International Journal of Current Advanced Research
ISSN: O: 2319-6475, ISSN: P: 2319-6505, Impact Factor: 6.614
Available Online at www.journalijcar.org
Volume 10; Issue 02 (A); February 2021; Page No.23734-23740
DOI: http://dx.doi.org/10.24327/ijcar.2021.23740.4706

Research Article

WIRELESS SENSOR NETWORK APPLICATIONS IN THE OIL AND GAS INDUSTRY: A SURVEY

Wosowei Julius[1] and Chandrasekar Shastry[2]

[1]Computer Science and Engineering, School of Engineering and Technology
JAIN (Deemed-to-be University), Bangalore, India
[2]Faculty of Engineering & Technology JAIN (Deemed-to-be University), Bangalore, India

A R T I C L E I N F O

Article History:
Received 6th November, 2020
Received in revised form 15th December, 2020
Accepted 12th January, 2021
Published online 28th February, 2021

Key words:
Wireless Sensor Networks Applications, Sensors, Actuators, Oil and Gas Industry.

A B S T R A C T

This paper is a survey based on the deployment of Wireless Sensor Network in the oil and gas industry especially in refineries, petrochemicals, hazardous under water operations and production platforms. The work dealt with networks that acquire data and monitor oil and gas production processes either for effective measurement or monitoring of desired field parameters such as pressure, temperature, flowrates and others necessary for safety and optimization of the production process where application of wired sensors and other gathering tools proved prohibitive. Wireless Sensor Networks are deployed to remotely monitor corrosion of pipeline, equipment condition, subsea installations, production performance, natural gas leaks and status of reservoir in real-time. Data acquired through WSN can be subjected to further analysis that can yield further insights that yield innovative solutions including cost effectiveness, faults tolerance and preventing problems.

INTRODUCTION

The oil and gas industry `have not had the best of times in the recent years and every effort is being made to cut costs and scale back on new field development projects. Other analysts believe that the sector is experiencing a digital disruption and technical reordering with current global trends in technology known as Industry 4.0 or the forth revolution. The era of industry 1.0 was the era of steam engine. Industry 2.0 brought about electrification whereas 3.0 became the Information technology era and in April 2013 in Germany, the Industry 4.0 was put forth for consideration. It is the era of the deployment and characterization of Digitization, Automation, modularization and possibly Intelligentization, and big data, Internet of things (IoT), wireless technology, block chain, cloud computing, SCADA and others became the key driving technologies [1], [2].

Industry 4.0 is anchored on constantly improving and enhancing existing technologies and wireless sensor networks (WSNs) is one of such novel innovations that has positively impacted the oil and gas industry as it helps in gathering and monitoring data in remote areas. Wireless sensor networks, according to Kazem *et al* [3], are an infrastructure of detecting, measuring, computing and communicating elements that offer administrator the capacity to instrument, observe and reacts questionable observations in a special environment.

Corresponding author:* **Wosowei Julius
Computer Science and Engineering, School of Engineering and Technology JAIN (Deemed-to-be University), Bangalore, India

The monitored environment could be a physical world, a biological system or an Information technology framework whereas the administrator represents a civil, government, commercial or an industrial entity.

Four basic components are identified in a wireless network. These include:

1. A string or an assembly of sensors either distributed or localized
2. An interconnecting of wireless networks.
3. The Sink in information clustering.
4. A set of computing resources to process sensor data and data mining.

The first phase of Oil and Gas field development is the search for hydrocarbon bearing rocks formations. Thereafter, geological maps are taken and reviewed to identify sedimentary basins. This may be followed by aerial photography to ascertain faults and anticlines. But exhaustive information is acquired using field geological assessment which follows one of the three main survey methods namely: magnetic (measuring the variations in intensity of magnetic fields in rocks), gravimetric (measures small variations in the gravitational field at the earth surface) and seismic survey which is used to identify geological structures and is the most used [4].

The petroleum industry supply chain is categorized into three sub-sectors namely; Upstream, Midstream and Downstream. The Upstream petroleum sector sometimes referred to as the

Exploration and Production (E & P) sector. Activities in the E & P include searching for, recovering and producing crude oil and natural gas. It is all about where to locate wells, the depth and distance to drill, the designing, constructing, operating, managing and delivering the best possible return on the capital outlay in safest operational manner. Exploration involves obtaining a lease either in offshore or onshore and conducting geological and geophysical surveys to ascertaining the first well also known as the "wildcat well" whereas drilling involves creating the borehole in the ground (reservoir) that becomes either an oil or gas well. Production on the other hand is where hydrocarbon reserves are translated to cash or wealth by maximizing the recovery of hydrocarbon from the reservoir. The Upstream is characterized by high risk, high return, industry regulations, global politics and intensive technology [5],[7].

The Midstream links producing areas and population centers. Its activities include field gathering, flow stations and transmission pipelines. The operations at the midstream also include some activities of upstream sector and the downstream sector. The Midstream is characterized by low risk business, regulated components and depends on upstream health. The Midstream transportation activities include the marine vessels, railroads, trucks and storage units. The Midstream precisely deals with the gathering, the transportation and the storage of hydrocarbon [6].

While the Downstream sector business activities include processing, transportation and selling of refined products to the primary users or consumers. It is involved with crude oil refining and purification of natural gas, the marketing and the distribution of petroleum product. The Downstream engages the final consumer with products such as gasoline, kerosene, lubricants, asphalt, natural gas, Liquefied Natural Gas (LNG) and assorted petrochemical products.

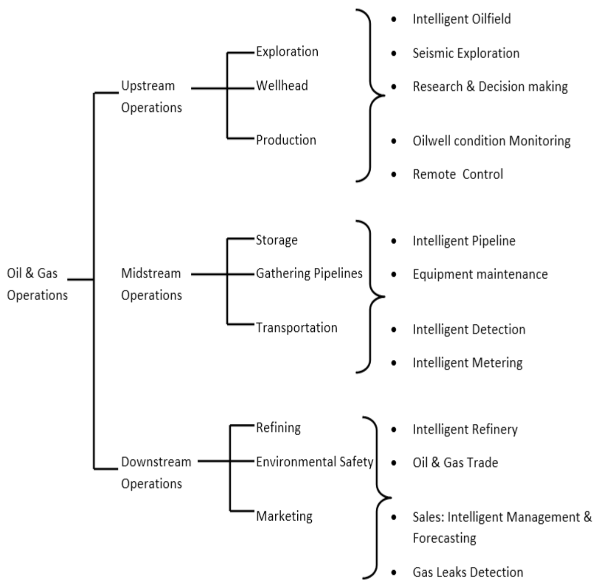

Figure 1 Oil and Gas Industry Subdivisions

Wireless Sensor Networks Applications Oil and Gas Industry

The fourth industrial revolution also known as Industry 4.0 came with the advancement in technology and the oil and gas industry is not left out. The revolution as it affects the petroleum industry started with the use of supervisory control and data acquisition (SCADA) systems to gather data in offshore locations and the emergence of wireless sensor networks (WSNs) became a major tool too. Some of the applications areas of WSNs are as follows:

1. Remote Monitoring-Wireless sensor networks are used to monitor oil and gas installations in the oceans, underwater and hazardous environments. Activities monitored include:
   - Pipeline monitoring
   - Separators operating level monitoring.
   - Wellhead monitoring.
   - Pressure relief valves (PRVs)
   - Pressure safety valves (PSVs)
   - High and Equipment pilots
   - Submersible pumps
   - Downhole gauges
   - Control valves
   - Instrumentations: pressure sensors, temperature sensors and level sensors.
2. Equipment condition monitoring-Facilities components are monitored by WSNs to ascertain their performance and status whether there are faulty components and if there is, what is the cause? Fault diagnosis can be either components faults diagnosis or system fault diagnosis. Component faults diagnosis deals cause of a failure and can be identified sensor measurements whereas system diagnosis is performed on a system of composite components [7]
3. Production performance- WSNs aid in determining performance status especially at the flow stations and wellheads where data from sensors is used to determine retention time of separators and sense whether wells are flowing or tripped. This is to ascertain whether the station is performing or operating optimally. Other performance activities include shutdowns, plant safety, turnarounds and other plants abnormal conditions.
4. Wellhead Automation- Drilling activities are optimized by wireless technology especially with the introduction of smart sensors and smart wells now a reality. Smart wells are wells that have embedded devices that allow a well to be controlled automatically or by operator at a remote location. They have smart mechanical devices that allow control in pressure and flowrates downhole to optimize performance thereby improving oil recovery.
5. H_2S monitoring-The effluent from the reservoir does not only contain oil, water and gas. It has the basic sediment and water (BS+W) and other assorted gases including methane, CO_2, ammonia and sulphur dioxide and hydrogen sulphide (H_2S) which is a toxic, colorless inflammable gas heavier the air and also soluble in water that causes serious corrosion and poses serious health hazards. WSNs are deployed to monitor leaks from such pipes.
6. Oil exploration and seismic survey-The exploration and seismic activities generate a vast amount data and the mode of transmission and analysis is a herculean task due to the remote and hazardous location of such environments. Sensors are used to capture and analyze such data. Sensors have the capacity to exist in remote areas to sense, compute and communicate such events.

Table 1 Types of wireless sensor networks

Serial	Type of Wireless Sensor Network	Description
1.	Terrestrial Wireless Sensor Networks (TWSNs)	These consist of several sensor nodes deployed on land. They positioned into either structured or unstructured nodes in specific areas where an ad-hoc network is used to communicate between the sensor nodes. Terrestrial sensor networks are faced the challenges of minimizing energy cost, reduction of the amount of data communication, finding optimal routes, maintaining network connectivity and eliminating redundancy. The application areas of TWSNs include environmental monitoring, military boarder monitoring, reservoir monitoring and surface exploration [8]
2.	Underground Wireless Sensor Networks (WUSNs)	These are placed under the ground for collecting information or monitoring underground conditions. Additional sensor nodes are positioned above the ground to disseminate information from the sensor nodes to the base station. The performance of WUSNs is limited by cost of deployment, difficulty in replacing battery, environmental threats on devices and high attenuation and loss of signal during communication. Underground WSN are costlier than TWSNs. Underground WSN supports intelligent agriculture, pipeline diagnosis, crude oil exploration and mine disaster rescue [9], [10].
3.	Underwater Wireless Sensor Networks (UWSNs)	These consist of vehicles and sensors deployed underwater and interactively used between nodes and ground-based stations. They have the challenge of limited bandwidth, high propagation delay; media access control, power constraints, high cost of sensors, and corrosion of hardware and battery replacement problems. These sensors are affected by the underwater environment in terms of mobility and are not static as can be found in underground wireless sensor networks. UWSNs are opposite of terrestrial WSN and as such are less dense but more expensive. The application areas of UWSNs include seismic monitoring, Underwater robotics and pollution monitoring [11], [12].
4.	Wireless Multimedia Sensor Networks (WMSNs)	These consist of tiny sensor nodes that sense, compute, communicate and have control components. That is, they are sensor devices that have the ability to store, process and retrieve multimedia data such as video, audio and images. They support monitoring and tracking of multimedia events. The multimedia node serves to collect the video, audio, image and transmit to sink which is the base entity. WMSs are constrained by High-energy consumption, QoS provisioning, effective cross-layer design, variable channel capacity and high bandwidth demand. Some of the new application areas of WMSNs include multimedia surveillance, traffic avoidance, enforcement and control system, advanced health care delivery, environmental and structural monitoring and industrial process control. [13], [14], [15].
5.	Mobile Wireless Sensor Networks (MWSNs)	MWSNs consist of sensor nodes that are mobile and can interact with its environment. These are more versatile than static wireless sensor networks as they can be easily deployed and monitored with topological changes. The main difference between MWSNs and others is the ability of nodes to reposition and organize themselves in the network. The application areas of MWSN include habitat monitoring, undersea navigations, process monitoring, target tracking, real-time monitoring, search and rescue and meteorology. The key design challenges facing MWSNs are hardware cost, dynamic topology, coverage, energy, node failure, QoS, cross-layer design and so on, [12], [16]

Operational Standards in the Petroleum Sector

The wireless sensor networks applications in the petroleum sector has become quite evident such that operational standards and guidelines have to be enforced to enhance throughput. Wireless sensor networks operations in oil and gas sector have offered great opportunities for production optimization. They monitor pipelines remotely, detect gas leaks, detect pipe corrosion, equipment conditioning and monitor status of reservoir in real-time. Data acquired from wireless sensor network in real-time reservoirs, refineries, petrochemicals and underwater enable new insights into plant operations and innovative solutions have evolved. A survey of wireless sensor network applications standards in the oil and gas industry operations are considered for discussions.

Regulatory Standards

The oil and gas industry activities include processes for exploration, extraction, refining, transporting, and marketing refined petroleum products. The largest volume of petroleum products are fuel, oil and gasoline (petrol), and this constitutes a major raw material for other industries including chemical products, pharmaceuticals, solvents, fertilizers, farm pesticides, and plastics. As the demand for fossil fuels continues to grow, oil and gas companies and the regulating authorities will have to develop new technologies and standards to improve operations in order to increase productivity and expand on their current abilities. Environmental regulations from government agencies are constantly changing. New set of approved rules on the management of surface waste from oil and gas operations are being promulgated to ensure that oil and gas industry players are properly directed to haul highly contaminated soil and water to permanent disposal sites rather than spread it back over the land after closing a well.

The concerned agencies are authorized to also approve penalties to enforce industry compliance with environmental standards [17]. Subsequently the oil and gas companies are forced to develop new methods to abide by new regulations and, reduce accidents and emissions without affecting production. To this end, the oil companies are seen to be organizing, adapting and applying wireless sensor networks to continually monitor and control environmental conditions and machinery in response to business drivers and requirements. The adoption of wireless sensor network technology by stakeholders in the petroleum sector for compliance with environmental standards in order to improve on their operational output are becoming obvious in the numerous remote and hazardous locations, where so much successes in hazard control and elimination has been achieved.

Furthermore, the difficulty and cost in introducing new-wired devices near pipelines have been reduced, and in most scenarios eliminated. The evolution of new control solutions that require further sensors, the demand for continuous production optimization and growth, and the demand for improved safety requirement for sensor installation have all been utilized.

Specification Standards

A wireless sensor network consists of spatially distributed sensor nodes, which has a capacity to process and gather sensory data and communicating such with other nodes. The usual hardware is the embedded processor, transceiver, memory, power source and other sensors. The embedded processor performs tasks of processing the sensed data and controls the functioning of other components in the sensor node. The concept of micro-sensing and wireless connection of these nodes has enabled the application of wireless sensor networks into the oil and gas industry, and to a wide variety of applications and systems with varying requirements and specifications [18]. One of such specifications in high application especially in the oil and gas industry are the international standards such as the IEEE 802.11 for wireless local area networks and the IEEE 802.15.4 [19] for low-rate wireless personal area networks (PANs), as well as numerous radio-frequency identification (RFID) specifications. These specified standards have enhanced the application of wireless networking with its benefits such as sensing, asset tracking, monitoring and elimination of cables during installations and the reduction of operation costs. The operational configurations of the WSNs consist of several types of sensors including seismic sensors, magnetic, pressure, gas and others.

All of these features embedded in the specified standards has allowed for cost efficient mobile systems, and has enabled installations in remote areas in addition to a new range of applications; particularly in the area of health, safety and environment (HSE). Some other very useful specifications for international standards for wireless sensor networks are ZigBee PRO [20], Wireless HART [13] and ISA100.11a [21], use stacks to provide a layered and abstract description of the network protocol design [14]. Each layer in the stack is a group of related functions, and layers are responsible for service provisions. A layer provides services to the layer above it and services are received from the layer below it below particularly for monitoring optimal performance according to the set standards in the oil and gas industry. These specifications are composed of the physical layer, the medium access control layer, the network layer, and the application layer. The physical layer controls the radiofrequency transceiver, manage signal, select channel, transmitting raw bits and other functions.

The medium access control layer is responsible for connection to physical radio channel, radio synchronization and providing link to peer MAC entities. The Network layer handles the joining and exiting a network. The Network layer ensures successful end-to-end delivery of network packets from source to destination. It also maintains the routing table. The Application layer on the other hand offers user services such as login file transfer, email, messages formatting, and defines the role of a device with the network. It ensures that the network performance functions of self-forming and self-healing allow data and control messages from one node to another through multiple paths [15].

Typical Wireless Sensor Networks Architecture

The architecture applications have benefited the oil and gas business since it began to serve as an important asset to the economic development of oil producing countries. Maintaining the economic progress of these countries is strongly depending on having good control over its oil and gas industry. With the fast development of the oil producing countries and an increase of demand for energy, petroleum and natural gas have become prized assets for these countries. The oil wellheads to export terminals flow rate monitoring for oil and gas are important parts of the national treasure vital to the national economy.

Deploying wireless technology in redistributable architectures has the potency to be useful in many aspects; eradicating the requirement for cables, contributing to the abridged installation and effective costs. It enables the installation of these sensors in difficult environments and allow for cost effective and portable device systems. WSNs allow for a variety of uses especially in Health, Safety and Environment (HSE), process control and real-time monitoring in the oil and gas industry.

Typical redistributable architecture as shown in figure 2 is simple and better structured to achieve the objectives of using a wireless sensor network as a network of embedded devices that can communicate the information gathered from a monitored field through wireless links.

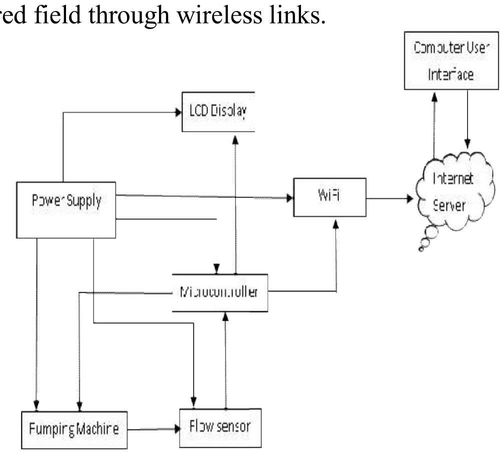

Figure 2 Redistributable Sensor Architecture

Due to rapid urbanization and its ubiquitous nature the rate of deployment of wireless sensor networks in the oil and gas industry has been on the increase. The major component in the structure of the sensors that is giving them this spanned capability is the presence of the nodes. The nodes hierarchy shown in figure 2 is like a star sensor network topology, which allows all nodes to connect to each other, and like a mesh. Each node receives information from the sensor and transmits the sensed data to the next node and eventually the processed data sent to the sink node, which ultimately transmits the processed data to the user via the Internet. A sensor node is composed of a microcontroller, an external memory, a transceiver, a power source, and other sensors.

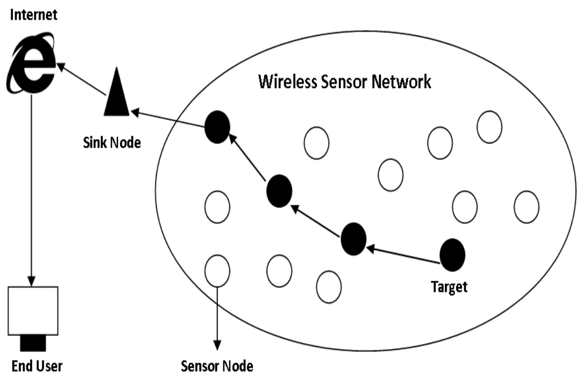

Figure 3 Wireless Sensor Network System Architecture.

With the arrival of embedded systems and micro-electro-mechanical system (MEMS) there is no doubt that the sensors field has advanced and its application is already ubiquitous in the oil and gas industry ranging from intelligent environmental monitoring, military surveillance over facility protection, air pollutant detection and monitoring intelligent decision support systems and others.

The ubiquitous nature of wireless sensor networks has also made it possible for the installation of cyber-physical systems (CPS) to bridge between wireless sensor networks and actuators integrated under intelligent decision system in the petroleum industry. Implementation of the installations is in areas with vast oil and gas facilities as part of proactive and preventive mechanism to stop or deter vandalisation of the oil and gas facilities. A cyber-physical system may consist of multiple motionless or mobile sensor and actuator networks integrated under an intelligent decision system. For each individual wireless sensor network, the issues such as network formation, network or power or mobility management, and security are considered and managed by cross-domain sensor cooperation, heterogeneous information flow, and intelligent decision actuation.

The wireless sensors monitor the oil and gas facilities and the role of the actuators is to instigate or initiate the intelligent decision systems to take action immediately a vandalisation of oil and gas facility is detected. The intelligent decision system can fire a warning shot, raise a very audible alarm or even physically apprehend the vandals or culprits.

DISCUSSION

The proficient and operational movement of oil and gas products from producing regions to consumption regions requires broad and elaborate transportation systems. In many instances, oil and gas products produced from a particular well will have to travel a great distance to reach its point of use. The transportation system for oil and gas products consists of a complex network of pipelines, designed to efficiently transport natural gas from its origin to areas of high natural gas demand [18]. Hence, oil and gas installations detecting equipment is periodically used by pipeline personnel on the surface to check for leaks. This is especially important in areas where the oil and gas products are not odorized.

Remote gas leak survey is a proactive way to prevent unnecessary loss of human life resulting from natural gas leaks. Since the existing active detection, system is too expensive and a passive detection system is less reliable, wireless sensor networks are being used to detect and corrects faults of varying degrees and statuses. The aim of fault diagnosis is the estimation of the component status through sensor measurements and careful monitoring of system components. Conventional techniques apply simplified linear pattern matching methods such as linear level threshold algorithms.

Sensors may detect vibration, temperature heat, dissolved gas, electromagnetic properties, power consumption, performance etc. When combined with other sensor outputs, these continuous signals represent significant information about the condition of a component. The cause of leakages can be excessive deformations caused by earthquakes, corrosion, wear and tear, material flaws or even intentional damage [23].

A pipeline inspection task involves both a stationary sensing system and portable sensors carried by maintenance workers. A stationary sensing system consists of sensors, power and signal cables and a control station in which the sensed data are processed. Because of the initial installation as well as maintenance cost, the deployed sensing system may not adequately cover the sensing field. As a result, each employee is required to carry with him a portable sensing device for safety reasons. A wireless sensor networks approach here may give a cross section of any potential leaks for broader analysis. Existing sensing systems consider reports from individual sensors independently; they do not correlate reports from spatially distributed sensors in order to determine the nature of a leakage report. For example, correlation of sensed data can be helpful to not only detect and localize a leakage, but also to determine whether a leakage report made by multiple sensors is a result of actual leakages or diffusion of the gas from a single source [23].

Therefore, maintaining the economic progress of these countries is strongly depending on having good control over these resources. For example, one of the biggest challenges that has remained unaddressed in the Nigerian oil and gas industry is the absence of metering infrastructure for measuring the quantity of crude oil flows from wellheads to export terminals [24]. In addition, without metering at both ends of the pipeline, no one can say how much oil the country is producing, let alone what it is losing through theft and vandalism. Therefore, this survey has discovered that some researchers have designed prototypes aimed at solving the above challenges with a less stress; by comfortably monitoring through a wireless system the flow rate of the oil and gas, calculate the amount lifted and remotely send the data to a database server. The data can be easily accessed through a web designed as a human interaction interface in order to get the detail records of the oil lifted for over period.

CONCLUSION

A wireless sensor network is a network consisting of numerous sensor nodes with sensing, wireless communications and computing capabilities. These sensor nodes are scattered in an unattended environment (i.e. sensing field) to sense the physical world. The sensed data can be collected by a few sink nodes which have access to infrastructure networks like the internet. Finally, an end user can remotely fetch the sensed data by accessing infrastructure networks. The sensor nodes form either a flat network topology where sensor nodes also act as routers and transfer data to a sink through multi-hop routing, or a hierarchical network topology where more powerful fixed or mobile relays are used to collect and route the sensor data to a sink. The sensor network protocol stack is much like the traditional protocol stack, with the following layers: application, transport, network, data link, and physical. The physical layer is responsible for frequency selection, carrier frequency generation, signal detection, modulation and data encryption. The data link layer is responsible for the multiplexing of data streams, data frame detection, medium access and error control. It ensures reliable point-to-point and point-to-multipoint connections in a communication network.

The network layer takes care of routing the data supplied by the transport layer. The network layer design must consider the power efficiency, data-centric communication, data aggregation, etc. The transportation layer helps to maintain the data flow and may be. Depending on the sensing tasks, different types of application software can be set up and used on the application layer. Wireless sensor networks must also be aware of the following management planes in order to function efficiently: mobility, power, and task, quality of service and security management planes. The power management plane is responsible for minimizing power consumption and may turn off functionality in order to preserve energy. The mobility management plane detects and registers movement of nodes so a data route to the sink is always maintained. The task management plane balances and schedules the sensing tasks assigned to the sensing field and thus only the necessary nodes are assigned with sensing tasks and the remainders are able to focus on routing and data aggregation.

Quality of service management in wireless sensor networks can be very important if there is a real-time requirement with regard to the data services. Security management is the process of managing, monitoring, and controlling the security related behavior of a network. The primary function of security management is in controlling access points to critical or sensitive data. Security management also includes the seamless integration of different security function modules, including encryption, authentication and intrusion detection. With all these potentials embedded in wireless sensor networks and devices, they are able to monitor plant performance and the operational environment of oil and gas resource exploration and production plants. When effectively deployed, well developed sensor solutions promote a safe and healthy workplace and simultaneously give the ability to optimize production, and operation safety in the oil and gas industry. Wireless technologies as such are fit for deployment, and can provide benefits such as improved platform safety, optimized operations, preventing problems, tolerating errors, and reducing operating costs. However, without an appropriate study on how they can be incorporated into existing work processes, these benefits cannot be fully realized. It is expected that wireless technologies will soon enable significant cost-effective applications of both a temporary, mobile and permanent nature in remote or hostile areas in the oil and gas and industries.

References

1. Lu, Hongfang, Guo, Lijun, Azimi, Mohammadamin, Huang, Kun. “Oil and Gas 4.0 era: A systematic review and outlook”, Computers in Industry. 111. 10.1016/j.compind.2019.06.007, June 2019.
2. U. Elangovan, Neel SMARTEC Consulting, “Wireless Monitoring to Modernise the Oil and Gas Industry”, Available at http://www.ee.co.za/article/ Wireless-Monitoring-to-Modernise-the-Oil-and-Gas-Industry.html, Accessed 02 Jan. 2020.
3. K. Sohraby, D. Minoli and T. Znati, “Wireless Sensor Networks: Technology, Protocols and Applications”, John Wiley & Sons Inc, Hoboken, New Jersey, 2007, ch. 1, pp. 1-37.
4. Exp Forum/ UNEP 1997, “UNEP IE/ PAC Technical Report 37”, Report number 2.72/254, 1997.
5. I. P. Asuquo *et al*, “Multinational Oil Companies and the Nigerian Oil Industry: A critical perspective”, Energy Resources Law (JIL 813), University of Lagos, 2018.
6. W. Z. Khan *et al*, “A reliable Internet of Things based Architecture for Oil and Gas Industry”, ICACT2017, 2017.
7. M. reza Akhondi, A. Talevski, S. Carlsen, S. Petersen, “Applications of Wireless Sensor Networks in the Oil, Gas and Resources Industries”, 24th IEEE International Conference on Advanced Information Networking and Applications, 2010.
8. Akyildiz, Ian & Su, Weilian & Sankarasubramaniam, Yogesh & Cayirci, E.. (2002). A Survey on Sensor Networks. Communications Magazine, IEEE. 40. 102 - 114. 10.1109/MCOM.2002.1024422.
9. X. Tan, Z. Sun and I. F. Akyildiz, "Wireless Underground Sensor Networks: MI-based communication systems for underground applications.," in IEEE Antennas and Propagation Magazine, vol. 57, no. 4, pp. 74-87, Aug. 2015.
10. M. Aftab, O. Ashraf, M. Irfan, M. Majid, A. Nisar, M. Habib, “A Review Study of Wireless Sensor Networks and Its Security. Communications and Network”, Volume 7, pp. 172-179. 2015.
11. K. M. Awan, P. A. Shah, K. Iqbal, S. Gillani, W. Ahmad, and Y. Nam, “Underwater Wireless Sensor Networks: A Review of Recent Issues and Challenges,” Wirel. Commun. Mob. Comput. vol. 2019, p. 6470359, 2019.
12. S. Krishna, P. Kovi, S. Jangam, G. Kumar, Kosgi, “Wireless Sensor Networks and Applications”, 10.13140/RG.2.2.23192.19207. 2017.
13. J. Yick, B. Mukherjee, D. Ghosal, "Wireless sensor network survey", Comput. Netw. Volume 52, pp. 2292–2330, August 2008.
14. M. Akhondi, A. Talevski, S. Carlsen and S. Petersen, "The role of wireless sensor networks (WSNs) in industrial oil and gas condition monitoring," 4th IEEE International Conference on Digital Ecosystems and Technologies, Dubai, 2010, pp. 618-623.
15. M. Akhondi, A. Talevski, S. Carlsen and S. Petersen, "Applications of Wireless Sensor Networks in the Oil, Gas and Resources Industries," 2010 24th IEEE International Conference on Advanced Information Networking and Applications, Perth, WA, 2010, pp. 941-948.
16. Ramasamy Velmani. "Mobile Wireless Sensor Networks: An Overview", 10.5772/intechopen.70592, 2017.
17. World Energy Council, “World Energy Scenarios 2016 report: Global energy demand growth set to fall”, Seymour, Ian OPEC: Instrument of Change, London, Macmillan Press Ltd, 2016.
18. A. Phil, “North Sea operators team up to reduce warehouse stock”, https://www.energyvoice.com/ oilandgas/north-sea/104585/north-sea-operators-team-reduce-warehouse-stock/. Energy Voice, 21 March 2016.
19. T. Andrew, “The Future of Cognitive Computing”, IBM Bluemix Blog, 23 November 2015.
20. G. Julianne, “How Millennials Could Bring the Oil Industry to its Knees”, https://oilprice.com/Energy/ Energy-General/How-Millennials-Could-Bring-The-Oil-Industry-To-Its-Knees.html, Oi Price 1 September 2016.
21. S. Petersen, P. Doyle, S. Vatland, C. Salbu Aasland, T. M. Andersen and D. Sjong, "Requirements, drivers and analysis of wireless sensor network solutions for the Oil & Gas industry," 2007 IEEE Conference on Emerging Technologies and Factory Automation (EFTA 2007), Patras, 2007, pp. 219-226.

22. S. Vaclav, “Energy at the crossroads: Global Perspectives and Uncertainties”, Cambridge, Massachusetts: The MIT Press Ltd, 2005.
23. Z. Lv, G. Wu, L. Yao, Z. Chen and F. Xia, “iCare: A Mobile Health Monitoring System for the Elderly", IEEE-ACM International Conference on Green Computing and Communications and International Conference on Cyber, Physical and Social Computing, Hangshou, Zhejiang Province, China, 2010 pp. 699-705.
24. J. Ayuba, J.A. Igimoh, "Implementation of Wireless Sensor Networks for Real Time Monitoring of Oil and Gas Flow Rate Metering Infrastructure", *Journal of Scientific Research*, Volume V. ISSN 2201-2796, 2017.

How to cite this article:

Wosowei Julius and Chandrasekar Shastry (2021) 'Wireless Sensor Network Applications In The oil And Gas Industry: A Survey', *International Journal of Current Advanced Research,* 10(02), pp. 23734-23740.
DOI: http://dx.doi.org/10.24327/ijcar.2021.23740.4706

****