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Application of the Internet of Things (IoT) for Development of Fire Monitoring System

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ABSTRACT

The internet of things (IoT) has witnessed substantial to have significant potential in monitoring and management of high-risk environments, and Safety industries. In the past decades, urbanization and industrialization have been expanded in the area east of the Gulf of Suez increasing health and safety issues. Attentions increasingly were paid to monitoring and management of these hazards that affect human health. One of these major health hazards in industrialization areas is a fire hazard. Besides, this background, the present research developed an internet of things (IoT) based safety model to provide real-time monitoring of fire monitoring and management. Accordingly, a multifunctional monitoring platform in the present work was developed for reducing fire hazard levels in the Ras Gharib area, Egypt. The integration of the programmable logic controller with supervisory control and data acquisition will be implemented for controlling the operating parameters of the firefighting system. Furthermore, the developed model not only identifies real-time fire hazard problems (i.e., near misses or reduced fire accident rates) but to stores the digital database to improve the system itself. Our finding indicates that developing systems for comprehensive network communication based on online management and information tracking devices and technologies would improve and monitor the firefighting system.

1. Introduction

The Internet of Things (IoT) has become one of the most powerful tools for communication paradigms and attracted many scientists and research interests in the 21st century (Gope et al. 2016; Wu et al. 2017). The pervasiveness of IoT makes the activities of every day easier and enhances the connection properties of humans (Ammar et al. 2018; Sai et al. 2019). However, the personal and portable measurements of environmental pollution devices are required in some workplaces, The IoT brings tracking services and real-time management for pollutants. Among the pollution risks and hazards, the present work will focus is the fire hazard levels in the Ras Gharib area, that impact human health. Advance machine learning and the internet of things have been recently considered as the most promising approaches and technologies for environmental pollution hazards management. Thus, using those technologies to improve safety in the outdoor workplace and reducing fire hazards. Previous studies focus on the assessment, evaluation, prediction, and monitoring the air pollution.

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Machine learning techniques have been used to build prediction models for the prevalence of pollutants and natural hazrds (Raimondo et al. 2007; Garcia et al. 2016; Yu et al. 2016; Park et al. 2018; Veljanovska and Dimoski 2018; Yi et al. 2018, Abu El-Magd et al. 2021; Abu El-Magd 2022). IoT term refers to the network of an everyday object (either called “things”) connecting intelligent sensors or platforms that exchange information about themselves and their surroundings (Munera et al. 2021).

Fire is the rapid oxidation of substances in the chemical process of combustion, releasing light, heat, and various reaction products. Well-planned firefighting system can save millions of dollars by preventing the destructiveness of fire, as well as saving lives. Therefore, adequate firefighting prevention and detection systems must be installed for the industry. However, the existing firefighting system has numerous disadvantages among them are frequent false alarms and no previous history data storing.

Previously, the manual data collection methods for environmental pollutants and hazards were the main way for data collection. Where the individuals or teams collect the samples or measure the parameters at various parts of the site using portable devices. This manual way of data collection seems to be costly and time-consuming; therefore, the role of the Internet of Things (IoT) comes in into insight. Recently, many researchers promoted their studies of environmental and fire hazards assessment based on the IoT (Kim et al. 2014; Firdhous et al. 2017; Moses et at. 2020; Zhao et al. 2020; Munera et al. 2021). However, the early detection of fires is critical and plays a very important role in protecting and saving lives and property. Having a fire detection system in place can significantly reduce damage and increase firefighting efforts. According, the physical devices integrated with IoT can achieve collaboration and information exchange without human intervention, and provide decision-makers with intelligent, and quick responses. As a rule of the sump, every place where people work is exposed to risks. If these risks are not controlled, this can lead to accidents and damage to property. Therefore, the proposed system is aimed at the present work at improving safety in the outdoor workplace and reducing fire hazards. The main contribution of the current paper is to provide an overview capability of IoT-based noise level monitoring systems. In this context, noise pollution monitoring units and platforms have been developed with the help of a wireless sensor network and this sensor network gives information about the fire level of a certain area by using a centralized internet platform server. A standalone gateway (local server), which is capable to process the raw sensor data and signals, display the physiological data, and trigger an alert if any emergency fire circumstance is detected. Wireless communication is also used through Wi-Fi, which can upload data to the cloud on the HTTP protocol.

Since fire alarm systems are essential in providing an early warning in the event of a fire and can help save lives and protect property whilst also fulfilling the needs of insurance companies and government departments. Fire alarm systems typically consist of several inter-linked components, such as smoke detectors, heat detectors, carbon monoxide, manual call points, sounders, alarms, and buzzers. The fire alarm system should give immediate information in order to prevent the fire spread and protect life and property. To get maximum protection general petroleum company in Egypt proposed a fire alarm system to monitor 25 production plants spread over 160 kilometers.

Fire and Gas detection and alarm system are essential aspects of fire control and prevention of hazard escalation. The purpose of this document is to provide guidance to the project on the appropriate methods and technology of Fire and Gas detection (PLC, SCADA, and IoT) to be employed for different fire hazards and to outline the main goals and performance standards for this system. All work was done in compliance with all relevant safety and environmental legislation. Giving preference to the use of international standards such as NFPA, API, and local laws that are most appropriate for Egypt. The primary objectives of firefighting systems are to provide the required water/foam on-demand in sufficient quantity and pressure on time to limit or prevent the escalation of fires, avoid risks to life, protect the environment, and minimize physical damage.

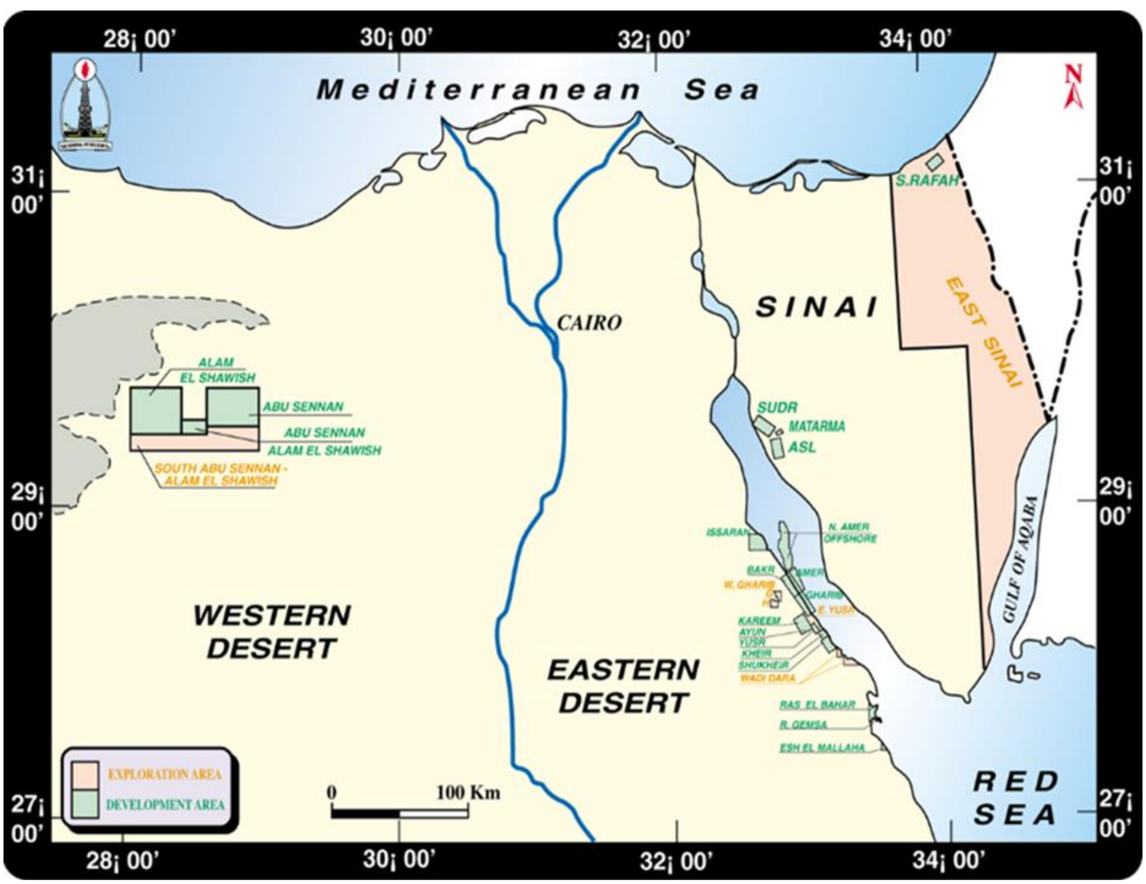

Figure 1: GPC oil fields location map.

2. Study area

Many development projects have been identified in the Eastern Desert of Egypt. The studied area is namely south baker station lies in the central part of the Eastern Desert and follows General Petroleum Company (GPC), which is one of the Egyptian General Petroleum Corporation companies and the main activity is research, exploration, processing, and shipping of crude oil from offshore and onshore wells. It is located in the coastal area between Zafarana and Ras Ghareb, 10 km from the city of Ras Gharib between latitudes 28° 29` 10.94\\ and 32° 59` 54.34\\ (Fig. 1). Which conducts research, exploration, production, and processing of crude oil and natural gas, which is one of the main sources of energy and is a basic and permanent resource for the Egyptian economy. They contribute to achieving the strategic direction of the state in this important activity. This area is characterized by an arid climate, the summers are hot, oppressive, arid, and clear; the winters are cool, dry, and mostly clear; and it is windy year-round. Over the course of the year, the temperature typically varies from 51°F to 89°F and is rarely below 46°F or above 95°F.

3. Background of Potential Fire Hazards

Storage and handling of oils present a major fire risk at Shukair Station. Installations and equipment used for handling oils may produce a flammable atmosphere that will burn when ignited by an accessible ignition source, resulting in a fire. The fire risk is minimized by strict control of ignition sources and other fire prevention measures/systems provided to stop the accidental release, avoid ignition and minimize the escalation.

Fire hazards at Baker station were found to be at the following locations:

- Storage tanks.
- Oils handling equipment “Pump House”.
- Oil catcher.
- Separator Area1 and 2.
- Electrical hazards present in transformers and electrical panels.

3.1 Active Fire Protection Measures

Besides fire preventive measures, Baker station is provided with active fire protection systems and equipment. The active fire protection measures prevent or limit the escalation of fire in order to avoid risk to life and to minimize the equipment damage. The principal concern in storage and handling facilities is hydrocarbon fires. The active fire protection measures shall comprise the following fixed fire protection systems and portable/mobile firefighting equipment:

- Fixed firewater and cooling systems.
- Fixed foam systems.
- Self-oscillating water/foam monitors.
- Fire water hydrants.
- Gaseous fire suppression system.
- Fire extinguishers.

4. Fire Scenarios

4.1 Minor Fire Scenarios

Minor fire scenarios such as small spill fires or small office fires are expected to be extinguished by personnel or operators using portable firefighting equipment. In general, the whole areas and buildings of the Station will be provided with first-aid firefighting equipment (i.e. Portable/Mobile Fire Extinguishers of different types and sizes).

4.2 Electrical Fire Scenarios

Buildings/rooms with critical control, electrical or telecom equipment provided with VESDA very early warning smoke detectors systems to provide early warning of fire allowing the appropriate executive actions to be taken to reduce the probability of the fire escalation. Carbon dioxide fire extinguishing system used for fires on electrical and/or electronic equipment. The clean agent fire extinguishing system, typically FM-200, provided for the protection of equipment located in places where people occupied such places.

Electrical fire hazards at baker Station were found to be at the following locations:

- Transformer room-1,
- Transformer room-2,
- Electrical panels at pump house

4.3 Major Fire Scenarios

Major fire scenarios which are defined and described in this document consider fires at storage tanks and handling facilities. They present fire scenarios with potentially serious consequences and require fixed fire protection systems to be operated. Major fire scenarios are defined based on the location of the facility, its purpose, separation distances, adjacent fire hazards, prevailing wind direction, etc. Only one major fire accident at a time is considered with another simultaneous occurrence of fire, either within a single fire area or in multiple locations at the Station

Major fire hazards at Shukair station were found out to be at the following locations:

- Storage tanks.
- Pump house.
- Separator area1 and 2,
- Oil catcher.

4.4 Worst-Case Fire Scenario

A list of fire scenarios will be considered as the basis for the calculation of minimum required firewater flow rates and the foam concentrate quantities; Additional flow rates for firefighting equipment are also included in Firewater and Fire Foam Demand Calculation Report “Doc. No. SHU-PTJ-FF-CAL-0001” as fire water requirements for supplementary protection. Supplementary fire protection considers portable/mobile firefighting equipment used simultaneously with fixed foam and/or firewater systems. The worst-case fire scenario requires the largest flow rate to be provided for simultaneous operation of fixed fire protection systems and portable/mobile firefighting equipment.

According to the total fire scenario flow rates presented in Firewater and Fire Foam Demand Calculation Report paragraph. The worst-case fire scenario is used for the sizing of fire pumps and firewater ring main. A list of fire scenarios and their consequences “Exposure Protection requirements” have been considered as the basis for the calculation of minimum required firewater flow rates and the foam solution quantities required for Baker station. Additional flow rates for firefighting equipment are also included in the water demand as fire water requirements for supplementary protection.

The purpose of the Fire and Gas detection and alarm system is to:

- Provide the correct type and quantity of detection and alarm devices based on likelihood.
- Fire scenarios for each protected area.
- Increase the performance level of the plant emergency response system.
- Provide asset protection.

5. System Architecture

Improving safety in the industrial workplace is one of the most significant considerations, where occupational injuries and illnesses may occur that could change the life of workers permanently. PLC, SCADA, and IoT infrastructures have been taken into account in this work and designed to achieve a reliable safety monitoring system for firefighting in terms of wireless technologies.

The overall architecture of the current system comprises three subsystems: (i) sensors and detectors nodes; (ii) IoT gateway; (iii) internet cloud.

(i) Sensor and detectors

They are devices that work as indicators for fire events, these devices can take many forms. They are of low sensitivity to false alarms. Furthermore, they are intended to respond automatically to any issue of detectable changes associated with fire events, including heat detector, emitted thermal energy, smoke detector, products of combustion, flame detector, radiant energy, flame detector, and carbon monoxide detector.

(ii) IoT gateway

According to several researchers e.g., Rahmani et al. (2015); Pace et al. (2018); Rahmani et al. (2018) the gateway acts as a linkage device between the local sensor and or detectors and the cloud services. Gateway gets information from the neighborhood devices and sends them to the cloud where information will be processed and shown to clients by means of web applications. The data visualizations can be shown on a web application that was developed as a local website. The gateway is responsible for connecting the sensors with the IoT cloud service; therefore, the gateway should have some capabilities. These capabilities include; Wi-Fi or Ethernet as internet connection, high processing speed, data storage unit, and user-friendly interface.

(iii) Internet cloud

The Internet cloud platform is a fully managed service that allows the user to manage and connect the gateway and dispersed devices easily and securely. Thus, the cloud server collects and receives the data from the gateway and stores the data in the cloud database. The data stored can be accessed for processing, analyzing, and visualizing in real-time to support improved safety efficiency.

The framework of fire monitoring information system

The framework of fire monitoring information system which is shown in Figure 2 consists of 5 architecture layers: the perception layer, transport layer, storage layer, intelligent decision-making layer and application layer. The monitoring terminal module can collect the information of real-time alarm of fire control cabinet, current and voltage of electrical equipment, pipeline flow and pressure, ambient temperature and humidity, valves switch, relay action with the set frequency. The collected data including the node number and time stamp will be packed in accordance with the agreement that is already made by the system before it is uploaded to the user information transfer module through the WIFI or CAN bus network. At the same time the camera inside the building may upload the collected graphic information to the user information transmission module through the local network. RFID fire equipment inventory operation and maintenance subsystem is included in the system and the inventory or maintenance information can be transmitted to the user information transmission module through the mobile RFID handheld terminal or the USB connection port. In the system, the user information transmission module is equivalent to the gateway which summarizes all the monitoring information in the perception layer.

6. Materials and methods

The goal of a fire alarm system is to give an early warning system about the presence of fire and give maximum protection to save lives and protect property. Because of its ease of installation and the ability to be able to be monitored from a central control room using Web Access’s remote monitoring and management.

In the present paper, fixed sensors were placed in some places at the site to detect fire or gas leakage from all activities within the site, These sensors of the platform can instantly communicate the presence of fire or gas leakage from sensors and provide early warning notification across the study site, without human intervention, and alert the responsible team if an unexpected change occurs, enabling them to take quick action

The platform here is designed based on the IoT platform architecture (Fig. 3) that is mainly comprised of three components includes: (i) the perception layer, which is the sensing component that is used to collect data using any measuring devices or any detecting sensors.

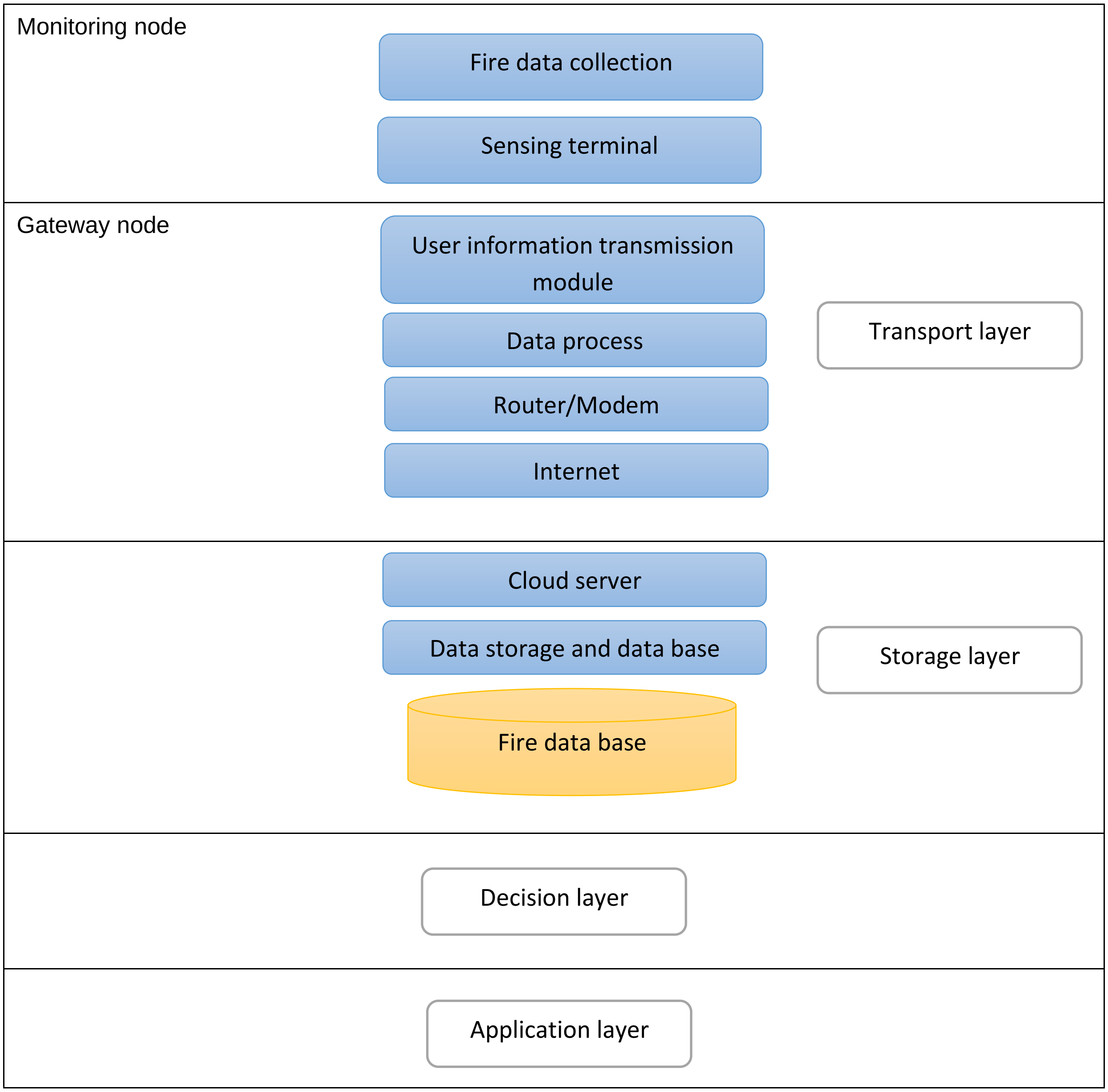

Figure 2: The framework of fire monitoring information system

Secondly (ii) the network layer, is a responsible layer for transmitting the measured or detected data with a wireless network module. The third component (iii) the presentation layer, allows data visualization and storage for efficient monitoring (Fan et al. 2014; Pavithra and Balakrishnan 2015; Stergiou et al. 2018).

System implementation

The IoT relay critically on connectivity, so the critical role to play for the operators is to provide secure communications connectivity. An automatic firefighting system in the present work is used to detect and prevent the presence of fire by monitoring the changes associated with combustion. Thus, the notification and evacuation of the public during fire events can be done by using the automatic fire alarm system (Fig. 4).

IoT-based fire alerting system uses two types of sensors, namely, temperature sensors, gas detectors and smoke sensors. There is an ADC converter, that converts the analog signal received at the sensor end to digital, then transmits them to the micro-controller, Arduino. The micro-controller is programmed to turn on the buzzer when the temperature and the smoke reach a threshold value. At the same time, Arduino sends the data to the Wi-Fi, which is used for connecting micro-controllers to the Wi-Fi network. Furthermore, the device ID's are the unique ID given to a device, which would help the firefighters get information related to the location, where the fire is detected. The Prerequisite for this IoT-based fire alarm system is that the Wi-Fi module should be connected to a Wi-Fi zone or a hotspot.

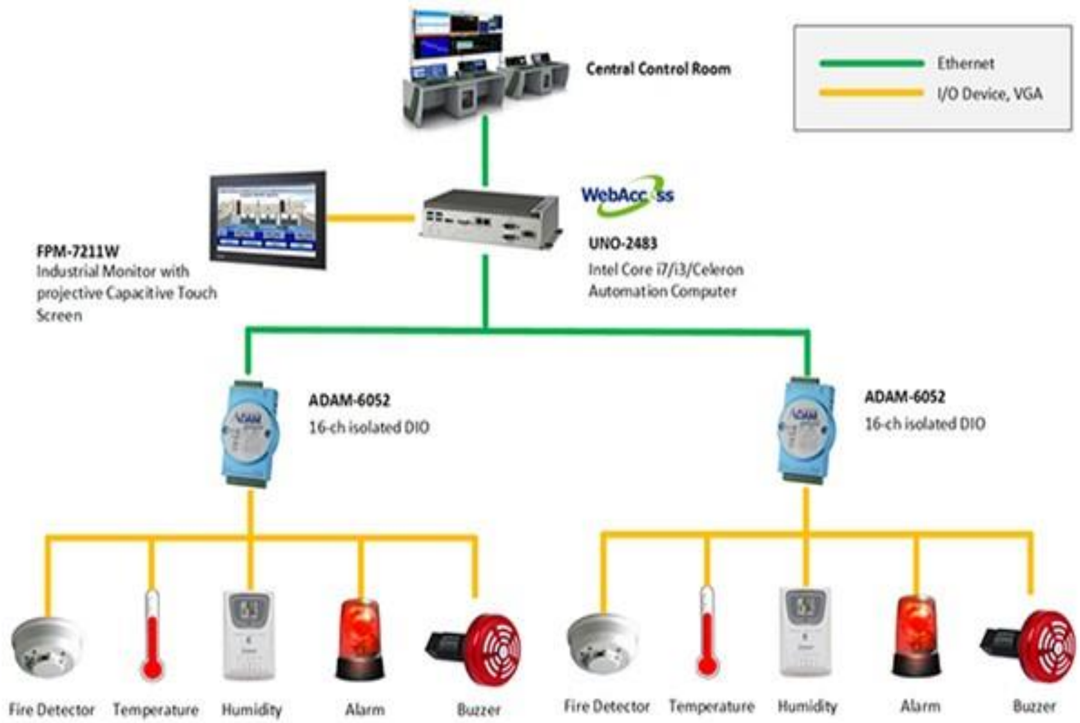

Figure 3: Graphical scheme of the IoT platform architecture.

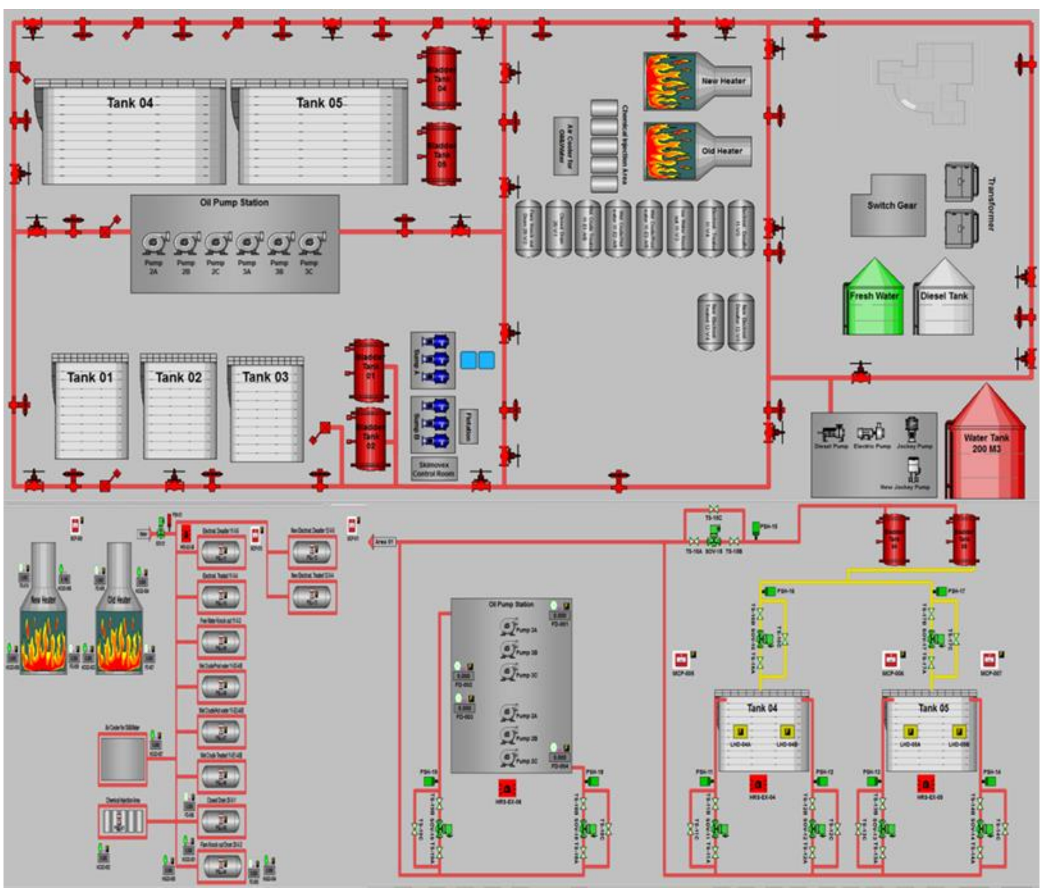

Figure 4: Various SCADA screens for pictorial representation of the process taking place in the plant and distribution of sensors.

6.1. Detection and alarm

In hydrocarbon process areas, the equipment containing flammable material is normally designed to contain all hazardous inventories and minimize the potential for leakages of flammable material to occur. This is normally achieved by good design practice in equipment design, rating, and material selection. Optimizing the equipment layout to minimize the probability of coincidence of a flammable Loss of Containment (LOC) and possible ignition sources (electrical / flame) is also a major factor in reducing the risk to more acceptable limits.

Nevertheless, accidents do happen in the oil and gas industry with a high potential for escalation. Early detection of a hazard beginning with the initial LOC (gas or liquid release) will allow very much-needed time to take appropriate action (ESD, firefighting Activation) to limit the extent of hazard escalation. Instrumented fire and gas detection is indispensable if hazard detection by humans is likely to be too late to prevent the escalation of incidents. The quantity, type, and location of detectors are verified according to assessing the probable fire/gas leak scenario associated with each protected area.

6.1.1. Heat fire detectors

Heat detectors are used for the detection of fires, which are expected to build up quickly and generate much heat. These types of detectors are generally simple and very sturdy for usage in harsh and corrosive environments. Their biggest strength is their reliability and low spurious alarm rate, which makes them much, relied upon to activate automatic fire fighting systems associated with the protected equipment.

Linear Heat detectors are used to initiate activation alarms for the water deluge system in process and storage areas. The detector shall provide a fire alarm and confirmed fire alarm for tank fires, Activation of the water spray system shall rely on a confirmed fire alarm throughout voting 2oo2 of linear heat detectors, to further enhance the reliability and low spurious alarms of the complete system.

6.1.2 Flame detectors

Flame detectors are used for the rapid detection of incipient fires. Flame detectors are very suited to the detection of gas fires, as it responds very effectively to the flame flickering of most hydrocarbon fires. However, these detectors are not much recommended to detect flames in liquid fires where fires are expected to produce heavy smoke, which will probably foul the lens and reduce the sensitivity of the detector. The Triple IR detectors are utilized in crude oil storage and Shipping Pumping Areas for flame detection and provide general plant fire alarms and activate the water spray system

6.1.3 Smoke detector

Smoke detectors are provided as the main fire detector type for the offices, electrical areas, and warehouses (Existing Control Room and Substation new extensions). Beam smoke detector (transceiver with reflector plate) used in open and high elevated areas at elevation 4 to 5 meters from floor level, the minimum horizontal spacing between the transceiver and reflector 10 meters free of any obstruction.

6.2. Gas Detection

6.2.1 Spot-type gas detection

Spot-type gas detection is located at the strategic location throughout the process area to provide point gas detection associated with specific parts of the plant. The concentrations of gas detected are indicated in the control panel as a percentage of gas Lower Flammable Limit (LFL). Hydrogen gas detector installed inside the battery room, classified for a hazardous area classification zone-1, Gas group IIC to monitor the hydrogen emission during the batteries charging inside the battery room. The gas detector alarms settled at 20 % and 50% % LEL volume concentrations of hydrogen.

6.3. Manual Detection and alarm

Bell/strobe activated inside the protected area to notify the person to leave the area immediately.

6.4. PLC Control System

The fire and gas system is supplied with SIL-2 rated and designed to perform the following functions automatically and manually:

- Provide alarms in case of fire.
- Activate fire protection systems.
- Initiating signals to emergency shutdowns (ESD).
- Save data to the cloud.

Due to the requirement that the Fire & Gas system must still be operational in case of power failure or plant shutdown. The new fire and gas system will be supplied with backup batteries & battery chargers as per NFPA 72 requirements with 24 hours in quiescent mode and five minutes in alarm mode.

6.5. Human-System Interface

6.5.1 Computer graphic display

Dedicated fire and gas Computer graphic display PC shall provide a complete plant overview showing relevant plants as a simplified plot plan with general block area alarm accompanied with relevant alarm messages. Protected area overview display showing common signals per each fire zone. Unit detail display shall consist of a simplified unit layout showing approximate physical locations of individual detectors in the field with complete status. Historical data archived to show all fire and gas alarms. Faults and other events in order of occurrence.

6.5.2 Communication Interfaces

With ESD: the fire and gas system shall provide a common hardwired ESD signal for each fire zone using voltage-free contact through interposing relays (SIL rated). With field devices: The hardwired interface between the field detectors and the control panel with HART support and to be either 4-20 mA or potential-free contact using intrinsic safe barriers for non-explosion proof devices (Linear Heat detector only).

With a firefighting system: a fire and gas system shall provide supervised output interface signals to the fire water deluges, fire water pumps (with feedback indication), and CO_2 extinguishing system. With PAGA system: Output interface signals for future PAGA systems (one for fire and one for gas alarms) to be considered on the new fire and gas system for any alarm system in the whole plant using volt-free contact through interposing relays.

7. System performance

Building interference in the area significantly affects the network coverage. Therefore, various gateway nodes were placed both outdoor and indoors to improve the network coverage and connectivity in the workplace.

8. Results and discussions

Internet of Things (IoT) is basically the network of 'things' in which the physical things can exchange the data with the help of electronics, sensors, software, and connectivity. These systems usually do not require any human interaction. In this context, we have designed an IoT-based fire system using temperature and a smoke sensor which would not only signal the presence of fire in a particular premise but will also send related information through IoT.

Generally, SCADA in the present work encompasses the collecting of the information and dataset, transferring it back to the central site, carrying out any necessary analysis, and then displaying that information on several screens or displays. The required control actions of the issues are then conveyed back to the process. One of the most widely used control systems is the programmable logic controller (PLC) in the industry-wide world (Fig. 4). As a result of the need to monitor and control several connecting devices on the site. Thus, the PLCs were distributed on the site (Figure 5).

An automatic firefighting system in the present work is used to detect and prevent the presence of fire by monitoring the changes associated with combustion. Thus, the notification and evacuation of the public during fire events can be done by using the automatic fire alarm system. In addition to the website application for sensor data display and notifications, a web-based smartphone application for receiving wireless data directly from the system. The mobile application is developed. The current system has the following advantage:

- The system can record and store a very large amount of data.
- The data can be displayed in any way the user requires.
- Thousands of sensors over a wide area can be connected to the system.
- The operator can incorporate real data simulations into the system.
- The data can be viewed from anywhere, not just on-site.

A mobile app populated with sensor data which already under development can provide visibility into emergency systems. Additionally, tells how to control specific locations in a building.

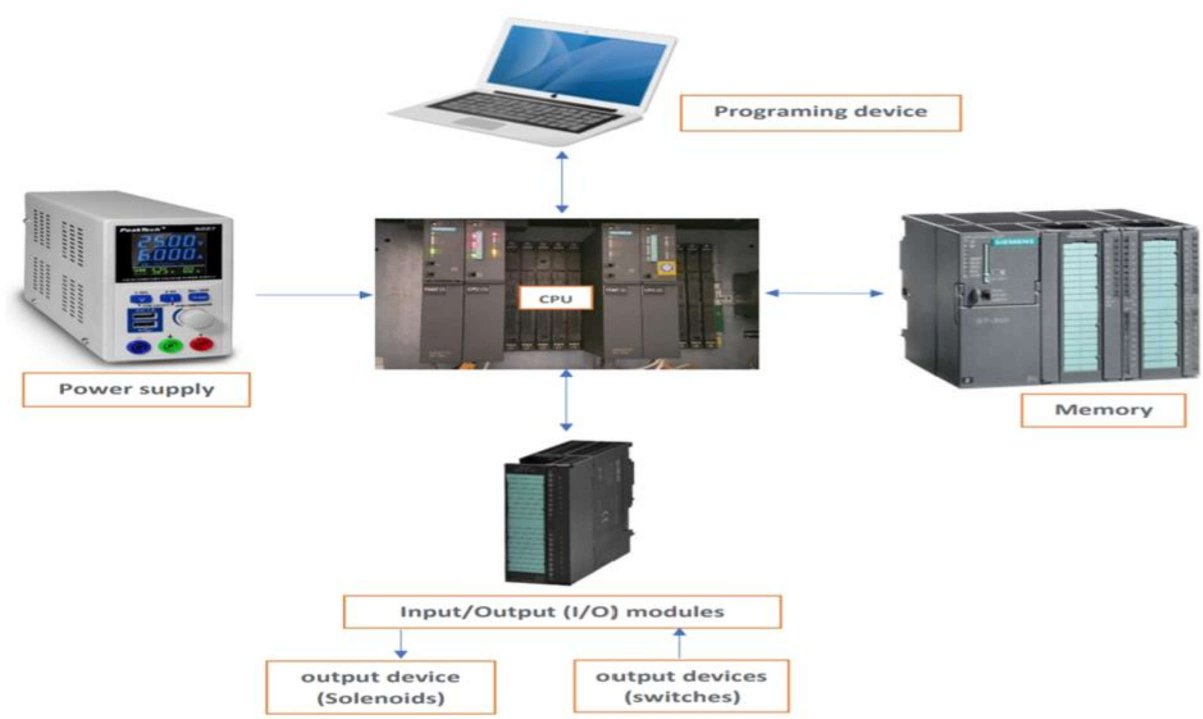

Figure 4: Block diagram of PLC.

9. Conclusion

This paper presents the implementation of a PLC and SCADA system for IoT-based firefighting safety monitoring applications. Remote diagnostic and monitoring capabilities of the IoT system help the decision-makers know where to locate the personnel and trucks or operation. Simply, an IoT system tells the fire personnel the locations of a smoke detector going off, then a heat detector sending signal or a water flow switch being activated. The system includes receiving sensor signals and alarms, processing raw data received in the real-time display, emergency notifications, as well as sending data to the Internet cloud server. The cloud will provide the IoT applications of the system, including data storage, website display, and mobile user interface. The proposed system-based IoT can be used in industrial safety monitoring applications such as firefighting with reasonable accuracy. Limitation and future work, applying a smart IoT gateway that can cope with multiple wireless technologies and perform faster edge computing will be deployed. Edge computing can reduce the latency and improve the efficiency of the network system. Future studies should enhance the emergency systems to become interconnected in the future, where the building, managers, and workers should get access to the dashboards in addition to firefighters. Furthermore, a smart fire detection system could use artificial intelligence (AI) to detect false alarms and provide contextual information.

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