Summarized Version published in
Ozean Journal of Applied Sciences 6(2), 2013. ISSN 1943-2429, Pages 39 – 43. Ozean publication

OIL AND GAS PROCESS MONITORING THROUGH WIRELESS SENSOR NETWORKS: A SURVEY

ACHONU O. ADEJO**, ADEIZA ONUMANYI, JANE M. ANYANYA AND OYEWOBI S. O
Telecommunications Engineering Department,
Federal University of Technology, Minna, Nigeria
Email: **achonu@futminna.edu.ng

***Abstract* – Effective measurement and monitoring of certain parameters (temperature, pressure, flow etc) is crucial for the safety and optimization of processes in the Oil and Gas Industry. Wired sensors have been extensively utilized for this purpose but are costly and difficult to deploy and maintain. Wireless Sensor Network (WSN) technology is an emerging alternative that introduces significant benefits in cost, ease of deployment, flexibility and convenience. The impact of WSN is expected to be tremendous in industrial automation owing to a report that projected the deployment of 24 million wireless-enabled sensors and actuators worldwide by 2016. With limited literature on this specific subject matter, this paper presents a critical survey into WSN applications as it directly impacts the Oil and Gas Industry. An overview of WSN is presented, case study applications from literature are highlighted and finally research challenges are discussed.**

1. INTRODUCTION

The Oil and Gas Industry is a major industry that drives several other industries, is crucial for world energy consumption and consequently has tremendous impact on the global economy. It includes processes for exploration, extraction, refining, transportation, and marketing petroleum products. (Mohammad et al., 2010)
In the course of the above processes, there exists a need for extensive monitoring of various parameters through the aid of large number of sensors. These sensors are placed at different locations to measure different data about plant performance and the operational environment. This is crucial to optimize plant safety, production, maintenance schedules, error tolerance and recovery. Over the years, deployed sensors have worked effectively together via wired cable links. These wired sensors are costly to deploy, operate and maintain, are not best suited for temporary installations and are difficult to set up in hostile and remote environments. (Stig et al. (2007), Alex et al. (2009))
Wireless Sensor Network (WSN) technology provides a faster, less costly, more flexible and more convenient option to the wired sensor systems. The field of WSN has evolved considerably due to engineering advances in Micro-Electro-Mechanical Systems (MEMS) technology which facilitated the development of smart sensors with reduced size, weight and cost. Advances in the field of internet, communications and information technologies have also contributed to development of WSNs. (Kazem et al. , 2007, Jennifer et al., 2008) WSNs are composed of sensing, computing and communication devices that collectively aid in observing and reacting to events and phenomena in specified environments where the communication is carried out over wireless

channels. WSNs can be applied in data collection, monitoring and surveillance systems. The technology has been widely deployed in Military/Security applications including surveillance and target tracking, Environmental monitoring applications, Health applications, Home applications and Industrial applications etc. Typical sensors deployed could be used to measure temperature, pressure, humidity, soil makeup, vehicular movement, noise levels, lighting conditions, the presence or absence of certain kinds of objects or substances, mechanical stress levels on attached objects, and other properties. (Kazem et al. (2007), Pathan et al. (2006))
WSNs have tremendous application in Industrial automation due to the fact that the sensors are becoming smarter, smaller, lighter and cheaper. The most monitored parameters are temperature, pressure, level and flow. Other parameters are position, proximity, image and security. Together, these parameters are very useful in manufacturing and process control automation.(marketresearch, 2012) The future prospects for WSN impact are very promising. Reports from (Mareca, 2012) show that the industrial WSN market has doubled over from 2010 - 2012. WSN technology is increasingly being adopted and applied with several sites having deployments of more than 3,000 nodes. This growth is due to increased education, reliability of today's WSN systems, maturing wireless mesh solutions, and a rapid migration to industry standards, such as WirelessHART and ISA100.11a. They project that there will be nearly 24 million wireless-enabled sensors and actuators deployed worldwide by 2016 and WSN technology would have a greater influence on applications.
With a more restricted consideration of the Oil and Gas industry, the impact of WSN is also very promising as reported in literature. A market Dynamics Report(Mareca et al., 2012) released by ONWorld's Research in 2012 show that Oil and gas expolaration, production and pipelines made up 27% of the global industrial WSN market in 2011. Two-thirds of the oil and gas end users in the survey are planning a standards based approach for future deployments of WSNs.

WSN applications in the Oil and Gas Industry are however not without challenges. These challenges are highlighted in (Stig et al. (2007) and include the cost of introducing and integrating the new technology, reliability of the system to meet industry standards, security, user friendliness, power consumption, maintenance and support activities, standardization, scalability, and development of internal wireless competence.
This paper seeks to present a critical look at the involvement of WSN in the Oil and Gas Industry, present the performance results from case studies available and identify the future prospects and research challenges. The rest of the paper is arranged as follows: Section 2 is an overview of WSN technology, Section 3 is a description of WSN application in Oil and Gas Industry, in Section 4, further research areas are presented and the conclusion of the paper is in Section 5.

2. OVERVIEW OF WSN

A Wireless Sensor Network is an infrastructure comprised of sensing (measuring), computing, and wireless-based communication elements that gives an administrator the ability to instrument, observe, and react to events and phenomena in a specified environment. The environment being monitored can be the physical world, a biological system, or an information technology (IT) framework while the administrator is usually a civil, governmental, commercial, or industrial entity. (Kazem et al., 2007)

The four basic components in a sensor network are:

1. An assembly of distributed or localized sensors
2. An interconnecting wireless network
3. A central point of information clustering; and
4. A set of computing resources at the central point (or beyond) to handle data correlation, event trending, status querying, and data mining

Nodes in the sensor network typically have one or more sensors, a radio transceiver or other wireless communication device, a small microcontroller and an energy source, usually a battery. (Romer and Friedemann, 2004) The diagrams below show the hardware and software structure of the sensor node:(Kazem et al., 2007)

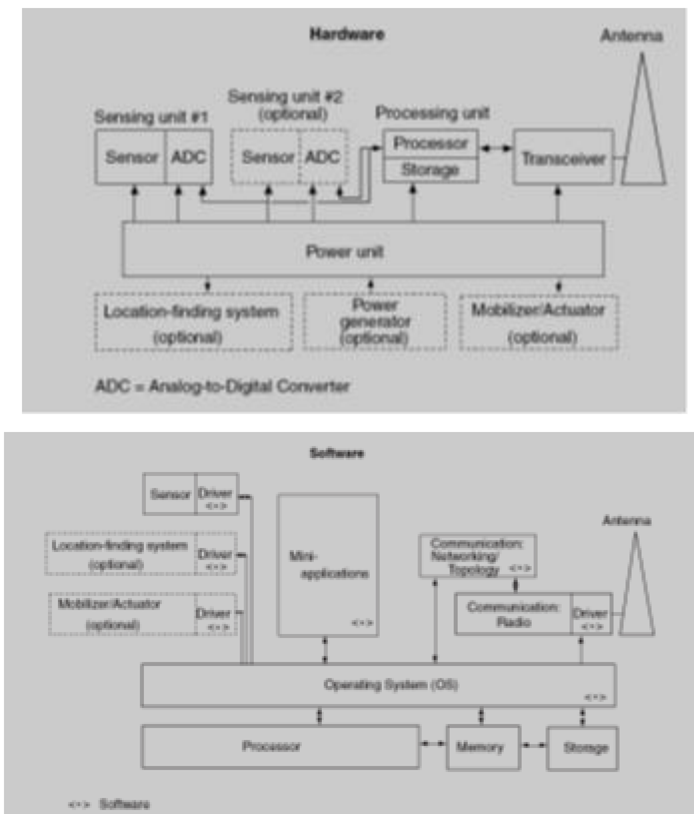

Fig1. Hardware and Software structure of sensor node (Kazem et al., 2007)

3. WSN APPLICATION IN OIL INDUSTRY

3.1 TYPICAL USE OF SENSORS:

In the Oil and Gas Industry, the type of data sensed includes pipeline pressure, flow, temperature, vibration, humidity, gas leaks, fire outbreaks, equipment conditions etc. (Alex et al., 2009) This is usually performed in typical application scenarios as described below:

A. Pipelines & Corrosion Monitoring: Pipelines are extensively used in the oil and gas industry including sub-sea, above ground, buried and gas pipelines. (Imad et al., 2008) Pipeline corrosion, especially for aging pipeline infrastructure leads to leaks, emissions and deadly explosions in production facilities and refineries. It is therefore crucial to perform real-time monitoring of flow, pressure build-ups, temperature changes, valve position to ensure safety, efficiency and streamline pipeline operation. WSN provide cheaper alternatives for this kind of monitoring. (Imad et al., 2008, Harry, 2012, Mareca, 2012)

B. Condition monitoring : Organized sensor systems are able to perform preventive and predictive maintenance and improve post-fault diagnosis. Decisions are made after sensor measurements are obtained from real-time monitoring to determine the condition of components. (Mohammad et al., 2010)

C. Monitoring Sub-sea installations: WSN can be used to monitor Oil and Gas installations embedded in the ocean. In order to optimize production it is necessary to constantly monitor equipments, and to ensure safety other parameters have to be monitored. WSN can be used to monitor production processes, prevent or detect oil and gas leakage, enhance production flow and yield of wells, improve working conditions and better protect the environment. (Martin et al., 2008) This type of application presents peculiar challenges since it is a deployment in water but nevertheless ongoing research is striving to ensure that WSN can provide sufficient reliability with less influence of interference on the wireless channels.

D. Production Performance: WSN can help optimize plant safety, production, turnarounds, shutdowns and maintenance and improve error tolerance and recovery. Sensor data can effectively monitor operation of plants and detect abnormal conditions. (Mohammad et al., 2010)

E. Wellhead Automation: WSN technology is used in optimizing the process of well drilling. New health monitoring systems are also being deployed in harsh and remote locations like offshore rigs. (Harry, 2012, Mareca, 2012)

F. Oil exploration and Seismic Surveys: The growing demand for energy worldwide is driving oil exploration and efficient and less expensive alternatives like WSN will be at the forefront. Major challenges in the industry include high complexity in real-time production and condition monitoring of facilities. There is a need for improved control over site performance and production has to be maximized through availability of consistent and reliable information upon which quick decisions should be made. WSN provides a means for real-time production monitoring with efficient acquisition and transmission of data. The technology fits well in harsh environments, has cost benefits and supports temporary deployments and sensor expansions. In the long run, if fully implemented, the derived benefits include remote equipment diagnosis, reduced equipment failures and shutdowns. (Harry, 2012)

WSN is also at the forefront of improved seismic surveys. The process of conducting surveys in deep and remote regions has been simplified and expanded, providing a possibility for millions of seismic sensors deployment around the world. (Harry, 2012, Mareca, 2012) Seismic explorations of new Oil and Gas reservoirs require large number of sensors (accelerometers) deployed over wide areas that measure back scattered wave fields. (Stefano and Umberto, 2009)

G. H_2S Monitoring: H_2S is an extremely toxic, colorless, flammable gas produced as a by-product of Oil exploration and refinery process and transported in pipelines for further processing. The pipelines have to be monitored for leaks. (Mohammad et al., 2010)

3.2 **CASE STUDY APPLICATIONS**

In this section, deployments of WSN in Oil and Gas scenarios are presented.

A. Typical Oil Site Laboratory testing: WSN solutions (SmartMesh network and SensiNet network) were deployed in laboratories having typical Oil and Gas equipments made of reinforced steel and concrete. The network performance tests proved that both SmartMesh and SensiNet are able to provide reliable communication in an Oil & Gas environment, and SmartMesh achieved this with relatively high stability and low latency. For interference with IEEE 802.11b networks, results show slight reduction in stability and increase in latency. The authors conclude that techniques to improve battery life have to be employed to make WSN suitable for Oil and Gas. (Stig et al., 2007)

B. Routing Protocol for WSN Pipeline monitoring: In (Imad et al., 2008), the authors considered the special linear structure where sensors are deployed on pipelines to monitor data. They presented an architectural model of the sensor network and based on this unique model for Oil and Gas pipelines, they demonstrated a multilayer addressing scheme with address assignments and communication schemes that ensure effective routing of data packets. The network also can utilize cellular GSM, GPRS networks, satellite cellular technology or WiMax to relay collected data to the Network control center.

C. WSN for Sub-sea (underwater) Oil installation: Authors (Martin et al., 2008) presented a heterogeneous multi-hop network solution for underwater deployment with a combination of ultrasonic, optical and RF networks as supplements to wires. This system ensures redundancy for robust and uninterrupted communication for critical industrial application like subsea oil and gas installations providing real-time information exchange and integration. Equipment position, movements and orientation can be monitored via sensor nodes placed on them.

They presented the design of the ultrasonic transceiver and Optical transceiver, and were able to control relative positioning of motes by measuring light intensities and also to find the distance and orientation between motes. The motion of the wireless sensor motes were also detected with the aid of a three axis MEMS accelerator which senses acceleration in the x, y and z directions. This is useful for manipulation and monitoring of sub-sea oil installations. Experimental results show a good match between the estimated distance between the motes based on voltage level (calculated data graph) and the actual measured distance.

D. WSN for seismic exploration of oil and gas reservoirs: In (Martin, 2012), authors presented a WSN system effective for seismic exploration of Oil and gas reservoirs on land. Controlled seismic vibrations were generated at some points in the exploration area. Vibration Sensor nodes spread across the area were then used to capture the vibration signals reflected from the geologic structure and then seismic images of the geologic subsurface were constructed from the distributed measurements at the backend. The design employed Digital Signal Processing (DSP) techniques to obtain high resolution images using an algorithm to jointly estimate location and time parameters of the sensor nodes. Results of high efficiency were obtained through MATLAB simulations.(Martin, 2012)

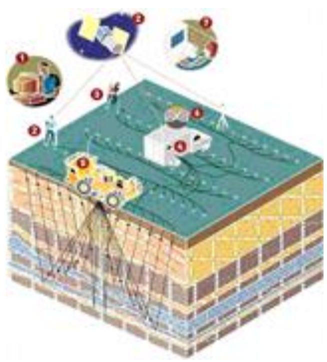

Fig. 2: Seismic exploration of gas and oil reservoirs on land.(Martin, 2012)

E. Oil and gas exploration: In (Harry, 2012), authors showed how sensors were deployed in harsh Oil and gas exploration scenarios; at depths of up to 12,000ft underground (sometimes in the ocean), pressures measured by down well sensors reached 20,000 PSI, temperatures could reach 1200^0C with the presence of corrosive fluids. Data measurements at exploration sites are very useful in monitoring and optimizing production. Through ongoing research in nanosensing and MEMS technology, highly sensitive wireless seismic sensor are being developed which can deliver high channel count and broader sensor frequency range.

F. Wireless Geophone Network: In (Stefano and Umberto, 2009), authors presented an architecture for a Wireless Geophone network exploits appropriate radio transmission technology to support short and long range transmissions in order to harness the advantages of both and provide efficiency as well as coverage. The system provides large-scale, real time, synchronous and spatially dense monitoring. There are three network entities: The Wireless Geophones ((WG) - sensors forming independent mesh sub networks), Wireless Geophone Gateways ((WGG) - GPS equipped sub network coordinators) and Storage unit (overall network coordinator). Ultra-wide band technology was proposed for short range WG to WG transmission within sub networks to conform to the data rate and power consumption requirement, guarantee network scalability and eas of use of other radio technologies. Specifications for the Medium access control (MAC) and network layer were also presented.

G. WSN remote monitoring of Oil Well (Pan et al., 2010)**:** A WSN based remote monitoring system for optimizing Oil reservoir production was presented. The system performs real time monitoring and surveillance of the oil well characteristics (temperature and pressure), gathers sensed data, processes it and forwards it to a database server on the internet for further processing. The system consists of a data acquisition terminal and a surveillance system (which has visualization and statistical capabilities). Authorized users at the surveillance center can view information via the web server and send control instructions remotely to the well. The design also incorporated sms notification facility.

4. RESEARCH CHALLENGES

WSN is a relatively new technology in the Oil and Gas Industry compared to the wired cables. The technology will continue to improve and provide performance that effectively meet the industry requirements. The sensing requirements have to be determined, the type of sensors that can withstand the conditions and the type of antennae required are areas for research. (innovateuk, 2012)

Power management is a challenge because the sensors are battery-powered devices. The lifespan of the battery determines the life of the sensor, so research will continue to develop efficient power management techniques to meet Oil and Gas requirements like energy harvesting, efficient scheduling etc. The effects of interference on wireless signals from the hostile environments where the sensors are deployed also have to be investigated to ensure that WSN can operate unhindered. Extreme temperature, wind, humidity, noise, dust rain etc could likely have interference effects. (Alex et al., 2009) RF penetration, noise immunity and dynamic network topology adaptation are critical for reliable data transmission. (Gianni, 2012) When deploying new WSN systems in existing plants, the required changes in factory and plant work processes must be considered. Developing efficient data processing, simple but powerful software interfaces, middleware and security (authentication, authorization, encryption) considerations are also research issues highlighted in (Alex et al., 2009)

Other issues include full development of standards, data rate/bandwidth, ease of use of system, scalability, seamless integration and range. (Mareca, 2012)

5. CONCLUSION

In this paper, an overview of WSN application in Oil and Gas Industry has been presented. WSN technology introduces significant benefits in cost, ease of deployment, flexibility and convenience in relation to the wired alternative that is well established in the industry. Significant research points to projection of widespread deployment of WSN in industrial automation. Case studies were presented showing WSN deployment in Condition monitoring, pipeline monitoring, seismic exploration and sub-sea installation. The technology is however not without its unique challenges which have been highlighted here as areas of research.

Summarized Version published in
Ozean Journal of Applied Sciences 6(2), 2013. ISSN 1943-2429, Pages 39 – 43. Ozean publication

REFERENCES

Alex Talevski, Simon Carlsen and Stig Petersen. Research Challenges in Applying Intelligent Wireless Sensors in the Oil, Gas and Resources Industries, 7th IEEE International Conference on Industrial Informatics (INDIN 2009), 2009

Gianni Minetti, Paradox Engineering SA. Wireless Sensor Networks Enable Remote Condition Monitoring. Pipeline & Gas Journal, July 2012, Vol. 239 No. 7. Accessed 20-12-2012 from http://www.pipelineandgasjournal.com/wireless-sensor-networks-enable-remote-condition-monitoring?page=show

Harry Zervos, Wireless sensors and energy harvesters in harsh environments. Online Journal: Energy Harvesting Journal, 12-07-2012, published by IDTechEx, Accessed 20-12-2012 from http://www.energyharvestingjournal.com/articles/wireless-sensors-and-energy-harvesters-in-harsh-environments-00004566.asp?sessionid=1

Imad Jawhar, Nader Mohamed, Mohamed M. Mohamed, and Junaid Aziz, "A Routing Protocol and Addressing Scheme for Oil, Gas, and Water Pipeline Monitoring Using Wireless Sensor Networks", 2008

Innovateuk.org, Advances in wireless sensor networks for hostile environments: Event details, 3-05-2012, The Derby Conference Centre, London Road, Derby, Derbyshire, England. Accessed 20-12-2012 fromhttps://connect.innovateuk.org/web/advances-in-wireless-sensor-networks-for-hostile-environments/speakers

Jennifer Yick, Biswanath Mukherjee and Dipak Ghosal. Wireless sensor network survey in Elsevier Journal of Computer Networks, 2008. www.elsevier.com/locate/comnet

Kazem Sohraby, Daniel Minoli and Taieb Znati. Wireless sensor networks: technology, protocols, and applications. Published by John Wiley & Sons, Inc., Hoboken, New Jersey, 2007 ISBN: 978-0-471-74300-2

Mareca Hatler, Darryl Gurganious, and Charlie Chi. Oil & Gas Wireless Sensor Networks (A Market Dynamics Report), Published: Q2 2012 Accessed 20-12-2012 from http://onworld.com/oilandgas/index.html, http://www.onworld.com/smartindustries/set/

Mareca Hatler. Industrial Wireless Sensor Networks: Trends and developments. (ON World Survey) Accessed 20-12-2012 fromhttp://www.isa.org/InTechTemplate.cfm?template=/ContentManagement/ContentDisplay.cfm&ContentID=90824

Marketresearch, Industrial Wireless Sensor Networks (IWSN) Market – Global Forecast & Analysis (2012 – 2017)June 19, 2012, Accessed 20-12-2012 fromhttp://www.marketresearch.com/MarketsandMarkets-v3719/Industrial-Wireless-Sensor-Networks-IWSN-7030069/

Martin Dalbro, Erik Eikeland, Aart Joakim in't Veld, Stein Gjessing, Tor Sverre Lande, Håvard Kolle Riis and Oddvar Søråsen. Wireless sensor networks for off-shore oil and gas installations, 2nd International Conference on Sensor Technologies and Applications, 2008

Martin Schmatz . WSN for seismic exploration of oil and gas reservoirs, , accessed 20-12-2012 from http://www.zurich.ibm.com/sys/energy/wireless_oilgas.html

Mohammad reza Akhondi, Alex Talevski, Simon Carlsen and Stig Petersen. Applications of Wireless Sensor Networks in the Oil, Gas and Resources Industries in 2010 24th IEEE International Conference on Advanced Information Networking and Applications.

Pan Yi, Xiao Lizhi and Zhang Yuanzhong, "Remote real-time Monitoring System for Oil and Gas Well Based on Wireless Sensor Networks", 2010

Pathan, A.S.K., Hyung-Woo Lee and Choong Seon Hong. Security in wireless sensor networks: issues and challenges, The 8th International Conference on Advanced Communication Technology, 2006. ICACT 2006. 20-22 Feb. 2006. Conference Publications Page(s): 6 pp. - 1048

Römer, Kay and Friedemann Mattern (December 2004), "The Design Space of Wireless Sensor Networks", IEEE Wireless Communications 11 (6): 54–61, doi:10.1109/MWC.2004.1368897

Stefano Savazzi and Umberto Spagnolin. Synchronous Ultra-Wide Band Wireless Sensors Networks for oil and gas exploration, 2009

Stig Petersen, Paula Doyle, Svein Vatland, Christian Salbu Aasland, Trond Michael Andersen and Dag Sjong Requirements. Drivers and Analysis of Wireless Sensor Network Solutions for the Oil & Gas Industry, 2007, IEEE