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Original Article

Development and Deployment of A Smart Electric Mud Pump

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Abstract *- This research is aimed at the development and implementation of a state-of-the-art mechanism which will enable real-time observation of gases around the drilling rig plus the management of a mud pump to boost the inception of well management measures, the measures plied in drilling activities to preserve the hydrostatic pressure in the well so as remedy the issue of susceptibility of personnel to harmful gases around the drilling rig as well as forestalling blow out thus preserving lives and equipment exploiting a provided IoT platform. The segmental technique was employed to achieve the aim of the research. These materials: microprocessor ESP32, pump, sensors, MQ-2, MQ-8, IoT SDK kit and a laptop were interlinked for the study. The microprocessor was programmed with C++ to interlink the separate sections and inked with the IoT to build the platform for management. The built set-up was implemented and test run. From the test run, it was found that the entire system, including the Losant suite, functioned according to the design aim.*

Keywords *- IoT, Mud, Pump, Losant, Gas, Rig.*

1. Introduction

Mankind has always found wealth on the surface of the earth and underneath. The wealth is mineral resources like oil, gas, brine and water [1]. Accessing this wealth safely has always been a challenge in the exploration industry [2]. The drilling rig is one of the machinery developed and used in the exploration of crude oil in oil companies. The mud pump is a major component of the drilling rig. It is a reciprocating piston designed to circulate drilling fluid under high pressure down the drill pipe and back up through the annulus. The mud pump has two sub-assemblies: the fluid section and the power section. The fluid section creates the pumping operation with faucets, cylinders and other components. The power section transforms the revolution of the propeller to the swapping movement of the cylinders. The mud pump is rated in horsepower. The chosen mud pump must be able to deliver mud flow frequencies that are substantial enough to convey drill flakes outside at every phase of drilling and also capable of providing pressure that is strong enough to overcome the total pressure loss and pressure drop in the circulating system of the total hole depth.

Well control is the strategy employed in drilling operations such as well work-over and well completions for handling the hydrostatic force [3]. Shutting down of mud pump and closing the annular preventer are key actions taken during well control situations. But, before the annular preventer is closed, the pump must be shut down to initiate well control operations. The annular preventer has three points of control: the rig floor, the Koomey unit and the Tool pusher's office. This makes it possible to operate the blowout preventer from a safe area within the rig site, unlike the mud pump that has just one point of control, which is on the driller's console. So operating the pump during a well control situation becomes very difficult as the driller's console is the heart where the uncontrolled release of gases is. The gases are hazardous to the health of the personnel, and if left uncontrolled, this could lead to loss of lives and properties of the oil company as well as damage to its reputation.

Companies in the drilling industries have continually strived to produce crude oil and refined products at a lower cost and to extend the existing value of their assets. Ecological benchmarks are getting more strict needing candidness in procedures and stiffer supervision on commercialization. In the past decades, there has been a huge incentive to improve efficiencies and reduce downtime due to injury, blowouts, and loss of equipment and assets. Oil and gas enterprises own several distal valuables that need superintendence, they have utilized some traditional monitoring methods like satellite communication, physical monitoring and programmable logic controller systems. These methods have their benefits and disadvantages. Satellite communication requires numerous communication links to deliver information; physical monitoring takes substantial effort and manpower.

This research aims to design and develop a system that will remotely control an electric mud pump based on some preset values of the concentration of some gases measured in real-time in a rig to prevent blowouts and other mishaps so as to protect lives and equipment. The work was realized following some set objectives:

- Designing a control system that monitors and notifies operators of the presence of highly dangerous gases within the rig plus automatically shut down the mud pump to enhance the initiation of well control processes to prevent blowouts and save lives and equipment
- Leveraging the Internet of Things (IoT) to communicate between the rig environment and an office where the values of the concentration of the gases are displayed in real-time.
- Deploying the designed system after a proven functionality test on it in a rig.
- Carrying out analysis of the test result for the prediction of possible blowouts and other mishaps to operators within the rig.

Since the emergence of Internet of Things (IoT) technology over a decade ago, some oil and gas enterprises have keyed into the technology to consolidate their connections further. This work will utilize the capabilities of the Internet of Things platform, real time monitoring and control of the mud pump in the drilling site. This work will be realized with the following components: microprocessor ESP32-S, low power on a chip integrated with RF components, pump, sensors MQ-2 and MQ-8; these measure the released gases within the drilling environment, voltage regulator, bridge rectifier, power supply module, IoT losant SDK kit, mobile phone or laptop equipped with Wi-Fi technology. The microprocessor will be programmed using C++ programming language. The programmed microcontroller unit interfaced with the various modules and interlinked with the IoT to create the Losant platform that initiates the real-time monitoring and control of the mud pump.

In this work, the mud pump will be remotely controlled during well control situations, and anytime the need to turn OFF and ON the mud pump arises, use the Internet of Things-based app on our mobile phone or laptop from the office. The project consists of smart sensors that sense gases such as oxygen, Hydrogen, Carbon monoxide, and Hydrocarbon gases. The various gas values are processed by the microprocessor and transmitted by the scheduling unit. From the mobile app in the office, these gas values are viewed, and the pump is controlled by the operator when the uncontrolled release of hydrocarbon has reached a dangerous level to initiate well control operation and also by itself when these values reach a dangerously high value of 300 ppm. With this control from a safe area, the driller can quickly leave the console and move to a safe area for further well control operations to take place. Several works have been done in different aspects of industrial equipment smart control in remote operational locations to avert hazards associated with the nature of their operations using modern technologies like wireless sensors, Wi-Fi and Internet of Things (IoT).

Drilling in the North Sea is confronted with challenging pressure-management issues because of narrow geo-pressure windows in depleted reservoirs. Also, the occurrence of packoffs caused serious damage to the formation and contributed to nonproductive time. To deal with these issues, mechanization of mud-pump control was developed to reduce the possibility of rupturing the structure as the mud pumps are being turned on or when rotating. [4] automated the mud pump to address these challenging pressure-management issues and packoffs encountered in the North Sea. Higher momentary temperatures with hydraulic prototypes were employed to evaluate, in real-time, the downhole condition.

Based on the latest state, valuations of maximal pump speeds, in addition to suitable gush velocities, were conducted and conveyed to the pump's controller, which was utilized as a capsule of conservation. In addition, to aid the driller during interconnections, the pump's powering-on process was semi-automated to reduce the period of connection. Outside the mud pump automation, other aspects of the drilling processes have been automated to improve quality and process efficiencies.

In cementing operations automation, the Cognitus Automated Cementing Platform, allowed an operator to control an offshore cement unit from onshore and fully automate the delivery of the job. The platform includes two main features remote-controlled functionality and automation [5]. These features permit the execution of coastal cement work with high efficacy, lower cost, and less exposure to hazards on the drilling site, which marks an important step towards carbon footprint reduction.

The remote-controlled utility of the Cognitus base binds the rig's cementing gadgetry as one [6]. The offshore cement unit's hand-operated controller, valves, and subsidiary gadgetry were fitted with automated controls and wired to PLC regulators to enable the setup to be managed by a Human Machine Interface (HMI). The HMI is duplicated ashore and enables the handler in a Real-time Onshore Center (ROC) to carry out the same operations ashore as inshore [7]. Remote capacities allow the centralism of experienced personnel to provide enhanced real-time oversight onshore. Additionally, because remote automated cementing capability can reduce the number of operators offshore at the rig site, that can also reduce exposure to the inherent risks present at the well site.

In downhole drilling automation, with the increase in well complexity, there is a problem harmonizing the real well model with the designed well model. A procedure automatizing the Bottom Hole Assembly (BHA) to accept rectification upon the discovery of a departure from the designed well track in a 3D coordinate area was developed [8]. The corrective paths may be orthodox fixed curvature curves and unothordox curves, like catenary and spline, that are proven to be smooth, thus lowering the rotational force and pull in the well.

The major restraint guiding the undefined details of the corrective route is the least well model energy standard, which is exceptional with regard to generating curves in that it reduces the curvature and torsion of the curve. A preceding study on downhole drilling automatization shows that the least energy approach juxtaposed with Proportional, Integral, and Derivative (PID) control and fuzzy control, in which the prototype was modelled for 2D and 3D coordinate area by taking into account orthodox fixed curvature curves for amendment provides more even wellbore courses. The study was extended to unorthodox well models in 2D wells, in which spline, catenary, and clothoid curves were employed to revert the veered well to the initially intended route [9].

In drilling fluid systems, an industry where the need for precision is ever propelling the reappraisal of verified traditional technologies, typical drilling fluid systems predicated on manual operations increase the risk of imprecision in the mud-mixing process. They also influence mud quality, increasing the handler's contact with chemical agents in addition to different dangers, thereby making the entire process more liable to human failure. The integration of automatized approaches within drilling solution commingling guidance setup offers prospects for significant enhancement in workers' protection and mud grade along with higher efficacies in asset utilization [10].

Ensuing from comprehensive field tests with automatized mud commingling setups in the North Sea, the efficacy-based response from the Valhall Water-Injection Platform (WIP) illustrated that an automatized approach can outturn practicable advantages. Not only was there an improved technical process, but there also was a potential increase in operational efficiency and stability because automation reduced both opportunities for human error and the operator's contact with hazardous chemicals [11].

The knowledge gained from the Valhall WIP established that a highly automatized drilling solution setup could deliver a highly efficacious commingling, minimize the gross environmental effect and offer aid for expense gleanings through the lowering of personnel demands. Automatized drilling equipment are guidance setups plied in accomplishing several drilling operations automatedly, from well ground work and blueprint to downhole activities.

This equipment restrains human mediation all through the drilling operation, thus effecting a securer and effectual operation. IoT-based sensors help in supervising the drilling process in real-time, recording vibrational numerical information, state of the paddle bit, downhole temperatures, and rock features, among others [12, 13]. They also aid in raising operative efficacy in addition to lessening the gross drilling budget. Apart from these, IoT has other areas where it is applied. The IoT technology is nothing new and has been used in Data processing, automotive, healthcare, aerospace, biomedical, fleet management, smart grid and energy saving, hospitality, traffic monitoring, smart homes and the downstream side of oil and gas.

In data processing, [14] proposed a new data processing model that allows you to build mobile IoT systems. He saw that cloud computing, which has been used for providing services for years, is not a solution for big modern networks that contain multiple distributed devices and produce huge amounts of data. In situations like this, prevailing data-optimizing templates predicated on cloud technologies are affected by slowness. To subdue this issue, he placed fog nodes in the vicinity of IoT gadgets and many problems were solved.

[15] carried out research using a Heuristic approach to examine theoretical aspects of IoT applications in service sectors. They used IoT tools to analyze and process services of airline operations in the airport. [16] carried out an investigation using an IoT approach to evolve a scheme that links noninvasive appraisal sensor information with real-time optimizing subroutine on an IoT kit/courseware device to offer prognosticative competencies for effectual information optimizing allied to SHM.

The proposed industrial IoT approach consisted of three elements: the Cloud, the Fog, and the Edge. The cloud was utilized to stow previous information, including executing tough calculations like offline machine learning. The Fog is the equipment that implements real-time analysis employing data acquired both from detection and the cloud. The Edge is the lowest limit equipment that captures information at the sensor stage. In this study, an implementation of this method to assess the health status of an aerospace rank hybrid article at test bed state was presented.

[17] built a new IoT-dependent healthcare scheme allied with WBANs and RFID technologies for hospital information systems. The designed framework was modeled and simulated using Riverbed Modeler software. The outcomes reveal that the QoS yardstick for bitrate and lag specified by the ISO/IEEE 11073 benchmark is met by plying the projected energy-aware scheme. It is well established that a number of surveys considered in the hospital info scheme could be readily achieved through the projected approach of devising an efficient replicative medium.

2. Materials and Method

This work proposes a design to address the hazardous nature of drilling rigs. Recent publications by the Occupational Safety and Health Administration stipulate that exposure to 400ppm of natural gas for 3 hours could cause headaches. At 800 ppm, symptoms of dizziness and nausea could be seen among personnel in 45 minutes. To guarantee the safety of workers, this research was conceived. Herein, the set limit for the pump to shut down to enable well control processes to kick in is 300 ppm. This will enable workers to work safely in a conducive environment. The step-by-step modular method has been employed in the development and deployment of the system, which comprises both hardware and software sections alongside the implementation of the IoT infrastructural platform to:

- Initiate smart control of the mud pump from a remote control center during a good control situation to enable well control procedures to be carried out. With this, the driller and the rig floor personnel can leave the rig floor, which is the centre of the hazardous gases. The gases will be monitored in real-time, and the pump is configured to automatically shut down when the LPG gas value goes beyond 300 parts per million (ppm). There will be real-time monitoring and control of activities in and around the drilling rig.
- Construct a prototype of a smart mud pump with IoT capabilities to simulate its functionality at the drilling rig site.

2.1. System Structure and Theory of Operation

The architecture of this work consists of six layers: the perception layer, network layer, middleware layer, Application layer, business layer and cloud. In the perception layer, we have the sensors MQ-2 and MQ-8 that help to sense the gases, Liquefied Petroleum Gas (LPG), Hydrogen, Smoke, and Oxygen. The network layer is the connecting layer between the perception and middleware layer.

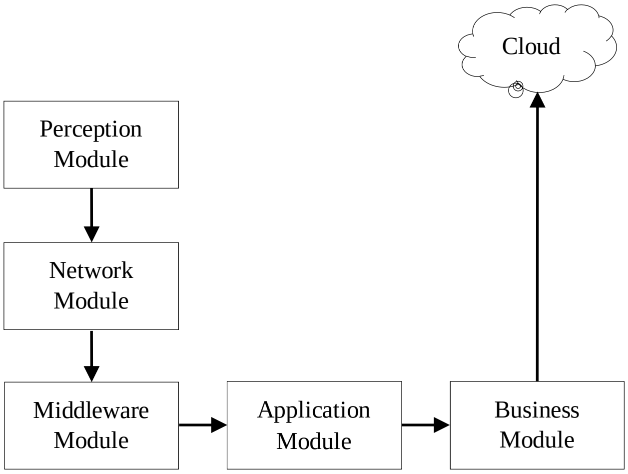

Fig. 1 Block diagram of the system structure

It gets data (various gases present and their concentrations on the rig) from the perception tier and passes these data to the middleware layer employing networking technologies such as 3G, 4G, UTMS, Wi-Fi and infrared. The Middleware Layer houses the (Microcontroller ESP32-S), and it possesses various state-of-the-art attributes such as storage, computation, processing, alongside execution capacities.

It stores all data-set, and depending on the gadget's location, it supplies relevant data to that gadget. The Application layer (microcontroller ESP32-S) manages all application processes depending on the information received from the middleware layer.

2.2. The Hardware Section

The hardware section of the design was realized with these components and materials which were adroitly interfaced- MQ-2 gas sensor, MQ-8 sensor, ESP32-S microcontroller, Wireless802.11 MAC standard, Losant IoT SDK, Adapter Wi-Fi cable, Mud pump, Step down transformer 220/15v, Voltage regulator (LM7805), Bridge rectifier circuit, Capacitors, Transistors, Relays, Diode, Resistors, Laptop, Mobile phone, 12volts, lithium battery, Arduino board, breadboard, Casing, C++ programming language was used to program the microcontroller ESP32-S.

2.3. The Software Section

The software section entails the software design and implementation/programming of a robust microcontroller with the ability to communicate over IEEE802.11 wireless standards for Media Access Control (MAC) and through the physical layer protocol to implement the cloud technology, creating a more intuitive web-based dashboard using the capabilities of IoT platform for effective monitoring and control of the mud pump in the drilling location.

The microcontroller that will interface the various units of the system is programmed with C++ programming language. Shown in Figure 3 is the conceptual flowchart for control of the mud pump, and shown in Figure 4 is the flowchart for the wireless control of the designed smart mud pump system.

2.4. Working Principle of a Smart Mud Pump

When the device is switched ON, power flows in it. The relay introduced into the power pack is basically to interface between the battery and mains supply. If the utility supply fails, the battery supplies the system until power is restored. This function improves the system's performance. +5V regulator is connected to the common of the relay to further fix the voltage and further smoothen the V_{dc} in other to obtain a perfect DC.

The perfect DC is used to power the main circuitry, transmitters' circuit, and receivers, respectively. The control unit, through its I/O pins, sends a signal to control the relay setup, which is designed to control the pump.

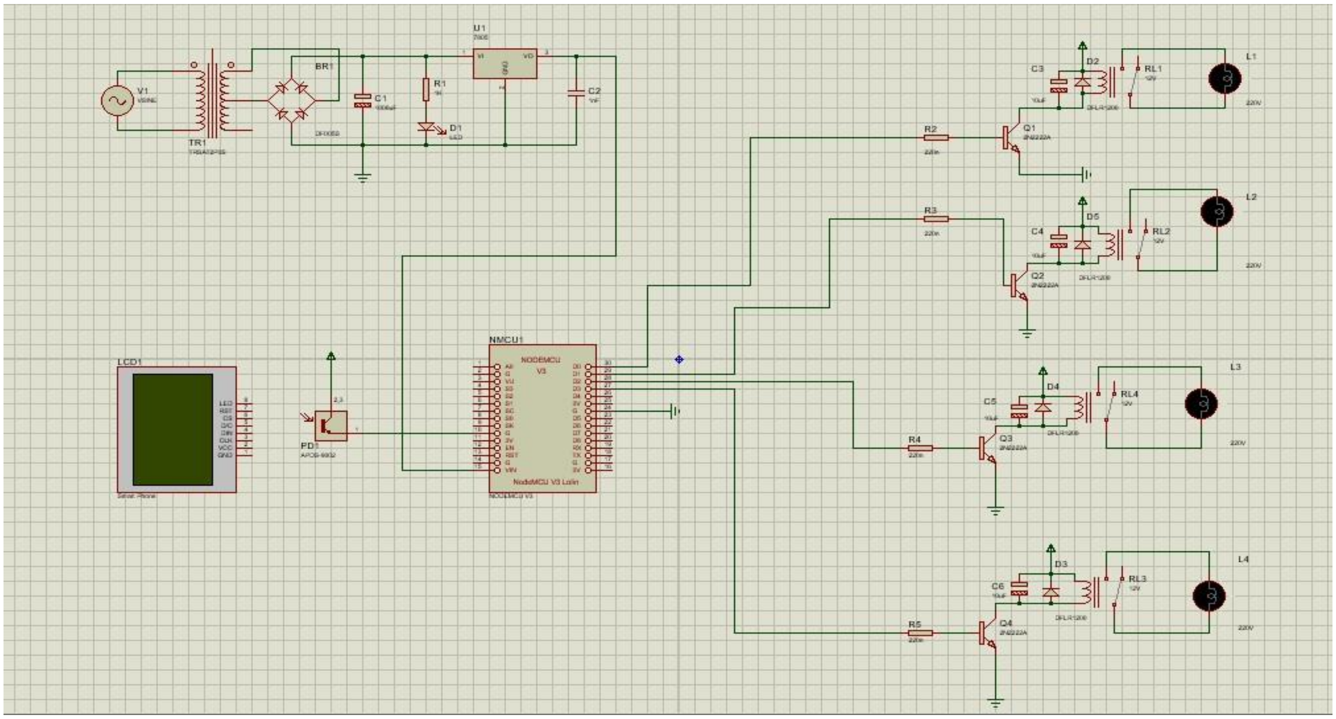

Fig. 2 Complete circuit diagram of the hardware section of the developed system/prototype

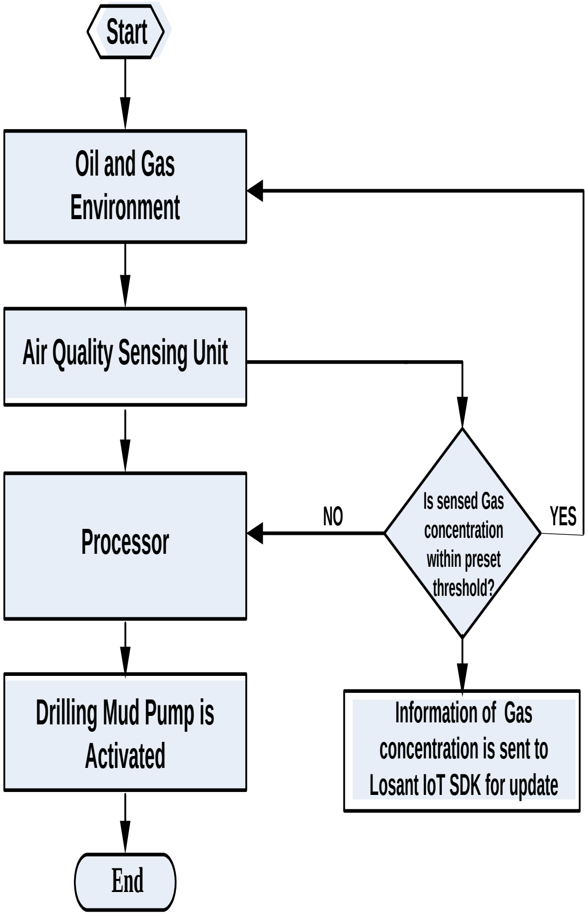

Fig. 3 Conceptual flow chart for the control of mud pump

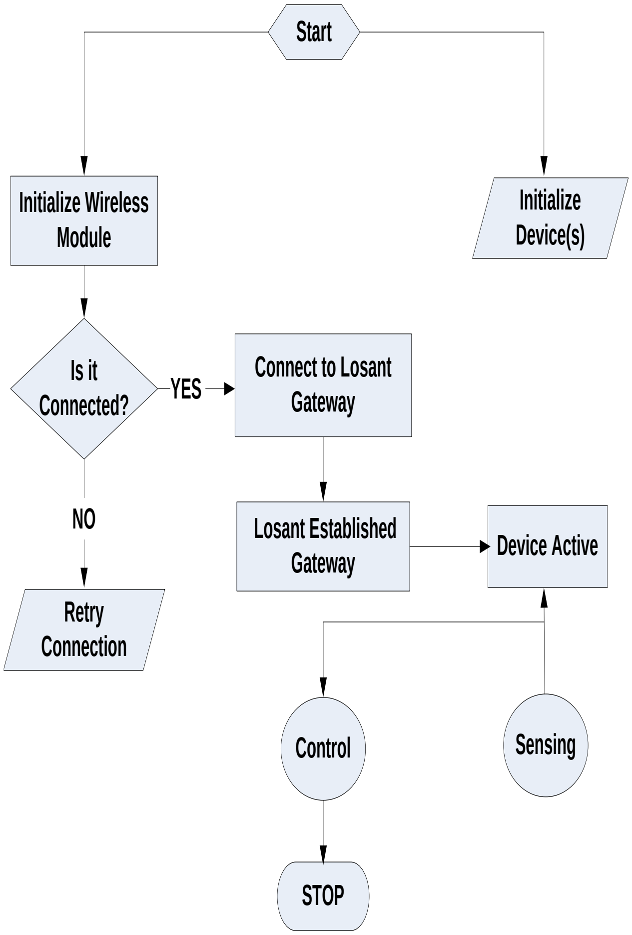

Fig. 4 Losant flow chart for wireless control of mud pump

Each relay is switched by a transistor circuit when the pump control on the web client is operated. Depending on the status of the pump at the time of operation, the pump can be switched ON or OFF from quite a remote distance.

2.5. Experiment

For experimentation, a prototype of the system was built. It comprises components like ESP32-S microcontroller as its memory chip as well as the communication module. Other components are the MQ-2 and MQ-6 among others. For the mud pump, a piston air compressor was employed.

The mud pump was connected to the system via a relay, which was connected through the I/O pin of the system. The various units of the system were interfaced and the whole arrangement was linked to the cloud so that real-time information could be transmitted and viewed on the Losant platform installed on a computer using Wi-Fi.

2.5.1. Experimental Procedures and Observations

- The system was set up and switched on; the mud pump was automatically turned on.
- Losant platform was turned on and observed for a few minutes, but no abnormal gas concentration was displayed.
- A small quantity of LPG contained in a cylinder was released; the sensors sensed the presence of LPG, and the Losant platform was updated in real-time, but the mud pump was still running as the concentration of LPG was still below the preset threshold.
- Further release of LPG was done, and the Losant platform was updated in real-time, but the pump was still running.
- More release of LPG was done until the concentration of LPG in the surroundings reached the preset threshold of 300ppm, as displayed by the Losant platform in real-time. The mud pup was automatically shut down at this stage.

The same experiment was conducted using hydrogen gas, smoke, and carbon monoxide. The mud pump shut down automatically at their different preset thresholds as displayed by the losant platform in real-time.

3. Results and Discussion

From the development and deployment of the smart mud pump as well as the losant platform for the smooth monitoring and control of the drilling rig operations, the various data of gases were measured and collected from the sensors in the integrated platform, and these are presented and analyzed using descriptive statistical methods in Figures 6, 7, and 8.

3.1. Data Presentations

Data presented in Tables 1, 2, 3 and 4 are the various types of gases and the concentrations measured in real-time from the losant platform in the control room for every half-hour interval for five hours per day. The variation of the various gases with time and the peak gas time can easily be noticed.

3.1.1. Liquefied Petroleum Gas

Table 1. Measured LPG values from the smart pump prototype

S. No.	Time	Concentration (ppm)
1	30m	25
2	1hr	50
3	1:30hr	80
4	2.0hr	120
5	2:30hr	90
6	3.0hr	80
7	3:30hr	100
8	4.0 hr	150
9	4:30hr	280
10	5.0hr	300

3.1.2. Hydrogen Gas

Table 2. Measured H_2 values from the smart pump prototype

S. No.	Time	Concentration (ppm)
1	30m	50
2	1hr	70
3	1:30hr	95
4	2.0hr	40
5	2:30hr	85
6	3.0hr	158
7	3:30hr	0
8	4.0 hr	250
9	4:30hr	54
10	5.0hr	300

3.1.3. Smoke

Table 3. Measured smoke values from the smart pump prototype

S. No.	Time	Concentration (ppm)
1	30m	100
2	1hr	174
3	1:30hr	99
4	2.0hr	150
5	2:30hr	246
6	3.0hr	230
7	3:30hr	233
8	4.0 hr	167
9	4:30hr	198
10	5.0hr	200

3.1.4. Carbon Monoxide (CO)

Table 4. Measured CO values from the smart pump prototype

S. No.	Time	Concentration (ppm)
1	30m	20
2	1hr	45
3	1:30hr	90
4	2.0hr	143
5	2:30hr	243
6	3.0hr	254
7	3:30hr	132
8	4.0 hr	255
9	4:30hr	276
10	5.0hr	298

3.2. Discussion

From the losant platform, the various gases and their concentrations are calibrated from 0 – 1000 ppm. The maximum threshold they reach to become hazardous to the personnel is also specified. The various gases and their thresholds are discussed as follows:

3.2.1. LPG

The calibration for this gas is from 0ppm -----200 ppm ----300ppm-------- 1000ppm. From 0 ppm to 200ppm range, gas concentration is acceptable and normal drilling can continue. At a dangerously high value of 300ppm and above, the mud pump shuts down automatically for the well control procedure to take place. For liquefied petroleum gas, which is our main focus, the maximum threshold is 300ppm.

3.2.2. Hydrogen (H_2) Gas

The calibration for this gas is from 0--- 500 ppm --- 750ppm ---- 1000ppm.From 0 ppm to 500 ppm, normal drilling can continue. The maximum threshold is 750 ppm. Any concentration of hydrogen gas above this threshold automatically shuts down the mud pump from the control room to initiate the well control process.

3.2.3. Smoke

The calibration for this gas is from 0--- 400ppm ---- 1000ppm.The threshold is 400 ppm; any concentration of smoke above this threshold becomes very unsafe for personnel and needs the muster at a safe place.

3.2.4. Carbon Monoxide

The calibration for this gas is from 0--- 400ppm ---- 1000ppm.The threshold is 400 ppm; any concentration of carbon monoxide gas above this threshold becomes very unsafe for personnel and needs the muster at a safe place.

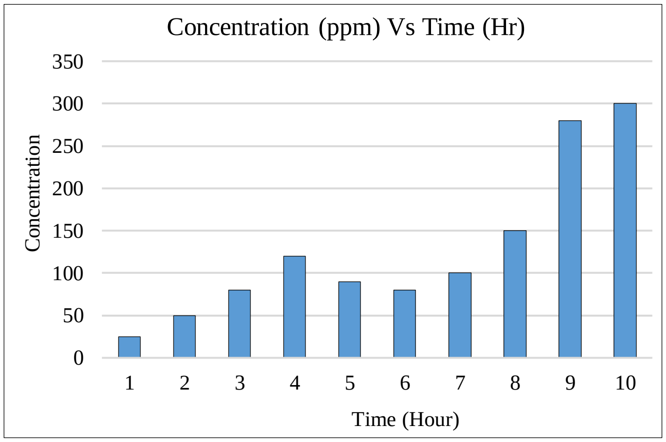

Fig. 5 A graph of time versus gas concentration

Tables 1 to 4 and Figure 5 reveal that for all the gases monitored and measured, their concentration increased with time. This clearly depicts that the duration of exposure of personnel to the gases is directly proportional to the level of hazard. The designed system is, therefore, very useful in shutting down the mud pump when the concentration of these gases reaches a preset threshold so that well control processes can commence and personnel safely evacuated to a safe place. Shown in Figures 6, 7, and 8 are the various gases and their concentration in ppm captured in real-time from the integrated platform.

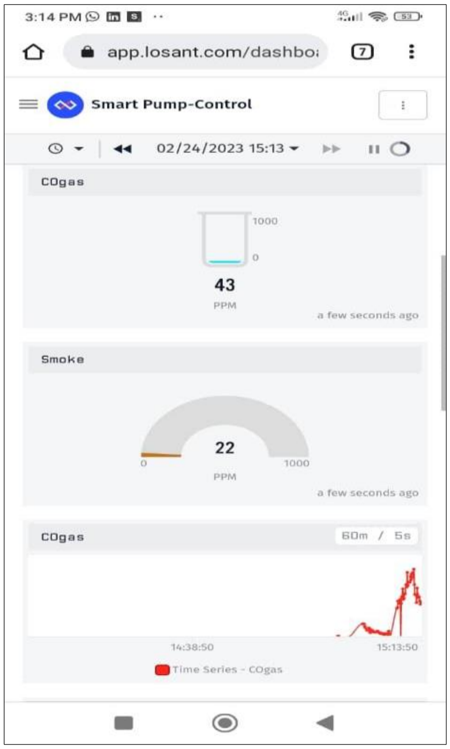

Fig. 6 Losant interface showing the descriptive statistical representation of the gases with time

Fig. 7 Losant interface showing a descriptive statistical representation of the gases and the soft control point for the smart pump

Fig. 8 Losant control room interface showing the variation of the gases being monitored in graphical form and a statistical representation of all the gases

From the losant integrated interface in the control room during testing of the prototype smart mud pump, the raw data received from the sensors are presented descriptively in Figures 6, 7 and 8. In Figure 6, the date of logging graphical and statistical representations of the concentration of smoke and carbon monoxide in the atmosphere with time is clearly shown. In Figure 7, the graphical and statistical representation of smoke and Hydrogen and the soft control of the pump when the gases reach a dangerous level are clearly shown. Figure 8 depicts all the gas concentrations being compared and the graphical representation of the concentration of liquefied petroleum gas and carbon monoxide.

4. Conclusion

The system was developed and deployed using IoT capabilities to initiate control and real-time monitoring of gases in and around the drilling rig to prevent loss of lives properties, and damage to the company's reputation. The system was achieved with these components: ESP32-S microprocessor integrated with RF components, pump, sensors MQ-2 and MQ-8, IoT SDK Kit, a mobile phone and a laptop equipped with Wi-Fi technology.

The microprocessor was programmed using the C++ programming language to interface the various units with the IoT losant platform. Upon the integration of the various modules of the system, the platform was put into use. From the losant platform dashboard in the remote control room, real-time measurement of gases in the drilling environment and control of the pump were carried out effectively. The developed prototype smart mud pump was tested, and it worked in line with the design specifications.

References

[1] Nabil Mohammed Al-Areeq et al., "Petroleum Source Rocks Characterization and Hydrocarbon Generation," *Recent Insights in Petroleum Science and Engineering*, IntechOpen, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[2] Zeyad Hassan, "Common Drilling Well Problems (Reasons, Indications, Mitigation and Prevention)," 2018. [Google Scholar]

[3] CNPS.COM, Well Control - Causes, Indicators, and Preventative Actions of Kick, 2022. [Online]. Available: https://www.cnps.com/well-control-causes-indicators-and-preventative-actions-of-kick/

[4] Eric Cayeux, Benoît Daireaux, and Erik Wolden Dvergsnes, "Automation of Mud-Pump Management, Application to Drilling Operations in the North Sea," *SPE Drilling & Completion*, vol. 26, no. 1, pp. 41-51, 2011. [CrossRef] [Google Scholar] [Publisher Link]

[5] Vildan V. Abdullin et al., "IoT-Based Approach to Industrial Equipment Condition Monitoring: Wireless Technology and Use Cases," *2020 Global Smart Industry Conference (GloSIC)*, Chelyabinsk, Russia, pp. 399-406, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Afif Jadalla Al Mghawish, "A Practical Approach for Mobile-Based Remote Control," *European Scientific Journal*, vol. 9, no. 18, pp. 194-201, 2013. [Google Scholar] [Publisher Link]

[7] Mohd Sabri Minhat et al., "Human Machine Interface for Research Reactor Instrumentation and Control System," *Research and Development Seminar*, vol. 43, no. 26, 2010. [Google Scholar] [Publisher Link]

[8] R. Desbrandes, and P. Mori, "Advances in Remote-Controlled Drilling," *Journal of Canadian Petroleum Technology*, vol. 21, no. 6, 1982. [CrossRef] [Google Scholar] [Publisher Link]

[9] Chong Ke, Dongzuo Tian, and Xingyong Song, "Down-Hole Directional Drilling Dynamics Modeling Based on a Hybrid Modeling Method with Model Order Reduction," *Journal of Energy Resources Technology*, vol. 143, no. 10, pp. 1-11, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] S.C. Magalhães et al., "Development of an Expert System to Remotely Build and Control Drilling Fluids," *Journal of Petroleum Science and Engineering*, vol. 181, pp. 1-8, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[11] Nediljka Gaurina-Međimurec et al., "Deep Underground Injection of Waste from Drilling Activities-An Overview," *Minerals*, vol. 10, no. 4, pp. 1-29, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[12] Mobolaji Aduramo Sodunke et al., "Design and Construction of a Two Channel Microcontroller Based Remote Control for Switching Electrical Appliances," *ABUAD Journal of Engineering Research and Development*, vol. 3, no. 1, pp. 76-82, 2020. [Google Scholar]

[13] Steven R. Thompson, and Harbour D. William, "Remote Mud Pump Control Apparatus," *United States Patent 4595343*, 1986. [Publisher Link]

[14] T.T. Aunga et al., "Data Processing Model for Mobile IoT Systems," *Procedia Computer Science*, vol. 186, pp. 235-241, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[15] Güzide Karakuş, Emre Karşıgil, and Leyla Polat, "The Role of IoT on Production of Services: A Research on Aviation Industry," *Proceedings of the International Symposium for Production Research*, pp. 503-511, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[16] Sarah Malik et al., "The Industry Internet of Things (IoT) as a Methodology for Autonomous Diagnostics in Aerospace Structural Health Monitoring," *Aerospace*, vol. 7, no. 5, pp. 1-13, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[17] Faruk Aktas, Celal Ceken, and Yunus Emre Erdemli, "IoT-Based Healthcare Framework for, Biomedical Applications," *Journal of Medical and Biological Engineering*, vol. 38, no. 6, pp. 966-979, 2018. [CrossRef] [Google Scholar] [Publisher Link]