

Wireless Sensor Network for Oil & Gas Industry

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Introduction

The Oil & Gas industry is one of the most prevalent industries for the application of Wireless Sensor Technology. Hostile terrain, remote locations and inclement weather are common barriers to properly monitoring, managing and serving field equipment such as compressors, generators, turbines, plunger heads, tanks, separators and wellheads. Wireless Sensor Network (WSN) solutions for the oil, gas and power generation reduce maintenance costs, lower energy consumption, minimize downtime, improve equipment performance, enhance safety and centralize otherwise discrete controls.

Facing rising costs in labor and energy combined with the need for exploration and research & development gives wireless sensor technology the advantage over traditional wired technology with the ability to access and report back on remote data locations, in areas where wired technology is expensive or is not even an option. The Gas & Oil industry has benefited from the use of Wireless Sensor Technology by lowering costs and expanding the possibilities for new and future improvements.

Oil & Gas Industry

Wireless technology has the potential to be beneficial in many regards. Eliminating the need for cables can contribute to reduced installation and operating costs, it enables installations in remote areas, and it allows for cost efficient, temporary and mobile systems. In addition, wireless technology enables a new range of applications; particularly in the area of health, safety and environment. Networks may be composed of many different types of sensors such as seismic, thermal, visual, acoustic, radar, magnetic, infrared, and many others which are able to monitor a wide variety of ambient conditions such as: Environmental weather conditions, Pressure, Temperature, Gas, Fire, Sound, Humidity, Vibration, Electrical characteristics, Mechanical stress, Soil makeup, Object movement, Presence or absence of objects, Speed, direction, and size of an object, Location etc. Beside of monitoring and managing applications, the ambient monitoring sometimes is extremely necessary to the human and environment safety.

For Oil & Gas Industry, the most common and important applications are related to the monitoring of real-time process control, safety, maintenance and production performance.

- **Remote Monitoring**

The WSN solution provides remote monitoring capabilities for oil and gas companies to meet this new technology, regulatory and production demands. Remote Monitoring solutions for oil and gas applications can greatly reduce, and in some cases, eliminate maintenance costs. Due to the rate of production and the cost of the product, these platforms require continuous operation for maximum productivity. Real-time data acquisition and monitoring cuts the cost of complying with regulations, reducing or eliminating down times for maintenance or unplanned machinery failure and allows for energy management and savings by giving the operator a constant view of the state of all aspects of the platform. Example Oil & Gas Remote Monitoring applications:

- Pipeline Integrity Monitoring
- Tank Level Monitoring
- Equipment Condition Based Monitoring

- Pipeline Pressure Relief Valve Monitoring
- Refineries Pressure Relief Valve Monitoring
- Wellhead Automation and Monitoring Offshore (marine environments) are particularly corrosive and require intensive maintenance.

- **Condition Monitoring and Maintenance**

The aim of fault diagnosis is the estimation of the component status through sensor measurements and monitoring of system components. Equipment diagnosis tries to determine the cause of a failure of a component where system diagnosis is performed on a system of composite components. Using sensor measurement, preventive and predictive maintenance can be performed and post-fault diagnosis is improved. Predictive maintenance methodologies require that components are monitored in real time, normally are applied techniques such linear level threshold.

Sensors may detect vibration, temperature heat, dissolved gas, electromagnetic properties, power consumption, performance etc. When combined with other sensor outputs, these continuous measure signals represent significant information about the condition of a component. These signals are processed and compared, and with result a component state can be determined. However, when such a setup exists, systems can detect and even predict potential upcoming component faults. This may limit downtime, repair costs, damage and potential danger. Component fault diagnosis can be performed off-line without direct coupling to real-time data and processing.

- **Safety Monitoring**

During oil exploration and refinery processes, many types of toxic gases are produced as product or sub-product. These include Ammonia (NH₃), Hydrogen Sulphide (H₂S), and Sulphur Dioxide (SO₂). Among which H₂S is a useful and common product, but also a cause of health and corrosion problems. It is used to recover sulphur, which is commonly used for manufacturing sulphuric acid, medicine, cosmetics, fertilizers and rubber products. In refinery processes, H₂S is carefully transported in pipelines to workshops where further processing takes place. The main concern at this stage is the potential of leaks that can have a severe impact on human beings as well as the environment. Leakages also mean putting a pipeline out of service for repair. The cause

of leakages can be excessive deformations caused by earthquakes, corrosion, abrasion, material flaws or even intentional damage.

Hydrogen sulphide is an extremely toxic, colorless, flammable gas that is heavier than air and soluble in water. Exposure to low levels of hydrogen sulphide will cause irritation, dizziness and headaches, while exposure to high levels of the prescribed limits will cause nervous system depression and, eventually, death. H₂S also impact the ecological system negatively. For instance, H₂S in water may change the PH value, which would result in an ecological imbalance between the microbes and aquatic species. So, it is important monitoring H₂S processes during oil exploration, and the use of WSNs could be interesting.

- **Production Performance Monitoring**

Given an appropriate amount of data from various performance aspects of an oil and gas functions as facilitated by the flexibility of WSNs, an unsupervised Self Organizing Map can prioritize key sensor values and classify operational performance. It can show when a plant is operating normally and appoint errors or defective behavior. Such networks are often used in combination with supervised approaches. The unsupervised networks perform data pre-processing and the supervised networks estimate the associated parameters.

New control tools need to be extensively tested before they can be integrated into such complex operating environments. Sensor data can be used to realize certain characteristics and patterns in operation data. Such solutions may enhance operational visualization, foresight, forecasting and maintenance schedules for effective and efficient operation and maintenance. This optimizes plant safety, production, turnarounds, shutdowns and maintenance and improves error tolerance and recovery.

WSN Application in Oil & Gas Industry

There are several challenges related to the introduction of such wireless devices in the oil, gas and resources industries. Such wireless devices must have the following properties:

- Restricted size, shape, construction and certification.
- Make do with limited processing power, memory, storage, battery consumption and screen real-estate.
- Self contained. When possible, devices should generate their own power or, contain battery packs with extended battery life of many years to reduce maintenance requirements.
- Operate in a difficult wireless environment both in terms of radio noise and obstructions but also where certain restrictions on such radio devices are present (such as flammable areas).
- Operate in hostile areas where environmental and platform conditions may be very harsh.
- Embedded platforms. Implement complex network algorithms with real-time requirements and adaptive routing protocols.
- Contribute in a simplified ad-hoc and multi-hop network.
- Seamlessly integrate with existing IT solutions.
- Self re-configurable, dynamic and adaptive.
- Provide services within a dynamically changing system environment.
- Exhibit fault tolerance and recovery (self-healing, robust and reliable).
- Based on open, international standards.
- Operate in the unlicensed portions of the frequency spectrum.
- Low maintenance.
- Secure operation and transmission.
- Clearly defined operational reliability and availability of the wireless network within the operational environment.

The studies show that the required changes in factory and plant work processes might be the largest impediment for the introduction of wireless technology in the oil, gas and resources industries. It has been noted that problems are typically experienced when the human factors are ignored in the adoption of new technology.

- **WSN Power Characteristics**

The Oil & Gas industry is pushing for battery lifetimes in excess of five years (at a one-minute update rate) for wireless sensors. A key driver for this requirement is the maintenance effort needed to replace either the batteries or, if the battery is encapsulated or otherwise non-rechargeable, the device. With the expectation that thousands of wireless sensors could be deployed in a single facility and will have to be replaced or re-engineered periodically, a tremendous effort would be necessary simply to maintain the network.

Power consumption has a dramatic impact on the life time of the sensors (if battery operated) or on the feasibility of a self-powered solution (harvesting energy from heat or vibration sources in the surrounding environment, for example). To reduce energy consumption, the node needs to be dormant as much as possible and, when active, send as few bits as possible. For condition monitoring applications, which typically have a lower update rate, the latency is less important whereas reliability, security and power consumption remain vital.

In order to ensure long battery life of the sensor nodes in a WSN, the sensor nodes must be able to enter a low-power sleep mode. The utilization of this sleep-mode feature requires the network to be completely time-synchronized so that the sensor nodes know when, and for how long, they can sleep before they have to transmit or receive data. In addition, battery life can be prolonged by employing efficient routing protocols that optimize network traffic so that the number of hops and retransmissions are kept to a minimum. The power consumption tests showed that current WSN technologies are not capable of fulfilling the Oil & Gas industry demand for battery lifetimes in excess of 5 years. Considering that the production lifetime of an oil well is about 10 years, in this scenario, the use of harvesting energy could be important to give a long life to WSN nodes, which is crucial to Oil & Gas industry environment.

Energy Harvesting

Some of the major benefits about Energy Harvesting (EH) suitable for WSN are:

1. Reduce installation cost. Self-powered wireless sensor nodes do not require power cables wiring and conduits, hence they are very easy to install and they also reduce the heavy installation cost.
2. Reduce maintenance cost. Energy harvesting allows for the sensor nodes to function unattended once deployed and eliminates service visits to replace batteries.
3. Provide sensing and actuation capabilities in hard-to-access hazardous environments on a continuous basis.
4. Provide long-term solutions. A reliable self-powered sensor node will remain functional virtually as long as the ambient energy is available. Self-powered sensor nodes are perfectly suited for long-term applications looking at decades of monitoring.

Harvesting energy for low-power devices like wireless sensors presents a new challenge as the energy harvesting device has to be comparable in size with the sensors. There are complex tradeoffs to be considered when designing energy harvesting circuits for WSNs arising from the interaction of various factors like the characteristics of the energy sources, energy storage device used, power management functionality of the nodes and protocols, and the applications' requirements.

Currently, the main sources of ambient energy considered suitable for use with WSNs are solar, mechanical (vibration or strain) and thermal energy. Solar power is the most common and matured among the different forms of energy harvesting. To optimize the energy extraction from the harvester to the wireless sensor, a low-power maximum power point tracker (MPPT) circuit has been proposed to efficiently transfer the harvested solar energy to rechargeable batteries even in non-optimal weather conditions.

The SiliconReef's EH01 solution is a complete power management system and it could be easily incorporated to an energy harvesting system for WSN application. EH01 system has capability of harvesting energy from a PV cell, for this it uses a MPPT algorithm to adjust the operating point dynamically, so the maximum power transfer is achieved. Such a tracking system can yield up to 20% more power than regular converters under similar conditions. The EH01 is divided in two DC/DC Converters, a Micro-USB Charging Port and a Li-Ion Battery Charger.

With the indoors WSN applications, mechanical and thermal energy are an alternative to power up the network sensors. Vibrational, kinetic and mechanical energy

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generated by movements of objects can also be harvested. One method of harvesting vibrational energy is through the use of a piezoelectric capacitor while kinetic energy can be harvested using a spring-loaded mechanism. Some systems use a vibration-based harvesting micro power generator to scavenge environmental energy for use in a sensor node. The efficiency of mechanical energy harvesting could be improved using the same concept used in solar cells. Maximum Power Point Tracker algorithms are applied to achieve a point with maximum power transfer after the alternate input energy are converted to constant energy using an AC/DC converter.

Current is generated when there is a temperature difference between two junctions of a conducting material. Thermal energy harvesting uses temperature differences or gradients to generate electricity. Due to the lack of moving parts in thermal energy harvesting devices, they tend to last longer than vibration-based devices.

For the commonly energy sources: mechanical, thermal, light and RF, Table 1 shows an approximate estimative of power levels harvested for each energy source. Power harvested from human motion or temperature difference achieved in human body level is much lower than in an industrial environment. For portable applications that use human energy harvesting, ultra low power systems are crucial. For industrial applications, functionality and range of WSN nodes, for example, are improved.

Energy Source	Harvested Power
Vibration/Motion	
Human	4 $\mu\text{W}/\text{cm}^2$
Industry	100 $\mu\text{W}/\text{cm}^2$
Temperature Difference	
Human	25 $\mu\text{W}/\text{cm}^2$
Industry	1–10 mW/cm^2
Light	
Indoor	10 $\mu\text{W}/\text{cm}^2$
Outdoor	10 mW/cm^2
RF	
GSM	0.1 $\mu\text{W}/\text{cm}^2$
WiFi	0.001 mW/cm^2

Table 1: Energy Harvesting Estimates

- **Energy Harvesting and Wireless Sensor Networks**

For Oil & Gas application, specifically, the sensors active life is related to the how long a battery could power up a sensor, and the difficulty to eventually do maintenance or replacement of the sense nodes or its battery. With energy being the key issue, the focus has been on power management.

In this respect, most of the efforts have proposed the use of energy harvesting to supplement the on-board battery. Therefore, efficient power management is important to maximize the benefits of having the extra harvested energy. The use of maximum power point tracker circuit for this application is extremely important to maximize the life time of sensor nodes with no repair needed, maximizing energy harvesting from every available source.

WSN can be used to remotely monitor pipelines, natural gas leaks, corrosion, H₂S, equipment condition, and real-time reservoir status. Data gathered by such devices enables new insights into plant operation and innovative solutions that improve platform safety, optimize operations, prevent problems, tolerate errors, and reduce operating costs.

Example of Oil & Gas WSN Systems

Some examples of wireless sensor nodes systems already in use in Oil & Gas industry are detailed above.

Wireless IO System

Wireless IO (input/output) is basically a mechanism by which analog discrete and other raw signals are transmitted via radio to and from a central processing device, such as a Distributive Control System (DCS), Programmable Logic Controller (PLC), or other Remote Terminal Unit (RTU). Specifically, the data transmitted includes level, pressure, flow, temperature, alarms and signals generated to actuate final control elements, such as valves. (<http://www.freewave.com/products/allproducts/fgrio.aspx>)



Figure 1: Freewave Wireless IO System

- **Wireless Temperature Sensor**

The device has a Resistance Temperature Detector (RTD) probe with a low power Wi-Fi sensing technology for remote monitoring that could be apply to a variety of applications, for example, freezers, containers or incubators. (http://www.aginova.com/wifi_sensor_sentinel_pro_rtd.php)

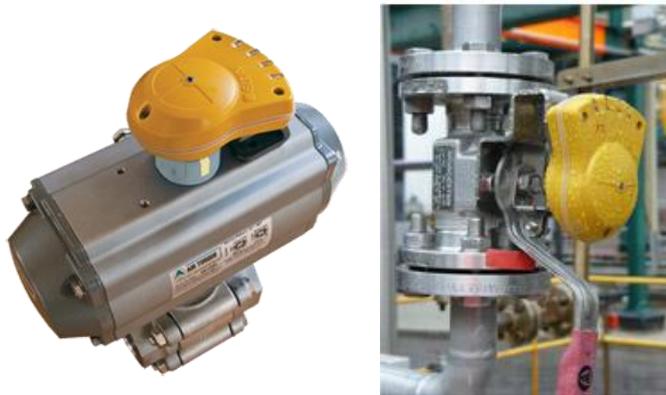


Figure 2 Temperature RTD Wi-Fi Sensor

Characteristics	
Radio	IEEE 802.11b
Typical power emission	33mW
Unit Accuracy	±0.2°C typical
Temperature range	from -200°C to +400°C
Resolution	0.1°C
Power	Internal AA 3.6V Lithium battery

- **Valve Device**

The Valve Device (VD) is connected to a valve and provides information about open or closed state, and also measures the valve’s angle position. Information like temperature and battery status is also transmitted. It collects changes dynamically of a valve and transmits it wireless to a central data and control management. This system provides preventive data on the health of the actuator/valve set. (<http://www.eltav.com/solutions.asp>)



Characteristics	
Position	Valve position is broadcast to Valve Device Routers (VDR) that are installed in the process line facility.
Operation	High accuracy valve angle is converted to % of opening and transferred to the local PLC or DCS via standard interfacing such as Modbus RTU/TCP.
Power	battery operated with a long-life battery that will last for years

Conclusion

In Oil & Gas industry, a safety and efficiently operation depends of a constant monitoring and management of a range of parameters and a variety of ambient condition, like temperature, pressure, vibration, gas, fire, tank level, gas leakage, equipment condition, mechanical stress, object speed, etc. The use of wireless sensor network reduce maintenance and installation costs and unplanned system failure, give the possibility to access and control remotely in dangerous environments. The use of energy harvesting improves these benefits to provide a self-powered solution. Because of these characteristics, WSN systems using energy harvesting became a feature commonly adopted in Oil & Gas industry.

Some measurement and control systems are already using energy harvesting in its sensors or actuators, like valve sense devices and remote sensing terminals, that measure and transmit parameters like temperature, pressure, tank level or flow.

A variety of energy sources could be used to power sensor nodes in a WSN. Solar, mechanical and thermal energy are the main sources. Between these options, solar energy is the most used and matured energy harvesting source. To optimize the energy extraction, methods of maximum power point tracker (MPPT) are used with solar panel, giving more autonomy to the sense nodes and improving energy extraction efficiency even in a no optimal weather condition. The SiliconReef EH01 system adds these benefits to a USB charger and battery charger modules. EH01 system could be incorporated in a solar energy harvesting module coupled to a sensor node, improving its autonomy and reducing the time between battery changes or maintenance.

About SiliconReef

SiliconReef is a Brazilian company driven by innovation in the microelectronics sector, which focuses on the development of integrated circuits (ICs) for harvesting alternative energies. By combining cutting-edge technology and sustainable energy, the company's mission is to develop efficient products and solutions for harvesting alternative energies.

Over the past seven years, the SiliconReef team has been developing projects for local industry and the export market. Currently, the company is preparing to launch its first product in 2013, the microchip Energy Harvesting 01 (EH01).

SiliconReef also offers design and project services for dedicated integrated circuits and the development of projects based on architectures for rapid prototyping (FPGAs). The company offers top-quality services in order to meet the needs of a number of industries, such as automotive parts, utilities, electronics and industrial automation, amongst others.

SiliconReef's differential in the field of energy efficiency and alternative energy sources may be translated as greater autonomy for electronic devices, consolidating the promotion of renewable energy within the semiconductor industry, an indispensable alternative in a world that will not easily relinquish connectivity.

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