{7}$$

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$$WM = \frac{\sum_{i=1}^{n} W_i X_i}{\sum_{I=1}^{n} X_i} \tag{8}$$

Where: SV = sensor value reading; Ao = analogue read of the parameter; SS = Resolution step size to discrete values in volts for the Arduino connection; Rs= sensor resistance that changes based on the gas concentration; Ro = sensor resistance at known concentration in fresh air or without other gases; Vin = input voltage; VOUT = analogue voltage reading from the sensor; p = percentage; d = digital output of the sensor's ADC; t = threshold value; T= Temperature in OC; WM = Weighted mean; Wi = number of sensors; Xi = number of SMS/Webpage alert per sensor.

Table 1. Pseudocode for the parameters detection.

1	*Initialize: SoftwareSerial mySerial();int sensor;int speaker; int sms_count; LPG_shut_val; *** Initialize sensors, IoT-interface module, LCD, push button, buzzer ****
2	*Input threshold values: LPG_alert_val, Alcohol_alert_Val; Fire_alert_val*
3	*Check status of parameters: Parameter_Status; LPG_Leak_Stat, Fire_temp_stat, Alcohol_stat*
4	*DO step (23)*
5	*Activate LPG leakage and fire detection*
6	*DO CheckFire() *** To detect fire temperature****
7	*WHILE Temperature detected >= 40^{O}C*
8	*Repeat step (8) and (9);*
9	*Activate sprinkler;*
10	*DO step (20) to (22)*
11	*ELSE DO CheckLPG() ***To detect LPG Leakage****
12	*WHILE LPG detection >= threshold,*
13	*DO step (20) to (22)*
14	*ELSE GO TO step (22)*
15	*Push button()= 1, ***activate alcohol detection****
16	*IF Alcohol level detected < 0.02,*
17	*Open door*
18	*DO (22)*
19	*ELSE*
20	*Lock door, DO (20) and (22)*
21	*Activate buzzer*
22	*Display status on LCD*
23	*Generate and Send parameter status through the website and dedicated GSM line*
24	*EndIF*
25	*Terminate*

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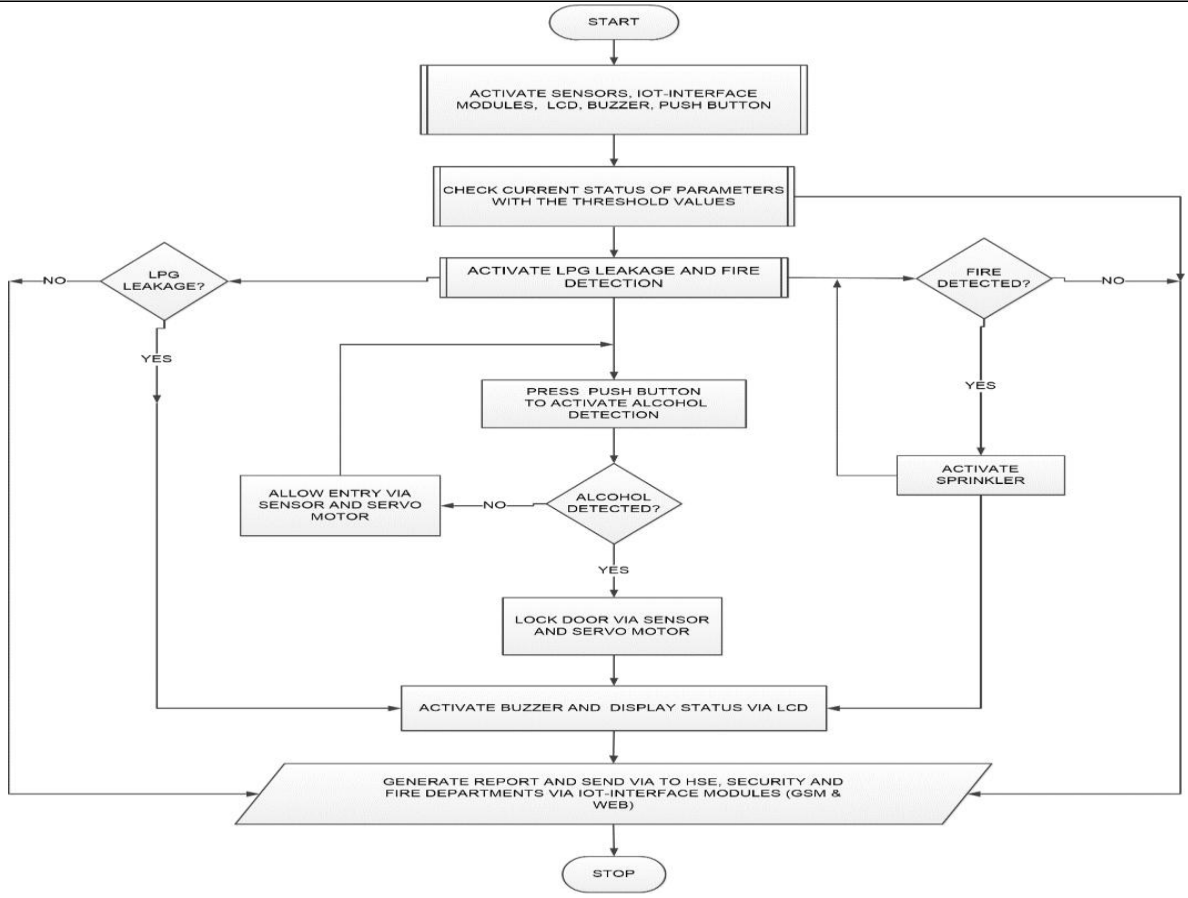

Fig. 4. Flowchart of the IoT based monitoring utility system.

IV. Results

The research was based on [28] and [29], that monitor and detects fire and/or gas. However, in this research, three parameters were monitored with sensors modules, and then status reports are sent to authorized departments for necessary actions. Fig 5(a)–(c) show the test-run of the MQ-3, MQ-2 and LM35 sensors interfaced with the ATmega MCU with the output readings displayed on the LCD and indication lights. The ATmega MCU send a 1 (HIGH) signal when the threshold value is reached to activate the buzzer and IoT modules. Fig 6 shows the SMS/text messages received by employees whenever there are LPG leakage and fire outbreak respectively. The employees receive the SMS through their dedicated GSM phone numbers on their mobile devices. The SMS and alarm create safety awareness for employees to rapidly leave the premises to safe muster points and also alert the management team of the status of the storage facility thus this system increased the safety of the employees within and outside the storage facility. Fig 7 shows the ThingSpeak interface, while Fig 8 shows the industry's automation control interface. The interfaces shown monitored statuses of the parameters and are accessed through the Internet. The industry's management, from any location in the world, used the Web interfaces to get accurate status reports and statistical measurements of the numbers of LPG, fire and alcohol incidents and safety responses. The various reports were used as data to conduct safety measures, facility's access control, employees' training schools and for the improvement of the entire facility. Due to this monitoring agent and associated utility, the HSE department reported a 90% drop in injuries and other safety issues related to LPG leakage, fire, and intoxicated employees showing up at work. The industry was able to improve its safety management and access control in its storage facility.

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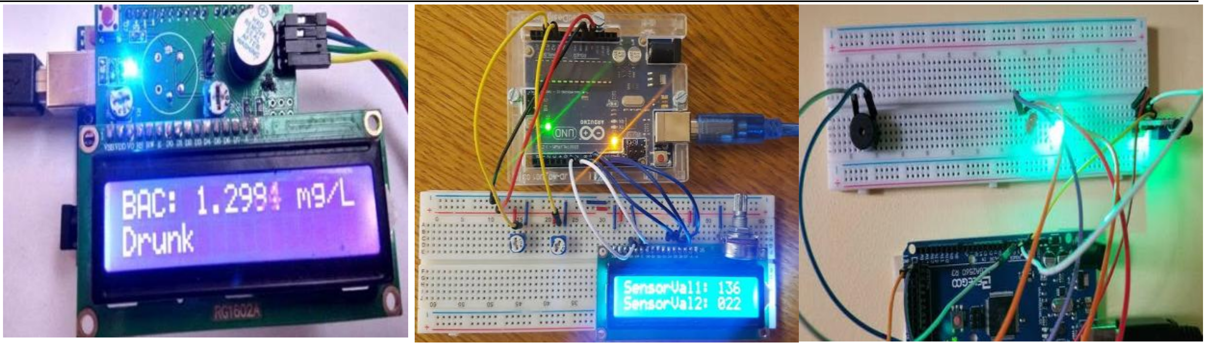

Fig. 5. Testing of the Alcohol, LPG and Fire sensors interfaced with the MCU.

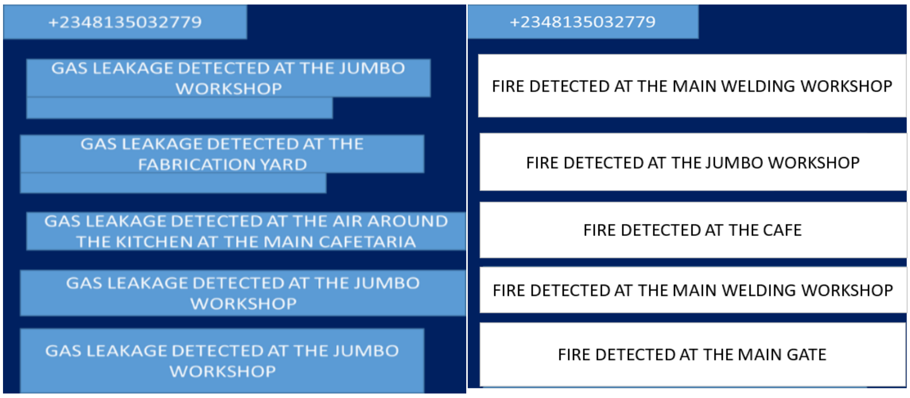

Fig. 6. Live SMS Alert received via dedicated GSM line.

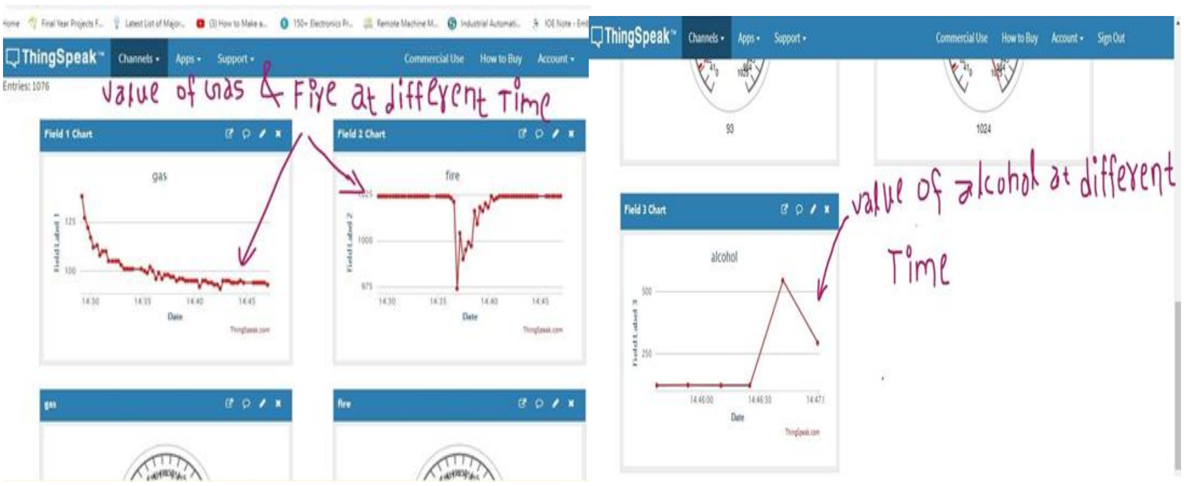

Fig. 6. The Industry's ThingSpeak interface for the monitoring system.

Fig. 7. Automation Control Interface.

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V. CONCLUSION

This research focused on the design and implementation of the IoT-based monitoring utility system for access control and safety management in a storage facility of an industrial plant. The monitoring system activates an alarm buzzer and gives out live SMS and Webpage alerts whenever LPG leakage, fire outbreak and high alcohol level are detected. When a fire occurs, the system also turns on the sprinkler system, as a mitigating factor, to douse the initial flame and reduce the fire damage. The results of the monitoring system, accidents and other HSE-related issues were minimized in the storage facility of the industry. Fire incidences were reduced due to rapid real-time time warning via a dedicated GSM line and Webpage, also, intoxicated employees were detected and denied entry into the facility. Through text and/or email alerts, real-time events and safety history events can be communicated to safety and security managers. The ThingSpeak IoT analytics platform enabled management to analyse the incidences and make data-driven decisions, to identify trends, find training opportunities and improve employee behaviour, therefore improving the safety management in the industry.

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