The Wireless Sensor Networks for Factory Automation

Dr. Javad Shakib, DeVry University, Pomona

The Wireless Sensor Networks for Factory Automation

Sensors are used in many devices and systems to provide information on the parameters being measured or to identify the states of control. In recent years, the concept of computer networking has gradually migrated into the sensor community, and the trend in industry is moving toward distributed control with intelligent sensing architecture. The rapid development and emergence of smart sensor and field network technologies have made the networking of smart transducers an economical and attractive solution for a broad range of measurement and control applications.

A Wireless sensor network (WSN) has a large number of small, low-powered sensor nodes (also called motes), usually densely located in the target area and one or more remote sinks organized into a cooperative network. These can be connected to other networks through gateways. Each node is equipped with sensing, processing and communication capabilities.

This paper explains in detail the wireless sensor network (WSN) architecture, Network Topologies, standards and protocols. It will delve into other IEEE 1451 standards and discuss how to create WSNs and intelligent interactive devices, and interface with smart sensors and transducers. Moreover, the WirelessHART(Highway Addressable Remote Transducer), IEEE 1451, ZigBee / 802.15.4, and 6LoWPAN standards will be explained. Networking actuators and smart sensors and real-world technical challenges will also be highlighted.

Advances in computing and instrumentation have sparked the need of engineering technology graduates who can update and improve manufacturing facilities and product design. This paper is an attempt to expose engineering technology students earlier to WSNs and other emerging technologies in lieu of taking WSN track in their technology curriculum.

1. Introduction

The field of wireless communications is diverse, and it may be difficult to get a picture of the different technologies utilized in a certain field. Wireless sensor network, WSN, technology has demonstrated a great potential for industrial, commercial, and consumer applications. In industry, the proposed and already employed technologies vary from short-range personal area networks to cellular networks, and in some cases even global communications via satellite are applied.

Researchers have explored the various aspects on applications of WSNs in process industry[1]. There have been tremendous efforts toward the product research and development in industry.

The WSNs have a wide range of applications. These can be divided into:
- Monitoring space;
- Monitoring things;
- Monitoring interactions with things with each other and the encompassing environment (monitoring complex interactions).

The increasing interest in wireless sensor networks can be promptly understood simply by thinking about what they essentially are: a large number of small sensing self-powered nodes which gather information or detect special events and communicate in a wireless fashion, with the end goal of handing their processed data to a base station. Sensing, processing and communication are three keys. Sensor networks provide endless opportunities but at the same time pose formidable challenges, such as the fact that energy is a scarce and usually non-renewable resource.

A node in sensor network consists of a microcontroller, data storage, sensor, analogue-to-digital converters (ADCs), a radio data transceiver, controllers that tie the pieces together, and an energy source. The nodes as shown in Figure 1 include wireless communications capability as well as sufficient computing resources for signal processing and data transmission[2].
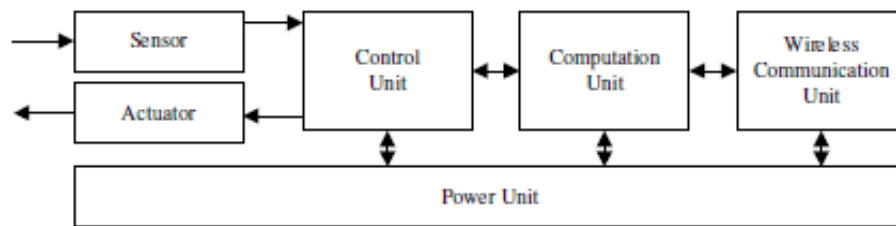

Figure 1: Node of WSN

Adopting WSNs for process monitoring and control provides great advantages over traditional wired systems. As a ubiquitous technology, general issues regarding WSNs have been extensively researched in the academic arena. However, WSN technology is not considered mature enough to be widely implemented in process control applications.

Even though wireless transmission of data has been utilized for over ten years in process control applications such as supervisory control and data acquisition (SCADA), industrial WSN products for process monitoring and control were not commercially available until recently due to their specific requirements and challenges. Nowadays, their most diffused application for factory automation is the so called "cable replacement", where wireless links are used for bridging two wired fieldbus segments. For instance, wireless communication is employed to replace brush-contacts in rotating machine. Up to now, a relatively small number of products have been available for industrial of applications.

Generally, WSNs are employed for monitoring and not for control since they still have reliability problems. In fact, radio transmission is subjected to a higher Bit Error Rate (BER) than cable transmission, especially if transmission power is low (in order to preserve battery charge) and interference is heavy (as on industrial sites). Moreover, most of the wireless technologies in use today have been developed without any kind of cooperation between their promoters. This means that, in general, wireless standards are not only incompatible but also "competing".

In addition to reviewing the recent research and development achievements, this paper will also analyze special issues for implementing WSN technology on industrial process monitoring and control.

2. What Is a Wireless Sensor Network?

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to monitor physical or environmental conditions. A WSN system incorporates a gateway that provides wireless connectivity back to the wired world and distributed nodes[3]. The wireless protocol you select depends on your application requirements. Some of the available standards include 2.4 GHz radios based on either IEEE 802.15.4 or IEEE 802.11 (Wi-Fi) standards or proprietary radios, which are usually 900 MHz.[4, 7]

The increasing interest in wireless sensor networks can be promptly understood simply by thinking about what they essentially are: a large number of small sensing self-powered nodes which gather information or detect special events and communicate in a wireless fashion, with the end goal of handing their processed data to a base station. Sensing, processing and communication are three key elements whose combination in one tiny device gives rise to a vast number of applications. Sensor networks provide endless opportunities but at the same time pose formidable challenges, such as the fact that energy is a scarce and usually non-renewable resource.

2.1 WSN System Architecture, Network Topologies and Standards

Wireless technology offers several advantages for those who can build wired and wireless systems and take advantage of the best technology for the application. To do this, you need flexible software architecture such as the NI LabVIEW graphical system design platform. LabVIEW offers the flexibility needed to connect a wide range of wired and wireless devices[3].

WSN nodes are typically organized in one of three types of network topologies. In a star topology, each node connects directly to a gateway. In a cluster tree network, each node connects to a node higher in the tree and then to the gateway, and data is routed from the lowest node on the tree to the gateway. Finally, to offer increased reliability, mesh networks feature nodes that can connect to multiple nodes in the system and pass data through the most reliable path available. This mesh link is often referred to as a router.

There are a number of standardization bodies in the field of WSNs. The IEEE focuses on the physical and MAC layers while others on layers 3 and above. There are also several non-standard, proprietary mechanisms and specifications.

Standards are used far less in WSNs than in other computing systems, which make most systems incapable of direct communication between different systems. However predominant standards commonly used in WSN communications include: WirelessHART, IEEE 1451, ZigBee / 802.15.4, and 6LoWPAN

IEEE 1451 is a set of smart transducer interface that describe a set of open, common, network-independent communication interfaces for connecting transducers (sensors or actuators) to microprocessors, instrumentation systems, and control/field networks. One of the key elements of these standards is the definition of Transducer electronic data sheets (TEDS) for each transducer. The TEDS is a memory device attached to the transducer, which stores transducer

identification, calibration, correction data, and manufacturer-related information. The goal of the IEEE 1451 family of standards is to allow the access of transducer data through a common set of interfaces whether the transducers are connected to systems or networks via a wired or wireless means[10].

IEEE 1451.1 defines a common object model and programming paradigm for smart transducer systems. The mission of IEEE 1451.2 was to separate the network issues from the transducer issues. This was accomplished with four concepts: the Smart Transducer Interface Module (STIM), the Network Capable Applications Processor (NCAP), the Transducer Independent Interface (TII), and the most important element of this strategy, the Transducer Electronic Data Sheet (TEDS). The TEDS is a memory device attached to the transducer which stores transducer identification, calibration, correction data, and manufacturer-related information. The STIM handles the sensor and actuator low-level interface stuff and formats the data communication messages between the NCAP and STIM in a standardized digital manner. The NCAP handles the network interface and also manages the TII dedicated interface port to the STIM.

2.2 A Second Look at Components of a WSN Node

A WSN node contains several technical components. These include the radio, battery, microcontroller, analog circuit, and sensor interface. When using WSN radio technology, you must make important trade-offs. In battery-powered systems, higher radio data rates and more frequent radio use consume more power. Often three years of battery life is a requirement, so many of the WSN systems today are based on ZigBee due to its low power-consumption[4].

Since battery life and power management technology are constantly evolving, and because of the available IEEE 802.11 bandwidth, Wi-Fi is an interesting technology.

The second technology consideration for WSN systems is the battery. In addition to long life requirements, you must consider the size and weight of batteries as well as international standards for shipping batteries and battery availability. The low cost and wide availability of carbon zinc and alkaline batteries make them a common choice.

To extend battery life, a WSN node periodically wakes up and transmits data by powering on the radio and then powering it back off to conserve energy. WSN radio technology must efficiently transmit a signal and allow the system to go back to sleep with minimal power use. This means the processor involved must also be able to wake power up, and return to sleep mode efficiently. Microprocessor trends for WSNs include reducing power consumption while maintaining or increasing processor speed. Much like your radio choice, the power consumption and processing speed trade-off is a key concern when selecting a processor for WSNs. This makes the x86 architecture a difficult option for battery-powered devices.

Wireless transmission of data in industrial applications has been around for a long time but recently it has gained importance, with attention from both market leaders and medium- and small-sized competitors. Successful use of wireless sensors in systems such as supervisory control and data acquisition (SCADA) proved that these devices could effectively address the needs of industrial applications. The attempt in most critical process applications is to wirelessly communicate and monitor temperature, flow, level, and pressure parameters.

3. Advantages of integrating WSN's in automation systems

Using WSN has a number of advantages over traditional wired industrial monitoring and control systems as expressed in the following:

3.1 No Wiring Constraints

Wireless sensor nodes are installed on industrial devices and equipment to monitor the measurements such as proximity, temperature, pressure, level, and power quality, and to transmit/receive control signals for activating the device accordingly. Without the wiring constraints, wireless sensors can also be installed more easily in unapproachable places or cost-prohibitive situations.

Furthermore, the industrial process system becomes highly scalable and flexible due to the device autonomy. For example, devices can be easily relocated and reorganized without tedious work on removing old cables and lay outing new ones. It is also possible to extend an existing system in order to increase the sensor coverage.

In addition, newly added devices can be installed at any location without running power supply and data communication wires through concrete walls during factory expansion.

3.2 Easy Maintenance

After the installation of wired device, control engineers have to deal with various wiring maintenance problems while wireless device is almost carefree; only a battery change is necessary after years of operation. In addition, it is also possible to relocate current wireless devices or deploy additional wireless devices on the control system after it has been installed with minimal changes to the existing configuration.

3.3 Reduced Cost

The installation costs of WSN are lower than that of traditional automation and control systems since wiring is avoided. Moreover, for some applications, sensing nodes can put their radio in off mode when necessary; this will save much energy compared to wired devices, which requires constant power supply. The decreased installation costs make it possible to increase the number of sensors and, hence, the spatial resolution. The increased spatial resolution allows for more fine-grained measurements and control.

A further advantage is that wireless technology enables temporary measurements: a network can be set up to perform measurements during a limited time in order to measure, optimize and evaluate the effect of the optimization. We call such an effort ad hoc benchmarking.

3.4 Performance

With these standards mentioned in section 2222, Industrial WSNs have the potential to outperform the existing process control network with wired devices. Firstly, it has higher data

transmission speed. Secondly, unlike wired control systems, where devices share a single bus, multiple wireless communications can act simultaneously if there is no mutual radio interference[10]. Thirdly, more sensors/datapoints can be used to beat the performance of traditional wired control system.

4. Issues and Challenges the Wireless Sensor Networks for Factory Automation

Although wireless sensing products for industrial applications now exist, the market is fragmented as shown in Figure 2, consisting of a number of participants and a variety of applications. The adoption process has also been slow as many challenges still need to be overcome despite the benefits offered.
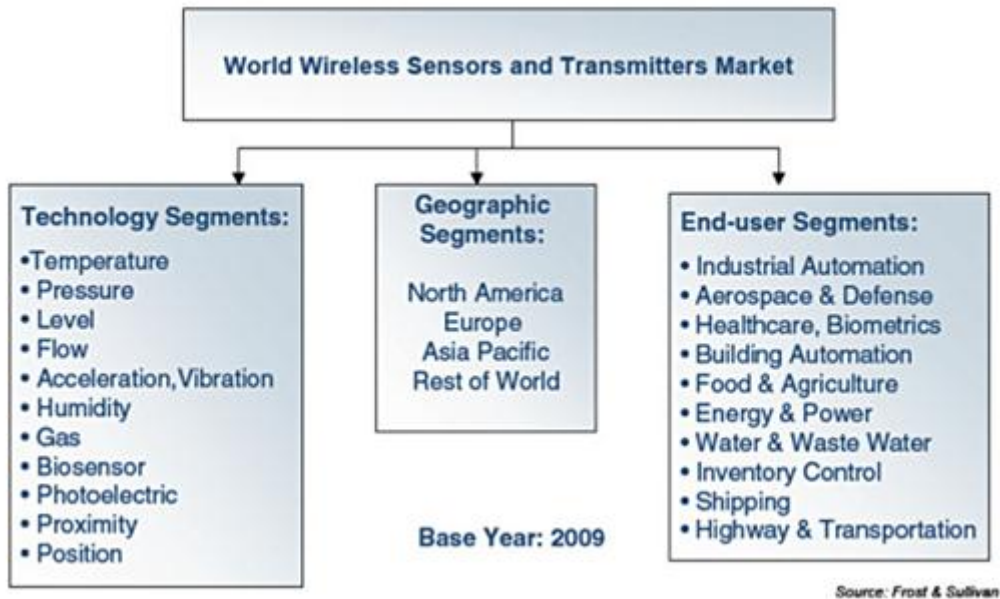

Figure 2: Scope and key areas of research for the wireless sensors market in 2009

Traditional control systems for factory automation are based on the wired and deterministic Fieldbus. Real-time estimation, detection and feedback control over the WSN with network uncertainty, bandwidth and energy constraints have posed myriad research challenges to the traditional control theory[2].

Industrial applications offer a broad scope for growth in wireless sensor use, but this growth cannot be achieved without overcoming some other key challenges facing the market[5], as shown in Figure 3.

1. Multivendor equipment interoperability
2. Demand for industrial-safety-rated wireless devices
3. Lack of adequate open bandwidth
4. Deployable network size and hopping challenge
5. Constantly evolving standards

Interoperability is a major challenge for market participants. This is further exacerbated by the embedding of proprietary communication protocols and support software. Wireless communication technology is successful only if the equipment of different vendors can communicate. Also, equipment must have plug-and-play options for ease of use as well as to improve market acceptance.

In terms of the development of industrial-safety-rated devices, vendors' ability to make a wireless sensor system fail-safe depends heavily on the type of application in which the wireless sensor is used.
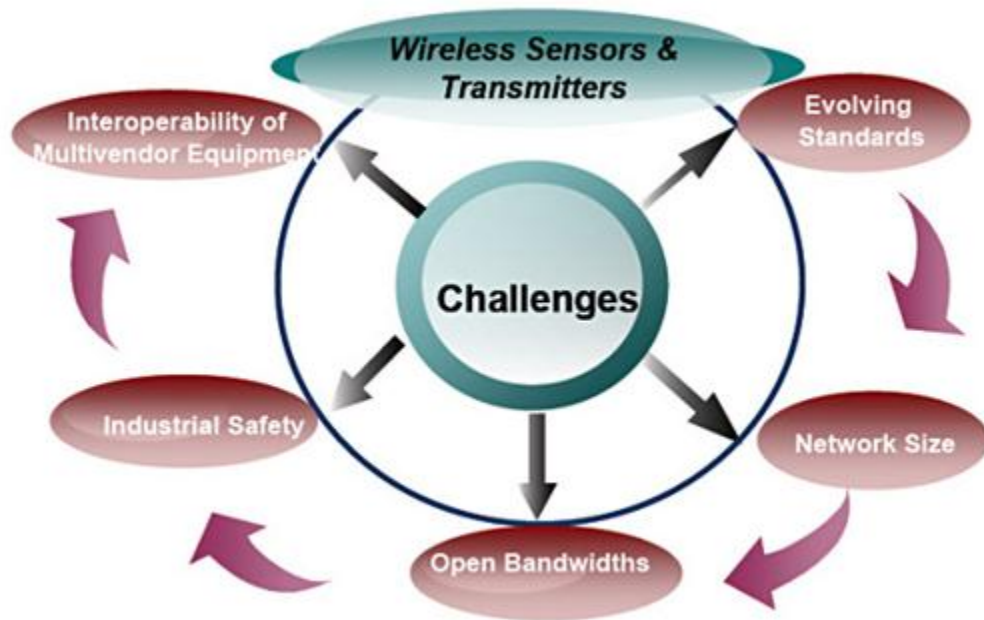

Figure 3: Key challenges for the wireless sensor market

Licensed bandwidths are a subject of disagreement in the market. Market leaders and large companies feel that the use of unlicensed bands interferes with the licensed ones and, therefore, should be completely eliminated. Presently, most wireless sensor network devices operate in unlicensed bands such as 915 MHz and 2.4 GHz, and reliable communication can be affected by interference from other devices operating in the same frequency band. However, the majority of the market participants feel that the use of unlicensed bands is likely to bring in larger benefits accompanied by unrestricted growth as well as to provide equal opportunity to market participants operating on the same platform. There are various initiatives taken up by companies to promote open bandwidths.

4.1 Key Hardware and Network Issues

There is no ideal wireless sensor or transmitter that could be used for all conceivable applications[5]. In fact, each application determines what attributes the wireless transmitters should have.

Wireless sensors, transmitters, and networks are used for diverse applications with varying requirements and characteristics as shown in Figure 4. Designers and the research community are developing a hardware design platform capable of supporting multiple applications.

Because wireless sensor networking is built around low-power radios, the nodes that make up the network play a key role in wireless communication. From a physical perspective, the deployment of nodes may take several forms depending on the sensor application and the desired pattern of communication. Deployment may also be a one-time activity, where the installation and use of a sensor network are strictly separate activities. It can also be a continuous process where more nodes are deployed over the lifetime of the network.

Figure 4: Hardware attributes most sought after by end users (2010).

The application needs determine the actual size of the network. The application can vary from a single sensor node to multiple sensor nodes. Again, the size of each sensor node can vary from a large box to a microscopically small particle. Most of these tiny nodes developed by labs have yet to be deployed in any application. However, these microscopically small particle-sized sensor nodes have the potential to be used in a number of military applications.

5. Trends

Despite a challenging economy, the industrial Wireless Sensor Network (WSN) market has doubled over the past two years. A recently completed survey points to increasing WSN adoption and expanding markets[6].
10 years ago, deployments of more than 20 nodes were rare. Today, network densities are increasing, and several sites have deployments of more than 3,000 nodes. The 2012 survey indicates this growth is a result of 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.

Over the past two to three years, there has been a rapid migration to wireless mesh standards. Nearly an equal number of industrial end users prefer WirelessHART or a hybrid strategy that combines WirelessHART and ISA100.11a[6].

Seventy-five percent of current WSN adopters—including vendors, suppliers and end users—indicate they are using a wireless mesh protocol for at least some of their wireless field devices, and 20% are only using wireless mesh systems. Over half of the WSN adopters are using energy harvesting for at least a few wireless sensor nodes, and 9% use energy harvesting to power the majority of their wireless field devices.

Compared with ON World's previous survey in 2010, data reliability has dropped to only about two-thirds as much of a concern compared with the previous 2010 survey. Costs, battery life, and standards confusion are ranked slightly higher as inhibitors in our current survey compared with the previous survey[6]. Seventy percent of end users indicate they are planning WSN or additional applications.

Looking forward, there will be many more wireless sensing applications and technology variations for industrial automation. In addition to wireless mesh systems, non-mesh products based on IEEE 802.15.4 are emerging, targeted at the process and discrete industries. Adoption for point-to-point and point-to-multipoint wireless sensor systems is accelerating for oil and gas exploration and production. In addition, interest in simpler, lower-cost wireless sensors, such as "passive wireless sensors," is a growing innovation area.

One thing that is certain is that wireless sensing solutions will continue to play a pivotal role for industrial automation.

6. Academia: WSN in Universities and Classrooms

The application of sensor networks is of interest to most diverse fields. Environmental monitoring, warfare, child education, surveillance, micro-surgery, and agriculture are only a few examples[9].

The field of wireless sensor networks is growing rapidly and has captured the interest of various sectors. The increasing popularity of WSN has motivated universities to provide students with a foundation in the area. It is crucial that the emerging field of wireless sensor networks be integrated into their related curriculums. This technology covers a variety of core ET, CS and CE concepts ranging from embedded systems , Wireless Communication, Sensors, computer architecture, computer network, , to software engineering. Its low cost and highly portable natures serve as a high cost-effective learning lab platform for these undergraduate curricula.

Through joint efforts of the University of California at Berkeley and the College of the Atlantic, was carried for environmental monitoring. Joint efforts between Harvard University, the University of New Hampshire, and the University of North Carolina have led to the deployment of a wireless sensor network to monitor eruptions at Volcán Tungurahua, an active volcano in central Ecuador.

Just as they can be used to monitor nature, sensor networks can likewise be used to monitor human behavior. In the Smart Kindergarten project at UCLA, wirelessly-networked, sensor-enhanced toys and other classroom objects supervise the learning process of children and allow unobtrusive monitoring by the teacher.

Medical research and healthcare can greatly benefit from sensor networks: vital sign monitoring and accident recognition are the most natural applications. With these ideas in mind, Harvard University in cooperation with the School of Medicine at Boston University developed CodeBlue, an infrastructure designed to support wireless medical sensors, PDAs, PCs, and other devices that may be used to monitor and treat patients in various medical scenarios[8].

On the hardware side, the research team has created Vital Dust, a set of devices based on the MICA21 sensor node platform (one of the most popular members of the Berkeley motes family), which collect heart rate, oxygen saturation, and EKG data and relay them over a medium-range (100 m) wireless network to a PDA[8]. Interactions between sensor networks and humans are already judged controversial.

Many Capstone and Senior projects by students are being done in this area. One recent example is 'Outlet Power Monitoring Using Wireless Sensor Networks'[9].

The need for increased power monitoring in residential and commercial units is becoming increasingly self-evident by the ongoing shortage of natural resources and rising costs of electricity. This need has been supported by recent government and private policies towards reducing power consumption and better power monitoring. This system is one that implements these features by taking advantage of several new technologies, including energy harvesting techniques and innovative low-power wireless protocols and hardware.

To obtain the set of detailed, specific information about electricity consumption, a wireless sensor network that monitors plug-load activity is devised. This network monitors power usage at individual outlets, aggregate the data, and report useful information about electricity use to the consumer. The user is able to access power monitoring data from a smartphone or traditional browser, including how much power each outlet in the unit is consuming independently. This is made possible by a network of sensors forming a mesh topology that is able to report specific power monitoring data for each outlet, but also aggregate data for the entire unit. This mesh network is able to interface directly to a hub that routes data to a web server, which enables accessing this data from smartphones and browsers easy web interface as, depicted in Figure 5.

Figure 6 shows the full circuit for no-contact power monitoring, including CW multiplier circuit, wireless module and microcontroller, and the sensing circuit labeled in red. The CW multiplier is needed to step up the voltage from the harvesting transformer to above 3.3 so that the GINA can be powered.

The sensing circuit on this board is much smaller than the direct-contact method because there is no need for a sensing inductor or chip. The signal from the transformer is routed directly underneath the board.
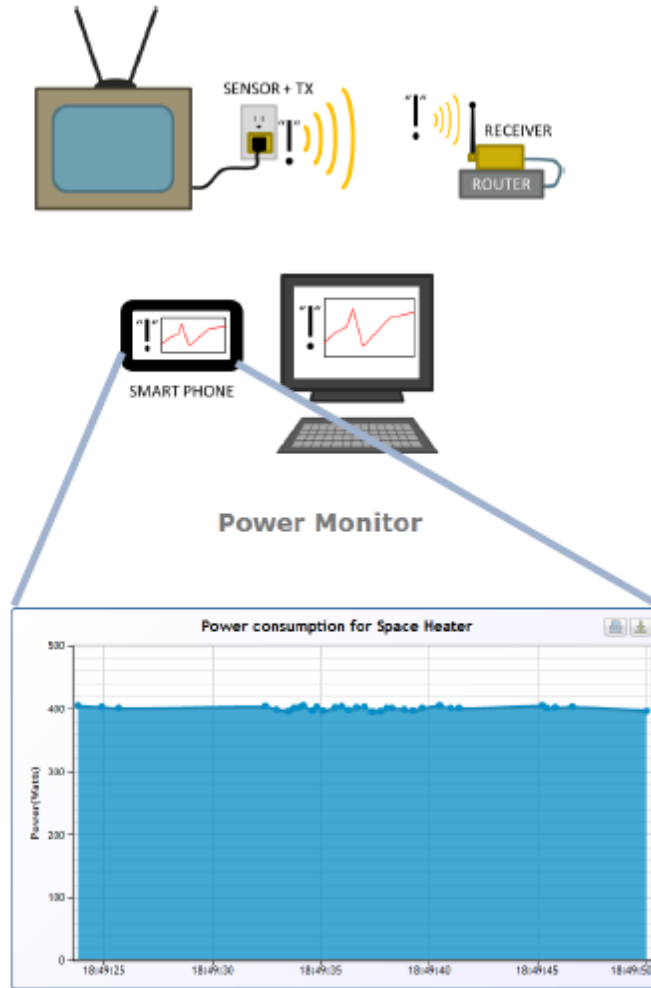
Figure 5: Overview of power monitoring system and the power monitoring web interface. This interface is available through a URL that can be accessed from any web-enabled device.
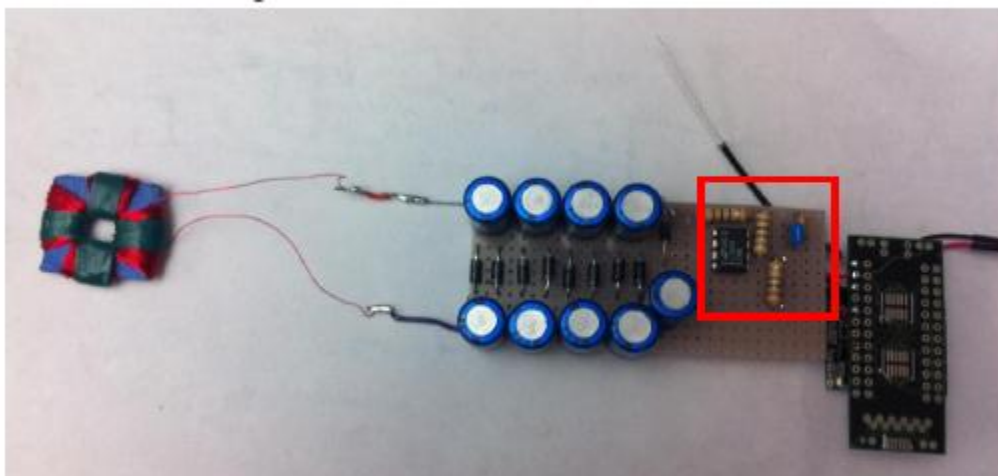

Figure 6: Full circuit board for the no-contact power monitor. Sensing circuit is labeled in red.

A number of approaches that are used by twenty five universities to integrate wireless sensor networks concepts into their curriculum were studied and published before[11]. Some institution are utilizing the model of integrating Wireless Sensor Networks concepts as modules into their existing courses, as seen by the Massachusetts Institute of Technology, Stanford University, the University of Vermont, and Drexel University.

At Devry University, there are couples of traditional courses that have contact with this topic: Embedded Microprocessor Systems, Mechatronics, Wireless Communication Systems, Data Communication Networks, in ECET program. Sensors and Instrumentations; Wired, Optical and Wireless Communication Systems in ECT program; and Wireless Technology and Service in NETW program are just a few to mention.

One of the purposes of this paper is to expose students in these programs to the WSNs topic in their technology curriculum. There is a strong recommendation in integrating Wireless Sensor Networks concepts into these courses and encouraging a wireless sensor network project for the senior project and capstone course.

7. Conclusion

To build the control and monitoring applications of factory automation over the WSN needs the solid background theory in terms of control, information processing and communications. To make them market success, the standardization plays key roles for cost reduction and interoperability.

Looking forward to the convergence of control, information and communication theory, there are many challenges ahead for researchers. Deploying the industrial standard to the factory automation demands more effort to be carried out by industrial practitioners.

In this paper, we suggest that coexistence of wireless-equipped machines must be reached with a minimum exchange of information among systems and with no alteration of the machine characteristics. In particular, the synchronization among WSNs is a good basis on which the coexistence among different types of network can be built. The idea is to have a central arbiter that knows the requirements of all the WSNs; it allocates medium-access rights to WSN coordinators that can apply these rules safely because they are synchronized by means of an RTE network.

In our opinion, the key feature that must be stressed to ensure the highest efficiency is coexistence. It stands for the ability of wireless systems to slightly modify their behavior in order to eliminate any mutual interference. In other words, two WSNs in the same area can change, accordingly, their media access strategies to avoid collisions (in the time and frequency domains). Clearly, the behavioral change is possible because the involved systems have knowledge about other co-located wireless devices.

References

1. Gang Zhao, Network Protocols and Algorithms, 2011, Vol. 3, No. 1, Wireless Sensor Networks for Industrial Process Monitoring and Control: A Survey.

2. L. Q. Zhuang, K. M. Goh and J. B. Zhang, 1-4244-0826-1/2007 IEEE , The Wireless Sensor Networks for Factory Automation: Issues and Challenges.

3. http://www.ni.com/white-paper/7142/en, published May 05, 2012

4. Javad Shakib, Mohammad Muqri ,118th Annual ASEE Conference, Session: AC 2011- 389, Wireless Technologies in Industrial Automation Systems

5. Dr. Rajender Thusu, PhD, Frost & Sullivan, June 1, 2010, http://www.sensorsmag.com/networking-communications/wireless-sensor/wireless-sensor-use-is-expanding-industrial-applications-7212, Wireless Sensor Use Is Expanding in Industrial Applications.

6. Mareca Hatler, September/October 2012: Industrial Wireless Sensor Networks: Trends and developments, http://www.isa.org/InTechTemplate.cfm?template=/ContentManagement/ContentDisplay.cfm&ContentID=90824,

7. Marko Paavola , Control Engineering Laboratory, Report A No 33, December 2007 ,Wireless Technologies in Process Automation - A Review and an Application Example.

8. Daniele Puccinelli and Martin Haenggi, IEEE Circuits and Systems Magazine, Third Quarter 2005, Wireless Sensor Networks: Applications and Challenges of Ubiquitous Sensing.

9. Ameer Ellaboudy, Kristofer Pister, EECS Department, UC Berkeley, Technical Report No. UCB/EECS-2012-152, Outlet Power Monitoring Using Wireless Sensor Networks.

10. J. Song, A. K. Mok, D. Chen, and M. Nixon, "Challenges of wireless control in process industry," Workshop on Research Directions for Security and Networking in Critical Real-Time and Embedded Systems, April 2006.

11. Afsaneh Minaie et al. ,119th Annual ASEE Conference, Session: AC 2012-4722, Integration of Wireless Sensor Networks in the Computer Science and Engineering Curricula