

Study on Wireless Sensor Based Industrial Tomography Systems

¹ Chiew Loon Goh, ¹ Nor Muzakir Nor Ayob, ^{1*} Ruzairi Abdul Rahim,
¹ Herlina Abdul Rahim, ¹ Muhammad Jaysuman Pusppanathan,
² Mohd. Hafiz Fazalul Rahiman, ¹ Leow Pei Ling, ² Zulkarnay Zakaria

¹ Process Tomography and Instrumentation Research Group (PROTOM-i),
INFOCOMM Research Alliance, Faculty of Electrical Engineering, Universiti Teknologi Malaysia
81310 UTM Skudai, Johor, Malaysia
Tel.: +607-5537801, fax: +607-5537811

² Tomography Imaging Research Group, School of Mechatronics, Universiti Malaysia Perlis,
Pauh Putra Campus, 02600 Pauh, Perlis, Malaysia
E-mail: clgoh2@live.utm.my, ruzairi@fke.utm.my

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Abstract: Wireless sensor technologies are promising in the field of industrial tomography system, to visualize the cross-sectional images of an industrial flow process. The aim of the paper is to review the technical and scientific state of the art of wireless technologies, current trend of standards for wireless communications and their sensor applications in industrial process flow measurements. The paper focuses on presenting recent researches in wireless sensor based industrial tomography system, presenting the different systems available, recent developments and challenges in industrial wireless system. We provide contemporary reviews on wireless technology and wireless based industrial tomography system. *Copyright © 2013 IFSA.*

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1. Introduction

Industrial Tomography System is a computerized system that can provide cross-sectional images of an investigated pipeline in industrial process. There are many methods of performing process tomography, major methods widely being researched are Electrical Capacitance Tomography (ECT), Electrical Impedance Tomography (EIT), Optical Tomography, Nuclear Magnetic Resonance Tomography (NMR), Radio Frequency (RF) Tomography, Electrode Resistance Tomography (ERT) and Ultrasonic Tomography. In year 2011, York Trevor A. *et al.*, introduced Agile Sensing Systems for tomography.

The achievement of measurement agility is accompanied by two further critical features that are characteristic of agile tomography systems. First is the bespoke engineering for sensor access to the measurement environment, ensuring physical process compliance of the sensor system. The second is the sophisticated electronics to achieve sensitivity to the desired measurement, to have high signal-to-noise ratio (SNR) for useful image reconstruction. The tomography system designer is faced with a major architectural decision in choosing between hard-field and soft-field modalities. Hard-field sensing methods, as explained in technical paper of Joon-Ha Jin, 2008, refer to the sensing contribution to the actual

measurements only depends on the process medium inside the volume defined by the source and detector. The simplest example is X-ray tomography, where the measurements based on the straight-line path through the subject, such as the measurements will not influenced by the environment outside the subject volume. For the latter, the soft-filed case arises where any change of measurement at any position in the subject can influence the measurement obtained on any detector in response to a given excitation because of the fringe effects related to electrical and electromagnetic fields, irrespective of excitation and detection geometry. The simplest example is ECT, which in ECT system, a change in permittivity anywhere in the subject will modify the electric field lines everywhere in the subject, and thus influence measurements for all geometrical configurations of voltage excitation/current detection as per concluded in research by Mohamad Elmy Johana *et al.* 2012. Many researchers have been engaged in developing schemes that address the unique challenges of wireless sensor approaches in industrial tomography system. In year 2010, Wireless tomography is introduced, which bring together wireless communication and radio frequency tomography in industrial tomography system.

The development of efficient and flexible wireless technology has created a wide variety of potentially new wireless systems. In this paper, we provide a review on the progress of wireless activities, and we focus on the application of wireless sensors in Industrial Tomography System (IPS), the challenges and the future wireless design modalities. In Section 2, we review on recent researches in the field of industrial tomography system based on wireless sensors. In Section 3, we provide a study on the wireless standardization activities applied in sensor technology. In Section 4, we identify the wireless design challenges and provide reviews on researches in overcome the challenges. In Section 5, we summary our reviews by providing the future wireless design modalities in field of industrial tomography system. Finally, this paper is concluded in Section 6.

2. Recent Developments in Wireless Sensor Based Industrial Tomography Systems

This section presents most relevant wireless sensor applications in recent industrial tomography researches. In year 2005, Infratography was introduced by Hoyle B.S. Infratography describes heterogeneous wired and wireless networks, augmented by smart cooperating agents in the entire network, to enable a variety of distributed monitoring and control functions in industrial system via wireless sensor network. In order to automatically detect the cardinal (highest or lowest) value in a wide area distribution, the developed system periodically sent a wireless single directed alert message to a monitoring

point. A simple message can notify the network of an interest in a threshold level, and again all the wireless nodes having this level can alert this status instantly.

Concurrently with the progress of Infratography, a new technique called "Ad hoc Wireless Sensor" had been introduced by York T. A., 2001. The technique was inspired by need of elimination of substantial modification to process vessels with the wiring challenges. In year 2006, York Trevor A. *et al.*, deployed the new technique in ERT system. This technique involved ad hoc wireless sensor networks that were hosted in a process vessel. In contrast to conventional arrangement of electrodes was at the outer layer of industrial pipeline, their unconventional arrangements of electrodes were free to move with the flow in the vessel. This wireless sensor technique had improved tomographic results, from the increased number of measurements, and to explore optimum techniques to reconstruct 3D images. Using same concept of ad hoc sensors, Renee Ka Yin Chin, 2010, further deployed the ad hoc technique in wireless communication and derived 3D tomographic imaging. The work difference with earlier work is besides ad hoc wireless sensors located inside the pipeline, there were also conventional wall-mounted electrodes. The ad hoc wireless sensors giving the mobility to assume any location inside a process vessel, properties of interest such as temperature, pressure, pH level and conductivity can be measured. Each the ad hoc sensors in the vessel system were equipped with the embedded wireless communication system, which consisted of a microcontroller, four RF antennas, and an 868MHz RF transceiver. The wireless communication transmitted data from sensors to PC, the base station for further analysis. Disadvantage of this system is that although the ad hoc sensors were designed to be as small as possible, it is still intruded on the process initially. In year 2011, Mark G. and York Trevor A, advanced the ad hoc wireless sensor concept into ultrasonic tomography system. The research team worked based on consideration on the two industrial scenarios, conducting and non-conducting media respectively. In non-conducting vessel, RF propagation is a natural candidate technology. However, when the media are conductive, RF is inappropriate and acoustic or ultrasonic techniques emerge as an attractive solution. The team concentrated on the challenge to determine the ad hoc wireless sensors' position, using small, low power and low cost ultrasonic transducers driven by a low voltage, 10 Vpk-pk. Their software modelling was able to provide strategic location of four ultrasonic transmitters that to be mounted around the periphery of the designed ad hoc pill. However, future works still need to be explored on the optimization of receiver locations at the outer pipeline of the process vessel with interest in how different modelling copes with the measurement errors.

The rapidly technology progress in wireless field has attracted considerable Radio Frequency (RF)

tomography research efforts since the early 2000s. RF tomography is a process of inferring information about an environment by capturing and analyzing RF signals transmitted between nodes in a wireless sensor network. In 2007, Mathew B. Cover *et al.* demonstrated tomographic imaging of room-sized spaces using the propagation properties of 2.4 GHz, IEEE 802.15.4 Direct Sequence Spread Spectrum (DSSS) radio waves. Instead of analyzing data located in the payload of packets, the network itself is used as a dynamic sensor to collect data. By using the received signal strength indication (RSSI) value of packets being received in the network with a known physical configuration, deflections in the RSSI value could indicate a physical obstruction in the network. Field test with phantom objects of known location, size, and material had been conducted, and results showed that the wireless application is feasible throughout an 802.15.4 network. In year 2009, Mohammad A. Kanso and Michael G. Rabbat, introduced Compressed Radio Frequency (RF) Tomography, an approach that combines RF tomography and compressed sensing for monitoring in a wireless sensor network. Information is processed based on RSSI measurements together with the basic analysis of the data located in the payload of the network packets. Under certain assumptions, compressed sensing techniques can accurately infer environment characteristics. This research demonstrated experiments with simulated and real data in proposed models to show the capabilities of their approach in both centralized and decentralized scenarios.

R. C. Qiu *et al.*, 2010, had a research breakthrough, with idea of wireless tomography, which is a new initiative to bring together two areas of technologies: wireless communication and radio frequency tomography. The research team suggested a self-coherent wireless tomography, by combining wireless communication and remote sensing. This novel approach has two steps. First, the phase retrieval is achieved using amplitude only data that are obtained through wireless sensors. Phase reconstruction means reconstructing the scattered field from the information in the incident field and squared amplitude of the total field. Second, standard radio tomographic imaging algorithms are used. Conclusion from the results of the research showing that the architecture of a phase reconstruction algorithm to retrieve the phase of a communications signal, combined with time reversal imaging, seems promising. In the phase two of the system design, R. C. Qiu *et al.*, 2010 have improved the wireless tomography system by applying machine learning and waveform diversity. Since the size of sample space in phase reconstruction is large, machine learning can be applied to reduce the dimensionality of dimensions—thus reducing the effect of measurement error induced by Commercial, Off-The-Shelf (COTS) communication components. The random errors introduced by the COTS components tend to be infinite, compared with the finite

dimensions. Machine learning has been applied before the phase reconstruction step and the coherent tomographic processing step. The new three-step approach works much better than the traditional two-step phase reconstruction approach. It has been demonstrated that the proposed machine learning and waveform diversity techniques improves the reconstructed scattering strength. In the phase three of wireless tomography system, Peng Zhang and R. C. Qiu, 2010 further proposed a compressed sensing (CS) based UWB channel recovery method considering pulse distortion. The concept has been demonstrated through simulations with the results of sampling rate is reduced as low as 2 Gsps, compared with the Nyquist rate of 50 Gsps.

Lately, Tushar Kanti Bera and J. Nagaraju, 2012, had developed a RF based wireless digital data transmission module (WDDTM) in electrode switching of an EIT system. An analogue multiplexers based electrode switching module (ESM) is developed with analogue multiplexers and switched with parallel digital data transmitted by a wireless transmitter/ receiver (Tx/Rx) module working with radio frequency technology. The transmitter/receiver module developed is properly interfaced with the personal computer (PC) and practical phantoms through the ESM and USB based DAQ system respectively. Comparisons had been analyzed based on wired and wireless system, and Results show that, the boundary potential profiles of obtained with or without inhomogeneity are of similar fashion both for opposite current injection with wired instrumentation and common ground current injection methods using WDDTM.

3. Activities in Wireless Standardization

In 1895, Guglielmo Marconi opened the way for modern wireless communications by transmitting the three-dot Morse code for the letter 'S' over a distance of three kilometers using electromagnetic waves. Since then, historically work on wireless networks has been focused on infrared (IR) light technology and wireless transmission. The IR technology suffers from line-of-sight limitations and the wireless technology restricted by regulations from the Federal Communications Commission (FCC). In 1985, the FCC released several frequency bands called the ISM bands for Industrial, Scientific, and Medical applications. The ISM frequency bands include 902-928 MHz, 2.2835-2.4 GHz, and 5.725-5.85 GHz.

According to Renzo Calcano *et al.*, 2006, the first generation of radio wireless local area network (LAN) was designed to interconnect stationary workstations, consuming approximately 20 watts supplied by the mains. LAN connects computers in an office building. As electronic devices become smaller, lower power, and less expensive, personal information and communication appliances such as cellular phones, personal digital assistants (PDA), pocket video games, pen based computer pads, and

palm top computers are being more and more popular. The personal area network (PAN) is a means to interconnect these personal devices, in a manner appropriate to the power, size, and cost of these devices. Wide area networks (WAN) connect distant computers using microwaves, radio waves, coaxial cable, and fibre optic. Metropolitan area networks (MAN) connect computers in a city. In the development of wireless sensor network, the range of communication is expected to be in personal (PAN) or local range (LAN). WAN and MAN seem to be less suitable to be applying in wireless sensor network for several reasons. First, they involve a strategic partnership with some public (licensed) telecom operator. Secondly, they involve higher costs (the costs due to the public services and the higher costs of the devices). Furthermore, they are quite rigid in their configuration with a star topology and a central base station. In report of Sinem Coleri Ergen, 2004, during the mid-1980s, the IEEE 802.11 working group, WLAN is formed to create a wireless local area network standard, and the IEEE 802.15 working group, WPAN is formed to create wireless wide area networks standard. WLAN was focus on

features such as Ethernet matching speed, long-range (100m), and complexity to handle seamless roaming, message forwarding, and data throughput of 2-11Mbps, while WPANs are focused on a space around a person or object that typically extends up to 10m in all directions. The focus of WPANs is low-cost, low power, short range and very small size. This group has currently defined three classes of WPANs that are differentiated by data rate, battery drain and quality of service (QoS). The high data rate WPAN (IEEE 802.15.3) is suitable for multi-media applications that require very high QoS. Medium rate WPANs (IEEE 802.15.1/Bluetooth) will handle a variety of tasks ranging from cell phones to PDA communications and have QoS suitable for voice communications. The low rate WPANs (IEEE 802.15.4/LR-WPAN) is intended to serve a set of industrial, residential and medical applications with very low power consumption and cost requirement not considered by the above WPANs and with relaxed needs for data rate and QoS. The low data rate enables the LR-WPAN to consume very little power.

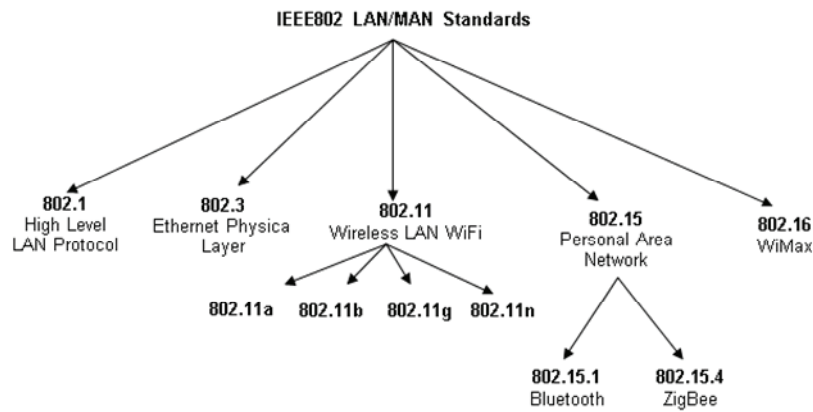


Fig. 1. Summary of IEEE Wireless Standard.

We discuss in below section the major standardization efforts related to wireless local area network, WLAN applying in most wireless sensor applications.

3.1. RFID

RFID is a wireless non-contact system that uses radio-frequency electromagnetic field to transfer sensors' data from a tag attached to an object, mostly for the purposes of automatic identification and tracking. In RFID system, there is a device that in presence of an RF Tag scanner transmits a short sequence of pre-defined bits. RFID operates at low frequencies (30–500 kHz). Usually passive RFID tag is in used, which this wireless system usually is passive (no battery), light, cheap and have a virtually unlimited operational life. However, the wireless

physical range is limited (2–5 m), the loaded information cannot be modified, and data rate is low. There are also active RF Tags, which incorporate battery, with considerable storage capacity. They operate at high frequencies (850–950 MHz and 2.4–2.5 GHz) with wider range up to 30 m and higher data rates. Consequently, cost is also higher as per concluded by Esteban Egea-Lopez et al., 2005. The major disadvantage of RFID is it cannot be applied in a safety critical solution. It is a low cost solution which offers limited payload and simple functionality. It is suitable to keep track of goods and recognize them throughout an industrial process, but not to pilot an industrial plant and to guarantee flexible and huge data exchange. RFID always works as an additional collateral technology, not as the main process.

3.2. IEEE 802.11/WiFi

The IEEE standard 802.11 specifies the most famous of Wireless Local Area Networks (WLAN), commonly known as WiFi. The 802.11 protocol, the first standard for WLAN, was introduced in 1997. A set of different physical layers exists for IEEE 802.11. They are commonly referred by an identification letter, 802.11a, 802.11b, 802.11g and 802.11n. Each of these standards achieves different performances which will be investigated below. The 2.4 GHz ISM band, which is available in most countries around the world, was chosen for the WiFi standard. High Data rates ranges from 1 Mbit/s up to 100 Mbits/s depending on the current interference and the distance between sender and receiver. WiFi is designed to be used indoors and outdoors at close range for exchanging data and providing Internet access to devices. In a WiFi network, devices are allowed roaming between access points to achieve mobility. Although popular in commercial applications such as wireless LAN within homes, business and stores, commented by Han W. *et al.*, 2008, WiFi has gain limited traction in remote monitoring and control due to its limited transmission range and security concerns. As references to Hirschmann Automation & Control GmbH Technical Paper, 2010, and report written by Renzo Calcagno *et al.*, 2016, the IEEE 802.11 existing solutions are shortly recalled as below.

802.11 the first IEEE 802.11 solutions were designed for the 2.4-2.4835 GHz band and used two different spread spectrum techniques: Frequency Hopping (FHSS) and Direct Sequence (DSSS). FHSS is not as complicated as DSSS and uses less energy, but DSSS has longer range. DSSS supports higher data rates from individual physical layers, which is why DSSS was chosen for a higher-rate 802.11 physical layer (802.11b). Both FHSS and DSSS reach 2 Mbps line rate and use approximately 30 MHz for transmission (one third of the band). This limits the number of no overlapping access points within coverage distance to a maximum of three.

802.11b specifies a physical modulation using DSSS at data rates of 5.5 Mbps and 11 Mbps. The frequency bands and number of channels is the same as for the early IEEE 802.11 standard.

802.11a operates in the 5 GHz band (5.150-5.350 GHz and 5.725-5.825 GHz). A technique called (Orthogonal Frequency Division Multiplex) OFDM is used to increase data rates to 54 Mbps. This modulates the data signal not on just one carrier signal but in parallel over several. With OFDM, the high-speed data signal is transported via 64 parallel sub-channels within a 20-MHz channel.

802.11g similarly to 802.11b, 802.11g operates in the 2.4 GHz band, and uses one third of the band per channel. 802.11g mimics 802.11a modulation (OFDM) so that it can reach 54 Mbps data rates. The number of non-overlapping channels is 12.

802.11n was announced in September 2009, is an amendment to previous 802.11 standards by adding

new mechanism of Multiple-Input Multiple-Output (MIMO) to significantly increase in data throughput. MIMO uses several transmitters and several receivers to transmit up to four parallel data streams on the same transmission channel. Networks based on 802.11n currently achieve a gross data throughput of up to 600 Mbps. For the first time speeds can actually exceed the 100 Mbps of wired-based Fast Ethernet networks, which are currently standard in most workplaces. Like 802.11a/g, 802.11n uses the OFDM scheme (Orthogonal Frequency Division Multiplex) as its method of modulation. MIMO is the most important new technology contained in 802.11n.

3.3. IEEE 802.16 / WiMax

IEEE 802.16 standard, also well known as WiMax is envisioned as a wireless replacement to a wired broadband, supports data rates up to 100 Mbits/s. WiMax control protocol requires the devices to transmit only when instructed by the central access point (base station). WiMax also requires the remote device to be in clear line-of-sight with the base station. The technology supports transmissions over extended range, up to 50 km. These differences make WiMax ideal as monitor network for fixed point-to-multipoint network that lets huge devices connect to an enterprise data network or the Internet from a central access point.

3.4. IEEE 802.15.4 / ZigBee

In May 2003, The IEEE 802.15.4 standard was first approved to define a standard that would provide a standard for ultra-low complexity, ultra-low cost, ultra-low power consumption, and low data rate wireless connectivity among inexpensive devices. ZigBee compliant wireless devices are expected to transmit 10 - 75 meters, depending on the RF environment and the power output consumption required for a given application, and will operate in the unlicensed RF worldwide (2.4 GHz global, 915 MHz Americas or 868 MHz Europe). The data rate for 802.15.4 varies depending on the device operating frequency. For the 2.4 GHz band, the raw data rate is 250 kb/s, 915 MHz data rate is 40 kb/s, and 868 MHz is 20 kb/s. The 802.15.4 standard defines that there are two types of devices that can participate in a network: a full-function device (FFD) and reduced-function devices (RFD). Only FFDs can serve as personal area network (PAN) coordinators. A reduced-function device (RFDs) is a device with a minimal implementation of the IEEE 802.15.4 protocol. The standard only allows RFDs to communicate with FFDs.

IEEE 802.15.4 committee started working on a low data rate standard, a short while later, the ZigBee Alliance and the IEEE decided to join forces and ZigBee is the commercial name for this technology.

The first version of the standard appeared in 2005. ZigBee is expected to provide low cost and low power connectivity for equipment that needs just two AA battery life as long as several months to two years but does not require high data transfer rates. In report of Sinem Coleri Ergen, 2004, ZigBee allows up to 254 nodes, and support very fast wake up time. When ZigBee node is powered down, the wake up time to receive a wireless packet is in around 15 ms. ZigBee is a mesh-networking standard based on IEEE 802.15.4 radio technology targeted at industrial control and monitoring, building and home automation, embedded sensing, and energy system automation. ZigBee is promoted by a large consortium of industry players. The good characteristics of the ZigBee are extremely low energy consumption and support for several different topologies, which makes it a good candidate for several sensor network applications. However, it is reported by Vehbi C. Gungor, and Gerhard P. Hancke, 2009, that ZigBee cannot meet all the requirements for at least some industrial applications due to it cannot serve the high number of nodes within the specified cycle time.

There is updated version appeared as IEEE 802.15.4a. In the report of Andreas Willig, 2008, on the physical layer the 2006 version of the standard operates in three different frequency bands, offering different rates: in the 868.0- / 868.6-MHz band at rates of 20/100/250 kbit/s, in the 902 – to 928-MHz band at rates of 40 and 250 kbit/s, and in the 2.4 – to 2.4835-GHz band at a rate of 250 kbit/s. In the 868-MHz band only a single channel is available, while ten channels are available in the 915-MHz band and 16 channels in the 2.4-GHz band.

3.5. IEEE 802.15.1 / Bluetooth and Bluetooth Low Energy

Bluetooth-Low-Energy specification is a part of the Bluetooth specification as an ultralow-power technology addressing devices with very low battery capacity. This extension to Bluetooth allows for data rates of up to 1 Mb/s over distances of 5–10 m (Bluetooth Class II) to 100 m (Bluetooth Class I) in the 2.45-GHz band. Although Bluetooth Low Energy is similar to Bluetooth and can employ the same chips and antennas, it has some important differences. Bluetooth Low Energy has a variable-length packet structure, compared to Bluetooth's fixed length. It also employs a different modulation scheme. Bluetooth uses frequency hopping spread spectrum, with a common bandwidth of 80 MHz, divided into 79 channels. The basic unit of networking in Bluetooth is called piconet, and it is made up of one master and up to seven slaves. All devices in a piconet share the same hopping sequence, which is calculated as a function of the master clock and identity. A device may exist in more than one piconet at a time, and may operate either as a master or as a slave in each one.

Therefore, the networks may overlap and form “scatternets”. However, reported by Sinem Coleri Ergen, 2004, when a Bluetooth device in power down mode, it would take slightly long time (about 3 s) to wake up and respond. Furthermore, the number of devices supported at a time is small, single Bluetooth supports maximum 8 nodes, and coverage range is also small. Bluetooth played an interesting role in the past of WPAN: it offers a good compromise between data rate (about 1 Mbps) and range (about 10 m or 100 m with lower data rates). However, this trade-off seems to be its main limit: UWB seems to be preferred for higher data rates and ZigBee for lower consumptions and longer battery life.

3.6. Wireless HART

Wireless HART (Wireless Highway Addressable Remote Transducer), an open-standard wireless networking technology developed by HART Communication Foundation, was introduced to the market in September 2007. Wireless HART is an extension of the HART protocol and is specifically designed for process monitoring and control. The technology employs IEEE 802.15.4-based radio, frequency hopping, redundant data paths, and retry mechanisms. Wireless HART networks utilize mesh networking, in which each device is able to transmit its own data as well as relay information from other devices in the network.

3.7. IEEE 802.15.3 UWB

Ultra wideband (UWB) is a short-range wireless communication technology based on transmission of very short impulses emitted in periodic sequences. UWB technologies provide option to the problem of narrowband interference. In 2002, the FCC allowed the usage of UWB devices for communications and measurement systems in the range between 3.1 and 10.7 GHz, high data transfer rate up to 450 Mbps, with the condition that the UWB signal must not exceed radiated power. Summary from the report of Andreas Willig, 2008, UWB stations are allowed to fully use the spectrum as long as it is ensured that at the location of a UWB transmitter the power spectral density of its signal is below a spectral mask defined by the FCC. UWB signals are kept below the level of unintentionally generated interference that any licensed user must accept from other devices. Due to the large bandwidth, UWB is robust against narrowband interferences from licensed bands, and theoretically very high data rates are achievable over short distances. UWB technology is conceived for high-rate personal-area networking applications. However, UWB is not a viable approach for communication over longer distances or measuring data from unsafe zone because of high peak energy of pulses.

3.8. ISA-SP-100

The Instrumentation, Systems, and Automation Society (ISA) were announced at the beginning of 2007 working on a series of standards addressing the adoption of wireless technologies in different industries. In a first step the process industry is addressed with the upcoming ISA-SP100.11a standard, addresses noncritical process applications that can tolerate delays up to 100 ms. The ISA100.11a, has been released on September 2009, with official description is "Wireless Systems for Industrial Automation: Process Control and Related Applications". Since this standard leverages the IEEE 802.15.4 standard in the 2006 version, it inherits some of its properties: low rates (up to 250 kbit/s) and low implementation complexity for simple end devices. Similar to ZigBee standard, ISA-SP100.11a adopts a frequency-hopping scheme in the 16 frequency channels offered by IEEE 802.15.4 in the 2.4-GHz ISM band. ISA-SP100.11a networks can be multihop networks having a mesh topology built among devices with routing. Gang Zha, 2011, summarized that both ISA-SP100 and ZigBee standards target overlapping application areas and are based on the same underlying wireless technology, and it will be very interesting to see the future development of ISA-SP100.11a, especially as compared to ZigBee.

4. Challenges in Wireless Sensing System of Industrial Tomography

This section reviews the challenges in wireless sensing systems. The major challenge that draws the attention of the researches is the energy efficiency, in term of prolonging battery life time. Besides that, design considerations shall be attended on the challenges in antenna efficiency, wireless interference, eavesdropping, and quality-of-service, QoS.

4.1. Energy Efficiency

The energy consumed by electronic components increases with frequency due to the dissipative losses incurred discharging capacitances, which amount to

$$P = (\frac{1}{2})CFV^2, \quad (1)$$

where P is the energy, C is the capacitance, F is the charging/discharging frequency, and V is the capacitance charging voltage. A wireless transmitting device would need to run at frequencies in the MHz to GHz in order to efficiently transmit as in reference by Thomas Guthrie Zimmerman, 1995, in his research. Using batteries as power source for the network sensor nodes is difficult due to their limited lifetime, making periodic replacements is unavoidable. Vehbi C. Gungor and Gerhard P. Hancke, 2009, discuss in their paper on energy-

harvesting techniques (also referred to as energy scavenging). This technique is to extract energy from the environment, to prolong the lifetime of sensor devices. Based on simple commercial photovoltaic cells coupled with rechargeable batteries and super capacitors, the designed systems able to perpetually provide power to sensors. Technologies to generate energy from background radio signals, thermoelectric conversion, vibrational excitation, and the human body are investigated in energy-harvesting techniques. Research by Thomas Guthrie Zimmerman, 1995, demonstrated that wireless power transfer using magnetic coupling between two copper coils is possible. Other energy-scavenging approaches employ piezoelectric materials. Andreas Willig, 2008, discussed in his paper on the battery management schemes in which having wireless sensor nodes coordinating each their activities properly through transmission protocols. For most of the transceiver designs, receiving requires approximately the same energy as transmitting. In wireless transmission scenario, there might also be the "idles state" situation that the transceiver is listening on the channel for incoming packets but without actually receiving something. The energy consumed in the idle state is often a significant fraction (50 % and more) of the energy consumed in receive mode. To reduce the average power consumption, protocols to have sensor nodes switch selected hardware components like the transceiver into a "sleep state" with ultra-low power consumption for most of the time, or even switch them off completely.

Vehbi Cagri Gungor, 2009, suggested that effective operation of wireless sensor networks requires knowledge of the current status of battery lifetime in sensor nodes. He proposed a new forecasting-based monitoring and tomography (FMT) framework to address the need for an energy efficient monitoring mechanism for WSNs. To reduce the amount of energy consumed for monitoring purposes, the FMT framework incorporates available energy forecasting and network aggregation mechanisms. Instead of collecting the available energy data from individual nodes periodically, the FMT framework enables energy information to be communicated to the monitoring node only when there is a variation in the network behaviour, which significantly reduces the amount of energy consumed for monitoring purposes. The comparative simulation results show that the FMT framework achieves accurate energy monitoring and obtains network energy tomography of large scale wireless sensor networks with minimum energy expenditure. Praveen Kaushik and Jyoti Singhai, 2011, reviewed in their paper various energy efficient routing algorithms to increase the lifetime of wireless sensor network. Performance of routing algorithms of Minimum Total Energy (MTE), average Flow Redirection (FR), Maximum Residual Energy Path Routing (MREP), and Flow augmentation algorithm (FA) being analyzed. In their study, the lifetime of wireless sensor network is

defined as the time until the first node fails (or runs out of energy). And it is important to adopt energy efficient routing algorithm in the wireless sensor network in order to have traffic routing through the minimum energy path to the destination to prevent all the nodes in network drain out their battery power in quick. The proposed solution route the traffic such that energy consumption is balanced among the nodes.

Another battery life prolong approach to reduce hardware power consumption is proposed by Ali Elkateeb, 2011. The researcher presented the design for the soft-core processor using Field Programmable Gate Array (FPGA) technology to support sensor networks nodes processing. In his research, he pointed out that existing sensor networks are using off-the shelf general purpose processor in the network nodes to support the processing capability required by different applications. Since the general-purpose processors have a design that support all types of applications, these processors are generally have high cost and consume large power. Supporting sensor nodes with soft-core processor will optimize the processor architecture to match the needs of the sensor networks applications. Therefore, the processor will support only those hardware components required by the target application and that will reduce the processor power consumption. In addition, the soft-core processor can be integrated on a chip with the other hardware components required to develop the sensor node and that will reduce the size of the Printed Circuit Board (PCB) required to implement the sensor node and hence, reduce the sensor node cost. The soft-core processor design with multi-cycle architecture is optimized to the processing needs of the sensor node used for surveillance application and therefore, such design will minimize the node's size and its power consumption. As the soft-core developed with VHDL code, a flexible and portable core design can be produced to be implemented over different FPGA product such as those chips from Xilinx, Altera, Actel, etc.

4.2. Antenna Efficiency

The fundamental of wireless transmission is demonstrated in antenna design. To maximize electrostatic coupling, electrode area is maximized. To maximize broadcast transmitter signal strength, the electrical impedance of the transmitter is matched to that of free space. The strength of the transmitted electromagnetic waves is a function of antenna current flow, which is inversely proportional to the reactance of the antenna. Maximum antenna current is achieved by operating the antenna at resonance. The shortest antenna length to achieve resonance is one half a wavelengths long. Thomas Guthrie Zimmerman, 1995, in his thesis concluded that Inductors can be used as a matching network to compensate for electrically short antennas; it can be

solved by decreasing the bandwidth of the antenna and increasing the power dissipation in the matching network.

4.3. Interference

Interference is due to the nature of radiation is to propagate to infinity until stopped. Multipath fade and radio frequency (RF) interference are the two primary factors that affect wireless communications. In technical paper of Cirronet, Inc., 2002, Multipath fading occurs when multiple copies of a source signal arrive at a receiver through different reflected paths. The phase variance in the signal copies can result in destructive interference that reduces signal strength, effective range, and data transfer rates. RF Interference signals can be classified in two categories: broadband and narrowband. Broadband interference signals have high constant energy spectrum over all frequencies, whereas narrowband interference signals are intentional and have less energy. Broadband interference can be caused by motors, inverters, computers, electric-switch contacts, voltage regulators, pulse generators, thermostats, and welding equipment. On the other hand, narrowband interference can be caused by UPS system, electronic ballasts, test equipment, cellular networks, radio-TV transmitters, signal generators, and microwave equipment. Vehbi C. Gungor, and Gerhard P. Hancke, 2009, in their research found that the attainable capacity of each wireless link depends on the interference level perceived at the receiver. High bit error rates ($10^{-2} - 10^{-6}$) are normally observed in wireless communication. Channel Bit Error Rate (BER) is usually two orders of magnitude higher than it is in a wired system. The challenge of operating many unregulated broadcasters is faced by wireless designers. Radiating transmitters are basically pollution to any receiver except the intended one. The emerging solution appears to be one of "spectrum etiquette" which promotes "listen before you transmit" and only transmit the power necessary to be heard by individual listener.

4.4. Eavesdropping

Some of the wireless data communicated will be of a sensitive nature, for example credit card and telephone numbers, business communications, and computer passwords. Radio systems can be made secure with cryptographic strategies, requiring additional processing overhead, but the best security is a message that is never intercepted. Security should be an essential feature in the wireless system design to make the communication safe from external denial-of-service (DoS) attacks and intrusion. Vehbi C. Gungor, and Gerhard P. Hancke, 2009, explained in their paper passive attacks are carried out by eavesdropping on transmissions including traffic analysis or disclosure of message contents. Active

attacks consist of modification, fabrication, and interruption, which in WSN cases may include node capturing, routing attacks, or flooding. If the distance between the transmitter and eavesdropper is large enough, the intercepted signal strength will be smaller than thermal noise, making reception of the message very difficult. One of the suggested solution to enhance security is by restricted the transmission signal strength, FCC limits a typical PAN transmitter has a signal strength less than 400 pV/m at 300 meters, in which this signal strength not only minimize interference, also enhance security in wireless system. Andreas Willig, 2008, suggested eavesdropping prevention through encryption technique. In order to prevent external insertion of malicious packets, mechanisms for ensuring authentication (“who sent this message?”) and message integrity (“is this the message originally sent?”) are to create mutual trust relationships between wireless sensor nodes.

The connectivity topology of the network may vary due to link and sensor-node failures. Network sensors may be subjected to highly caustic or corrosive environments, high humidity levels, vibrations, dirt and dust, or other conditions that challenge performance. These harsh environmental conditions and dynamic network topologies may cause wireless sensors to malfunction in term of low quality-of-service (QoS). The QoS refers to the accuracy between the data reported to the sink node (the control center) and the actual event occurring in the network environment. Since sensor data are typically time-sensitive, it is important to receive the data at the sink in a timely manner. Data with long latency due to processing or communication may be outdated and lead to wrong decisions in the computation system.

5. Future Wireless Sensor Modality in Industrial Tomography

Summary from above literature reviews, wireless sensing system in industrial tomography generally can be deployed in two areas of technologies: wireless communication and radio Frequency (RF) tomography. Wireless communication is referred to communication protocol between sensor front-end design and image application. A success implemented communication protocol makes hardware system a real time system. Ruzairi Abdul Rahman *et al.*, 2007, implemented industrial ultrasonic tomography for monitoring water and oil flow, a commercial data acquisition card which using computer compatible PCI bus had been deployed to master the front-end electronic system, and acquiring data into PC system. Recent developed systems of Hudabiyah Arshad Amari *et al.*, 2010, Mohd Hafiz Fazalul Rahiman *et al.*, 2012, Ruzairi Abdul Rahim *et al.*, 2007, were wired based data acquisition, which leads to the usage of serial bus RS232 or USB bus, was the communication link to PC for further data analysis in

image reconstruction. Surveying from the recent researches in area of industrial tomography, it is found that wireless communication protocol is less attended as crucial experiment as focuses are more on the sensors improvement, noise elimination, and image algorithms. As we are in the midst of a wireless revolution, wireless technology shall be a potential element in industrial tomography that enable a major saving in system instalment and maintenance cost.

As this cast market opens up, today, there are legion of choices exists for implementing wireless data connections from embedded system to computer, not only via PCI bus interface, USB, RS232 serial port, also through variety of wireless communication interfaces such as ZigBee, Bluetooth and WiFi to the core processor of the embedded system. These off-the-shelf wireless evaluation modules help designers in overall in getting their designs with shorter time to market. Instead of spending significant time and money developing wireless specific hardware and protocol stack, designers can focus more on the core competence in sensor hardware and product application. In the report of M. Park *et al.*, 2008, within a short decade, the data rate of 802.11 family products have evolved at an amazing pace, from 1 Mb/s with the first generation of 802.11 products, to 11 Mb/s with 11 b, to 54 Mb/s with 11a/g, to up to 600 Mb/s with in MIMO 802.11n products. It is about 30 times faster over this period, roughly matching Moore’s law advances in computing speed. There is also an on-going effort to migrate indoor LAN and PAN networks toward less congested higher frequency unlicensed spectrum bands such as 60 GHz. C. Park and T. S. Rappaport, (2007), in their study on 60 GHz millimetre-wave WPAN, and ZigBee, discussed that there are significant propagation-related differences and challenges between the 60-GHz band and the lower frequency unlicensed WiFi bands at 2.4 and 5.0 GHz. Several standardization bodies have been working on the 60-GHz PHY and MAC protocols approaching 1 Gbps service rate. The 60-GHz technology is expected to mature during the next three to five years, and this future technology is expected to provide an important option for high-speed indoor connectivity associated with applications.

Another important industrial factor in embedded wireless sensor design modality is the energy source. Silicon Labs white paper, 2012, reviews that thin-film batteries are proper used in embedded systems due to the battery ultra-thin profile and low leakage characteristics. Conventional batteries, such as coin cells, AA lithium batteries and lithium-thionyl-chloride batteries are bulky and non-flexible, and the battery energy to weight ratio factor causes the output energy is quite low. The introduction of thin-film batteries has created a new option for system designers with trade-offs in cost, size and safety. The credit for developing thin film batteries goes to a team of scientists lead by Dr. John Bates. They conducted, since 1997, research at the Oak Ridge National Laboratory for the development of a thin

film battery. For over a decade, the size of the thin-film battery has been reduced to the thinnest profile (as small as 0.17 mm) of any battery type. The total lifetime capacity of thin film batteries is equivalent to four lithium AA batteries. Thin-film batteries are rechargeable, thus batteries only store a portion of total lifetime capacity at any given time. This makes the thin-film battery much safer if it is accidentally shorted or exposed to extreme heat or an open flame.

In order to maximize battery lifetime, the standby power of the computation and communication circuits in the industrial wireless system must be minimized. The new term to wireless solution is the power efficiency, the measure of a system's passive and active techniques to minimize power consumption. Anantha Chandrakasan *et al.*, 2009, addresses the wireless sensor system should be designed to deal with low duty cycles since the environmental conditions may not change rapidly or the sensors remain in a sleep state until some interesting event happens (detected by some simple front-end electronics. In their study, for transmission at GHz carrier a frequency, the power is dominated by the radio electronics (frequency synthesizer, mixers, etc.) besides actual transmits power. Sensors may have very low data rates (<1 kbs) and utilize short packet sizes (100's of bits). In order to save power in the wireless module, the designed system must be duty cycled to have ability to turn off during periods of inactivity. The higher the system efficiency the more power is conserved. Future wireless design modality in industrial tomography shall be power-efficient portable system, in which it is a solution that continually focuses on minimizing its output power to ensure only the lowest level necessary to wireless communicate is used. It shall be an embedded wireless application that can minimize its on-air time. The goal of a future wireless sensor industrial tomography system is to achieve a perpetually powered system without a necessary maintenance for battery replacement.

6. Conclusions

As utilization increases, and the great progress on development of wireless technologies, wireless industrial flow tomography system will be able to replace conventional wire-based industrial tomography system in many well-testing industrial applications and eliminate the need for costly and space-consuming wired based instalments. Researchers still need to explore quite a few issues during the design of the efficiency embedded wireless tomography system as per the technologies outlined in sections above as far as further development towards more real-time measurements can be designed. In this paper, we survey the state of the art in wireless standardizations, challenges, trend and industrial tomography system developments in applying wireless sensing technologies. The wireless sensors in industrial tomography system create the

great potential to improve productivity of any automation systems by providing greater wariness, control, and integration of business processes. Despite of the great progress on development of recent researches in field of wireless industrial tomography system, quite a few issues still need to be explored in the future. An efficient deployment of wireless industrial tomography system in the real world is highly dependent on the ability to have communication latency, reliability, and quality and energy efficiency. Others than that, optimal sensor-node deployment, localization, security, and to cope with interference issue is another challenging area yet to be explored.

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