Wireless Sensor Network deployment inside RA-6 Argentine Nuclear Research Reactor for environmental measurement.

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Abstract. In this paper we present a low-cost Wireless Sensor Network (WSN) inside of the Nuclear Research Reactor RA-6 in Argentina. The WSN measures environmental parameters to offer a support system for the operators in the Control Room and to provide readily available information on the internet, for public access or other uses. Wireless sensors, also known as motes, measure radiation, temperature, vibration, light, pressure and send information to a gateway that bridges data between the internet and conventional instrumentation.

1 Introduction.

Over the last few years there has been an important development of a new class of elements, known as motes. Motes are small sized autonomous computers with wireless networking capabilities that can offer new possibilities for monitoring physical or environmental conditions. By taking advantage of it's small size, it can be integrated in moving equipment and the use of batteries enable the acquisition of data in hard to reach places. Sensors are integrated to Motes to measure radiation, temperature, vibration, pressure, motion, light [1].

Motes can be part of a Wireless Sensor Networks (WSN). WSN are attractive for environmental monitoring systems inside and outside Nuclear Research Reactors [2].

Once the WSN is working, it can be integrated into a conventional instrumentation system through open industrial protocols standards that specifies the communication of real-time plant data between control devices from different manufacturers. An example is OLE for Process Control (OPC).

The WSN measures environmental parameters to offer a support system to the operators in Control Room and to provide readily available information on the internet, for public access or other user. Radiation measurement is important inside as it is outside the containment, helping in the detection of leakages.

In this work, a WSN was developed to measure environmental variables in the Argentinean Nuclear Research Reactor, RA-6. Radiation and pressure were of particular interest because of their importance in reactor operation.

Several motes were developed with temperature, light humidity and vibration sensors. One such mote has a modified Geiger-Müller (GM) Counter radiation sensor integrated. The device polarizes GM with high voltage, but at sufficient low power to function in a WSN.

2 Wireless Sensor Network.

A WSN consists of spatially distributed autonomous sensors which monitor environmental conditions, such as temperature, radiation, vibration. Data is passed through the network to a information collection gateway (Fig. 1).

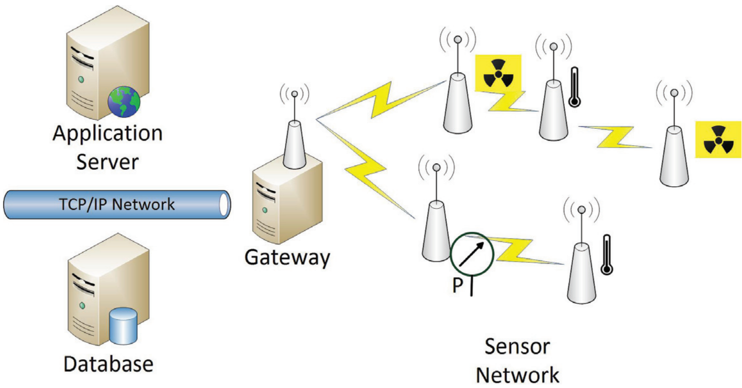


Fig. 1. General WSN layout.

As the most energy-consuming task in a sensor, data transmission must be power-cycled in order to extend the lifetime of the node. Taking this into consideration, the sensor network nodes were designed to operate in one of two different modes. The first is dedicated to sense and transmit every period of time desired. When the node is not sensing a low power mode is used in order to conserve energy. Nodes operating in this mode are usually powered by batteries. The second mode provides a permanent data route to the gateway node, which requires the transmitter to be constantly powered. In this mode high power batteries, any kind of energy harvesting or an AC adapter is used.

Sensor nodes, Motes. Motes have several parts: a low-power microcontroller, a radio transceiver with an internal antenna or connector for external antenna, an energy source like batteries and embedded sensors or an interface to connect external sensors.

The motes function in a network and typically fulfill one of two purposes: - either data-logging, whereby sensor information from environment is processed, or sinks in the ad-hoc wireless to pass data back to a collection point or gateway.

(a) Telosb or Tmote Sky (b) Zolertia Z1 (c) Epic Core

Fig. 2. Different motes models.

Different motes were used in the RA-6 WSN. Some technical specifications of which are as follows:

1. Telosb or Tmote Sky Fig. 2(a)
   TI MSP430 8MHz processor, 10kB RAM, 48kB flash, 1MB external flash, 250kbps radio 802.15.4 compatible. Digital temperature, light and humidity sensor embedded. Maximum consumption 63mW and 15μW in sleep mode.

2. Zolertia Z1 Fig. 2(b)
   TI MSP430 16MHz processor second generation, 8kB RAM, 92kB flash, 512kB external flash, 250kbps radio 802.15.4 compatible. Digital accelerometer and temperature sensor embedded. Maximum consumption 60mW and 9μW in sleep mode.

3. Epic Core Fig. 2(d)
   TI MSP430 8MHz processor, 10kB RAM, 48kB flash, 512kB external flash, 250kbps radio 802.15.4 compatible. Integrated mote-in package module. Maximum consumption 63mW and 9μW in sleep mode.

Every mote support TinyOS, open-source operating system used specially designed for WSN in UC Berkeley. TinyOS is independent from hardware and makes focus in low power devices [3], [4].

2.1 Gateway services.

In order to process, store and distribute environmental data gathered by the sensor network a gateway is needed. This information is used to build graphical representations of the data and to facilitate data distribution to industrial automation software and web services. The gateway used in this application is shown in Fig. 3: a single board computer and a mote connected with an embedded antenna.

The gateway service was built so that the data can flow in near real time, from the motes to the graphical interface and industrial systems. To achieve this,

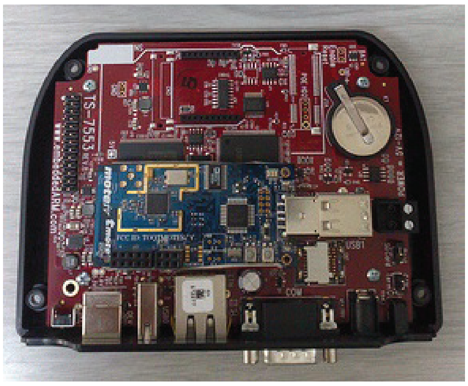


Fig. 3. Gateway. Single board with a mote attached.

the database was removed from the data processing and distribution path. It is only used as a data repository accessible from a web interface.

The connection between the sensor network and the data service is made with the SerialForwarder tool provided by TinyOS. This tool runs inside a computer with a mote attached, and bridges the sensor network with a TCP/IP network where the application is running. As the network bridging is separated from the data service, it is possible to connect many network gateways from different zones, as long as they have a connection.

Both gateway and data storage applications require minimal computational resources. Embedded computers, such as the RaspberryPi, would be suitable options for handling these tasks. Data, however, is stored in a computer with a conventional hard disk in order to prevent early storage failure.

2.2 Argentine Research Reactor RA-6.

The RA-6 4, inaugurated in 1982, is located in San Carlos de Bariloche, Río Negro, in the Centro Atómico Bariloche (CAB) belonging to the Argentine Atomic Energy Commission (CNEA). As an educational reactor, the RA-6 was part of the training of hundreds of Argentine and foreign professionals in the fields of physics, engineering, nuclear radiochemistry and materials science. Besides, the reactor is used for research in different areas. This open-pool research reactor, with a variable core arrangement, has a plain and versatile design and may function as a multipurpose unit.

For instance, in 2002 one of its bunkers was turned into a BNCT (Boron neutron capture therapy) facility, for the treatment of cancer. The RA-6 is a multipurpose reactor (MPR), used for training and research, with a power output of 1MW thermal, an open pool, is designed to use 20 per cent enriched uranium fuel, and is cooled with light water.

Fig. 4. RA-6 Nuclear Research Reactor.

2.3 Radiation sensor.

One of the objectives of this work was to integrate a radiation sensor in a mote. A radiation sensor based on a Geiger-Müller (GM) chamber was designed to detect alpha, beta and gamma radiation [7]. GM chambers are generally small and robust, and detect and measure using a simple circuit. Sensors of this type feature a tube (cathode) with a thin wire inside (anode). The tube is filled with a gas, and a high voltage is applied to the wire of about 200 to 1600 volts.

The mote counts and emits via radio pulses generated in the polarized chamber. Particle interactions with the detector can be counted, but the type and energy of the incident radiation cannot be determined using this device.

A special circuit with the following specifications was designed to polarize the GM chamber:

- High voltage circuit to polarize GM chamber 200-700V.
- Low power for suitability in a WSN.
- Low voltage supply (3V) and low power consumption (<20mW).
- Interface between the GM chamber and mote to count pulses.

It is also important that the circuit have two modes of operation: continuous or discontinuous.Radiation measurements as part of conventional instrumentation must be taken continuously inside the research reactor. In other locations, inside and around the reactor building for example, continuous measurement is unnecessary. Irradiation rates over a certain time interval is sufficient in such cases.

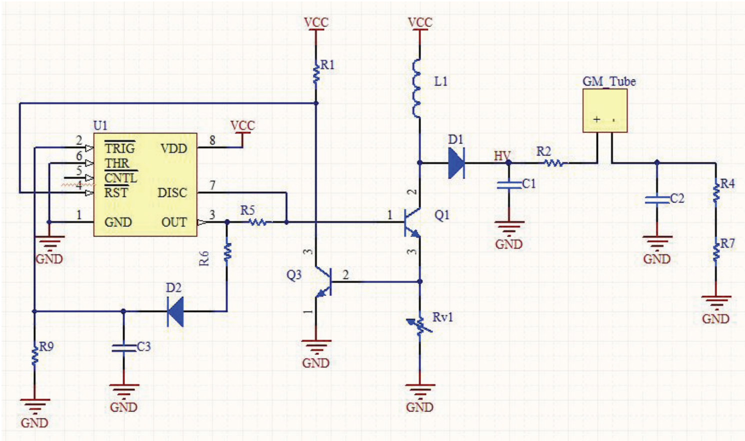


Fig. 5. HV schematic circuit.

2.4 High Voltage (HV) Circuit.

In a battery-powered instrument, HV needed to operate GM must be generated efficiently. A flyback generator based on a 10 mH inductor and a high-voltage switching transistor meets this requirement. When the transistor is on, the battery voltage is applied to the inductor. When a threshold current is reached, the transistor is rapidly switched off. This generates a positive high-voltage spike that charges a capacitor via a fast HV diode. A schematic circuit is shown in Fig. 5

The advantage of this HV circuit is the very low supply current consumption and the independence of the supplying voltage.

Each particle detected generates a 20-30 μs pulse up to 100 V high at the GM tube's cathode. A transistor turns on to detect each pulse with the mote.

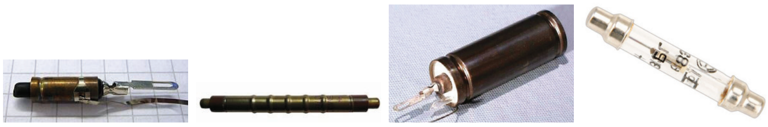
2.5 GM tubes used.

Different GM tubes were used, ZP1400 Fig.6(a), SBM20 Fig.6(b), ZP1300 Fig.6(c), and SI3BG Fig.6(d). Each GM has a different Gamma sensitivity to Co60, which determines suitability to background or to high dose radiation. ZP1400 and SBM20 have high sensitivity suitable for measuring background radiation and ZP1300 and SI3BG for measuring high dose rate.

3 Test inside RA-6.

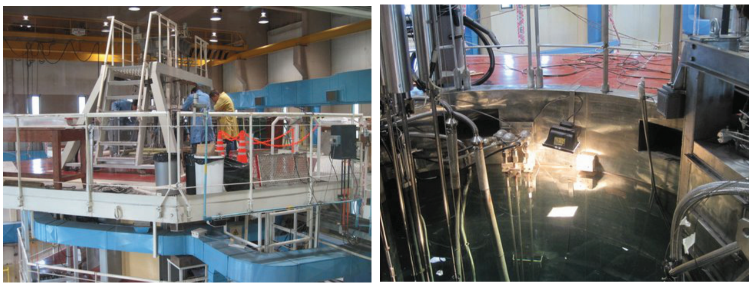
3.1 RA-6 radiation measurement.

Measurements were made inside RA-6 at the point of air extraction. From the top of the open pool, air extraction holes, Fig. 7(a), remove air, which is then sent



(a) ZP1300 (b) SBM20 (c) ZP1400 (d) SI3BG

Fig. 6. Different Geiger - Müller tubes.



(a) RA-6 pool top. (b) Holes with air extraction.

Fig. 7. RA-6 radiation measurement test. Pool top and air extraction.

through filters and released outside. A mote with the GM module was placed inside an air duct column and measures every 15 seconds, seen in Fig. 7(b).

Background radiation measurement is shown in Fig. 8.

Another Geiger was placed on the primary coolant circuit loop to measure, in this case, one minute each half an hour.

3.2 Vibration sensor.

Vibration sensors are used to monitor structures and machinery health. Vibrational signals can be used to detect and identify problems before they occur [8]. The Z1 mote measures vibrations with an embedded digital accelerometer and sends data to the gateway.

ADXL345 accelerometer embedded in the Z1 is a 3-axis accelerometer made by Analog Devices. The mote measures vibrations at 1 kHz with 1 Hz resolution in each axis.

Vibration analysis was made to primary loop pump output, Fig.9(a) where vibration was producing some problems with pump seal. The pipe is in between the pump output and a heater exchanger.

A vibration power spectrum from primary loop pump is shown in Fig. 9(b).

3.3 Pressure sensor.

The reactor building must operate at a low pressure relative to the atmosphere while the reactor is in operation. This ensures that material or particles remain inside building.

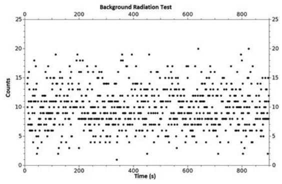
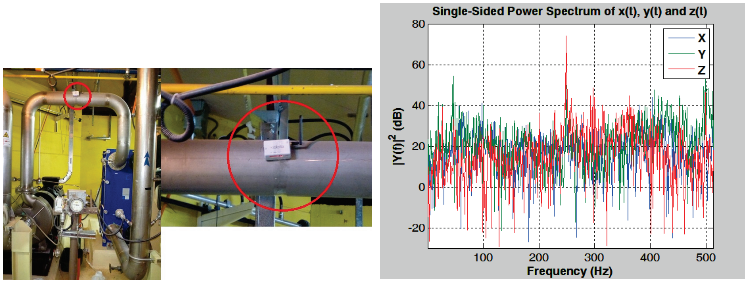


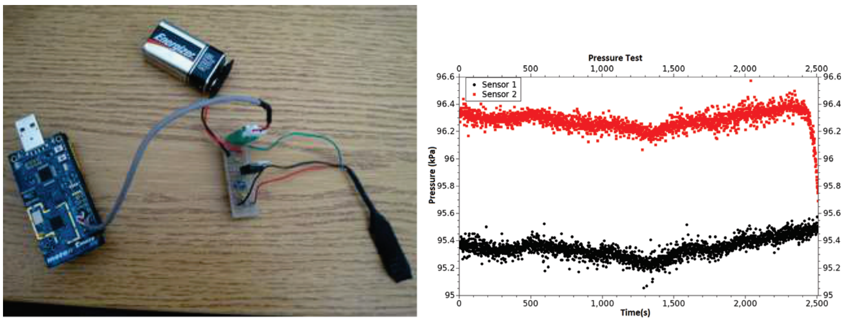
Fig. 8. Background radiation test.



(a) Primary loop pump and output pipe.

(b) Vibration Power spectrum.

Fig. 9. Radiation measurement test in RA-6 reactor.



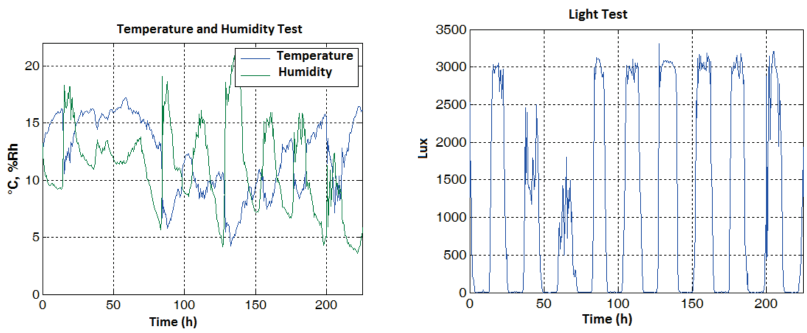
(a) Integrated pressure circuit.

(b) Pressure measurement.

Fig. 10. Pressure sensor.

A pressure sensor was integrated in a mote, as seen in Fig. 10(a). The MPXH6250A is a linear pressure sensor designed to produce tension linearly with respect to the pressure applied. This voltage reaches the mote through the ADC port.

A measurement realized in the building can be appreciated in Fig. 10(b).



(a) Humidity and temperature test. (b) Light test.

Fig. 11. Light, humidity and temperature measurement.

3.4 Light, humidity and temperature sensors.

Tmote Sky has embedded 2 digital sensors to measure light, humidity and temperature. Sensirion SHT10 measures both temperature and humidity and Hamamatsu S1087 light.

It is important that these measurements are received from the same Mote at the same time for reliable correlations between the different readings. In Fig. 11, results are presented from a test conducted inside of the reactor building.

4 Conclusion.

A Wireless Sensor Network was successfully deployed in the RA-6 Argentine research reactor. Vibrations, environmental parameters such as radiation, pressure, temperature, humidity and light were measured. Integration of motes and sensors is easy and low-cost, which makes this new technology attractive for applications in and around research nuclear reactors.

A data collection system was developed to acquire and store information from wireless sensors, it provides a means of displaying information over the internet, and in a future will act as a bridge with conventional instrumentation systems through, for example, an OPC interface.

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