Wireless Sensor Technologies in Food Industry: Applications and Trends

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***Abstract*— Wireless Sensors Networks (WSNs) have emerged as an exciting new computing technology in food industry, particularly with the proliferation in Micro-Electro-Mechanical Systems (MEMS) technology providing advanced development of smart sensors. Such convergences of technologies which involve deploying self-contained sensor devices that sense and process data have opened up a revolution in the application domain of sensors in food industry. This includes the realization of more versatile systems in food industry regarding measurements, instrumentation and automation of functions. The vision of this technology is to develop a real time monitoring of in-door and outdoor environments. WSNs are deployed in various applications which enhance interaction between users and the physical environment. This has allowed physical environment in systems, such as in food industry, to be measured using a high resolution with the aim of increasing and monitoring the quantity and quality of real-time data and information collected for the applications. This paper reviews the application of wireless sensor technologies in food industry, looks into its application in real-time monitoring of food supply chain, food security and food intelligent packaging while discussing various challenges that should be addressed in order to push the technology further.**

Keywords- food industry; Wireless Sensor Networks; RFID; packaging.

I. INTRODUCTION

The food industry is known to be receptive to the use of information systems in all aspects. For many years, technology in food industry had focused on Enterprise Resource Planning (ERP) software. However, this has recently changed as many companies in the food industry have started adopting state-of-the-art technologies to provide solutions in areas such as traceability and logistics. With recent incidents in food safety issues, there has been an inevitable increase in interest in Production Life Cycle Management Software in combination with Radio Frequency Identification Technology (RFID) focusing on providing solutions for addressing food safety [1]. The potential applications of Smart Sensor Networks are diverse, especially in external systems in which Bluetooth has proven to be the communication standard between sensors. Wireless sensor networks consist of tiny devices referred to as sensor nodes that are battery-powered and equipped with sensing devices, a data processing unit and a communication unit [2]. Depending on the external interface in application, sensors for an attended wireless network, when randomly deployed in the field, are able to collect and aggregate data as well as communicate with electronic devices, such as PCs, PDAs and Laptops through which data can be transmitted to any network [3]. Regarding food security as a pressing issue in the food industry globally, wireless sensor networks can be used to detect contaminants in the food supply chain, provide real time monitoring of the cold chain industry [4], pest detection and control in farms [3] and food intelligent packing through the use of RFID and Surface Acoustic Wave (SAW) [5].

The rest of this paper is organized as follows: Section II summarizes a review of literature. Section III discusses some important applications of WSN technologies in the food industry. Section IV discusses in finer detail, the aim of the paper. Section V includes an acknowledgement and conclusions.

II. LITERATURE REVIEW

A. *Overview of Wireless Sensor Networks*

Wireless sensors consist of small devices called sensor nodes which are powered and equipped with self-contained sensing, data processing, data storage and communication unit. When deployed to any environment, the sensor nodes create a random wireless network in which data can be collected, aggregated and packaged for further fusion through other devices such as PCs and PDAs. Increasing capabilities of sensor nodes have led to the realization of wireless sensor networks. Advancements in wireless sensor node technology have been targeted by universities and research laboratories in experiments and development tests. However, there is increasing interest by many companies globally which intend to use the technology in building and industrial automation markets [1].

A sensor network is composed of thousands of small devices known as sensor nodes that are deployed inside or close to the phenomenon. Sensors are generally devised to sense information and transmit the same to a mote. The

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information collected is used to measure changes in the physical environment such as pressure, humidity, sound and vibration. A mote consists of a processing unit, storage unit and power source, which can be a battery and a radio transmitter which it uses to form an adhoc network. Combining a mote and a sensor forms a sensor node. A typical wireless sensor node is composed of a sensing unit, a processing unit, a communication and power unit. Advancements have also been made to include location finding systems, power generators and mobilizers into sensor node. Recent technology advancements have enabled the development of self-contained motes [2]. High power density batteries are commonly preferred to achieve longer lifetime of the sensor nodes. Future wireless sensor nodes trends focus on smaller node size as well as very low energy consumption [6]. WSN differs from RFID in that it is able to integrate with other network devices in the field while an RFID tag can only be read with the RFID tag reader. WSN is comprised of Wi-Fi, Bluetooth, and ZigBee. The latter two operate within the Industrial Scientific and Medical (ISM) band of 2.4 GHz, which provides license-free operations, enormous spectrum allocation, and global compatibility [7]. Table I provides a comparison between these WSN technologies.

TABLE I. COMPARISON OF WIRELESS SENSOR NETWORKS TECHNOLOGIES AND STANDARDS

Feature	Technology		
	Wi-Fi	***Bluetooth***	***ZigBee***
Physica Layer Standard	IEEE 802.11	802.15.1	802.15.4
Data rate	11 Mbps	1Mbps	250kbps
Node per master	32	8	64000
Range	10 to 100 m	10 m	10 to 300 m
Data type	video, audio, graphics, pictures, files	video, audio, graphics, pictures, files	Small data packet
Topology	star	Star	Mesh,stsr,tree
Complexity	complex	very complex	simple
Battery life	hours	1Week	1year

There are thousands of sensor node platforms developed with varying components and operating systems depending on the categories of their research groups. Current WSNs are deployed on land, underground and underwater, which presents different challenges depending on the environment. The common types of wireless sensor networks in the market include; terrestrial WSN, Underground WSN, Underwater WSN, Multi-media WSN and Mobile WSN [6]. In terrestrial WSNs, a large number of wireless sensor nodes are deployed by placing them in the target area by a plane using 2-d, 3-d placement models. This enables multi-hop optimal routing, shorter transmission ranges and low data redundancy as well as minimal delays. Underground WSN is a group of nodes whose means of data transmission and reception is completely underground. It may be completely embedded in dense soil or rock.

B. Challenges to be addressed in order to push the WSN technology further

In underground WSNs, underground sensor nodes are supported by additional sinks nodes above ground to boost information relay from the sensor nodes to the base station. This presents a challenge in wireless communication due to frequent signal losses and high level of attenuation. Sensor nodes deployed underground require longer battery life due to lack of recharging media beneath surface. In underwater WSNs, the sensor nodes rely on acoustic wave transmissions which are challenged by limited bandwidth, long propagation, delays and signal fading. Multi-media WSNs consist of sensor nodes equipped with cameras and microphones, which interconnect over wireless networks to be able to retrieve the process and compress data. The main challenge in this model is a high bandwidth demand, high energy consumption and quality of service provisioning [6].

Power consumption is the main challenge that all wireless sensor networks consider during design. Since wireless sensors are powered by battery or energy harvesters, hardware that uses power intelligently is critical in determining the longevity of the devices. Development of ultra-low power networks is one of the developments being undertaken in wireless sensor technologies. With the current development of ultra-low power transceiver radio chips, it is now possible to develop low power wireless sensor applications with efficient energy harvesting, conversion and usage. Hardware costs also pose a challenge through increasing the overall expenditure in wireless sensor network developments. Most of the systems being used in wireless sensor applications and networking architecture are vertically integrated to be able to utilize performance. This can be improved through the development of more stable and mature systems and networking architecture. The use of low power radio frequency transceivers are affected by poor wireless reception in indoors environment such as buildings

Energy management in WSNs is another critical viewpoint because of the resource constraints. Remotely deployed energy stringent sensor nodes are typically powered by attached batteries. Also, resource constraints are addressed utilizing the diverse equipment units, protocols, and radio. Data transmission, in particular, is one of the most power consuming aspect. Hence, the power efficiency of communication between the base station and surrounding components is of paramount importance. Another issue may be that WSNs, due to their continuous monitoring nature, make tremendous amounts of data that are hard to manage, bringing about a colossal increment in the daily volume of information stored in a corporate data warehouse system.

B WSNs for real time monitoring of the food supply chain

With increasing strict regulations in the food supply chain management with the aim of increasing higher product quality and public safety, the need to track and trace the treatments of all ingredients and the use of wireless sensor network technology has become prevalent in most researches. Traceability, global standards and adoption of radio frequency (RF) technologies have been widely investigated through scientific experiments in universities and by companies in food industry. It is now possible to track food products in the market in the entire food supply chain using RFID tags, which is a more superior technology to barcodes and labels. RFID tags have sensors equipped with unique ID for products or their batches. The sensors attached on tags are able to form a sensor network, which monitors food temperature and humidity. This provides continuous monitoring of data throughout the food supply chain, which provides assurance to retailer requirements such as maintaining the required temperature throughout the delivery and storage process of products.

WSN technology is used in agriculture industry for monitoring and surveillance of crops within a farm. However, weather variation is the sole challenge that affects performance of WSN in this industry. The technology utilizes radio frequencies that can be interfered byweather conditions. The technology is used in maintenance and monitoring of farmlands. This is achieved through installation of sensors and cameras on the field. These devices are linked to the control station on the farm via the mentioned wireless technology. Monitoring fields enables identification of severe conditions of the soil and weather; with such information, farmers may make comprehensive decisions concerning planting activities. Wireless technology also enables pest control and irrigation activities that are essential when pursuing maximum yield. Sensors deployed on the soil are able to determine moisture content of the soil. When soil moisture content is below the minimum, the information is transferred to the control that commands the irrigator to sprinkle the soil. Phytophotra is a disease that affects potatoes and is influenced by temperature and humidity conditions. Between 868MHz and 916MHz, motes can be used in determining moisture content on air and temperature [8]. Extreme temperatures can be reflected and relayed to the control station, which initiates spray of pesticides.

III. Selected Applications of WSNs in Food Industry

WSNs have proved to be vital in certain applications that require data to be monitored in real time. Particularly, such networks have been widely used in precision agriculture. In this regard, agricultural sector has recently made use of WSNs in an attempt to enhance the monitoring operations associated with this sector. In light of this, precision agriculture refers to the science involving precise comprehending, approximating as well as evaluating the crop condition with the intent of determining the real irrigation needs, and correct utilizers during harvesting and sowing seasons.

Precision agriculture is actually an integrated product-based farming system and information specifically designed to boost productivity and minimize unintended effects of equipment failure, the environment and wildlife. Figure 1 depicts WSN deployment for agriculture.

Since wireless sensor network is an ad-hoc kind of network, it does not need infrastructure as it is the case for other technologies. It can contain several nodes (unassisted embedded components) which are used in processing and transmitting data gathered from various onboard physical sensors such as soil moisture, humidity, pressure wetness and temperature. It also entails base section which serves as the gateway between end users and nodes or between nodes.

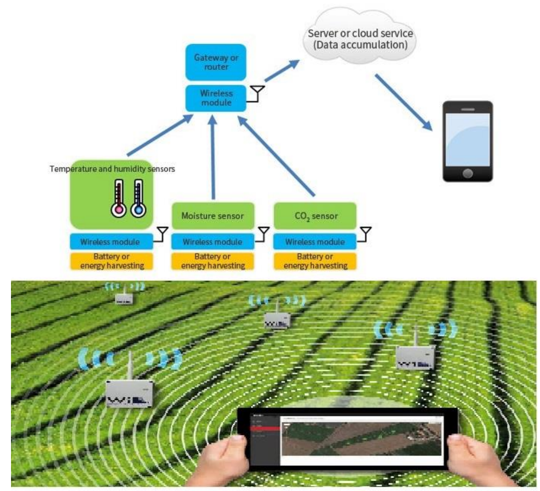

Figure 1. WSN deployment for the agricultural applications

Wireless sensor network technology has a variety of advantages as well as limitations. For instance, proper utilization of fertilizers and controlled irrigation can preserve resources and reduce wastage. Additionally, proper utilization of pesticides can minimize losses and improve and maintain the quality of product as well as enhance profitability. However, limitations associated with the deployment of WSNs for agricultural applications include security challenges concerning routing operations, physical security of software and hardware, and limited power [3].

Precision agriculture assists in reducing carbon dioxide, methane, nitrogen as well as other harmful liquid and gases emission. On the other hand, crop surveillance mainly focuses on understanding and monitoring the needs of crops in accordance to weather, as well as managing the available resources. Wireless sensor network also assists in preserving precious resources, effective utilization of such resources, and reducing wastage. This is referred to as proficient resource distribution [9].

Generally, wireless sensor networks have been employed in agriculture for pest control. In this regard, it is argued that “sensor network-based decision support system for agriculture” is used to conduct an experiment regarding pests and crop-weather [3]. Researchers are further trying to comprehend the hidden correlation between weather and pest and disease. In this case, a corrective prediction model has been developed that could be used to understand the correlation between such parameters in the future. The proposed model is shown in Figure 2.

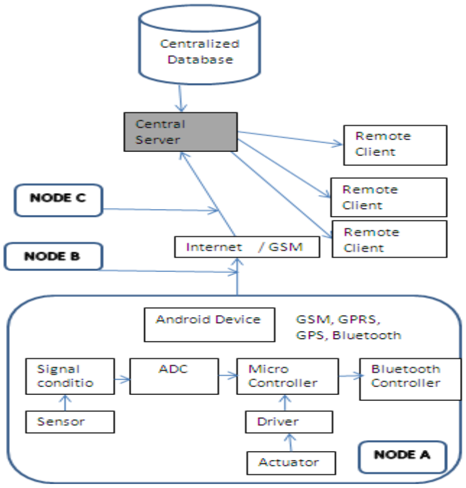

Figure 2. Proposed corrective prediction model for understanding the correlation between weather and pest and disease [3]

The proposed model is to offer ultra-low cost to the remote node because the user can only maintain a remote node rather than the primary node at the farm. The central server can then be accessed via web applications in order to obtain the relevant details regarding disease forecast and weather conditions [10].

On the other hand, the technology referred to as food intelligent packaging (IP) are currently under review with a special focus on the likelihood of using SAW and RFID technologies. According to [5], passive SAW and RFID technologies are more likely to attain a food intelligent packaging which can be used to wirelessly communicate to the food chains' different agents.

IV. Discussion

Quality wireless sensor networks are required at different stages of food production and marketing. There are different types of wireless sensor networks including terrestrial WSN, underground WSN, underwater WSN, multimedia WSN and mobile WSN. All these WSNs are crucial in maintaining food security and quality throughout the supply chain. It is necessary for all companies in the food chain to adopt WSN to ensure that products can be traced, beginning from the producer to the consumer. This ensures that food products are clean, well labeled, and of good quality. Despite the fact that WSNs have had a positive impact on the agricultural sector, there are some visible constrains that inhibits their adoption in many countries. These challenges are both technically and culturally based.

Agronomists have been in opposition of WSN and distrust them with the belief that they are more informed and experienced in managing food production process. Secondly, there is still a big over-reliance on 1D optical barcodes, which inhibits successful application of other technologies.

The third challenge emerges from the costs of acquiring and setting up WSN [11]. For instant, many people around the world and more importantly in developing countries still practice small scale farming. As such, setting up WSN would offset other benefits such as low costs of farming. Still, the benefits associated with WSN regarding food security are immense and many countries are struggling to ensure a strong industrial adoption.

TABLE II. Applications of WSNs in Agrofood Industry

Main Field of Application	Technology Used	Specific Function	Sensing Parameters
Environmental monitoring	Surface Acoustic Waves Resonator (SAW)	Weather monitoring Geo-referenced environment monitoring	Temperature, moisture, sunlight intensity
Advantage/ Functions	Easy to organize and process parameters		
Precision Agriculture	-Silage yield mapping system - Wireless infrared thermometer system -Automatic irrigation system	Spatial Data Collection Precision irrigation Variable rate technology Supplying data to farmers Automated fertilizer applicator for tree crops	Soil water availability, soil compaction, soil fertility, biomass yield, leaf area index, leaf temperature, leaf chlorophyll content, plant water status, insect disease weed infestation, grain yield.
Advantage/ Functions	-The system provides accurate field survey data enabling farm managers and engineers to monitor performance -The system is proved to have saved between 30-60% water usage		
Machine and process control	M2M technology Wireless personal safety device (WPSRD) Remote service system for agricultural machinery -Wireless Probe System (WPS)	Vehicle guidance Machinery management Robotic control Process control	State and condition of machinery, seamless remote control, cost efficiency
Advantage/ Functions	-The system prevents collision between human and motor vehicle properties in farms -The systems maximized production through ensuring minimum breakdown time -WPS improves accuracy and efficiency of food drying process and cost of data collection		
Facility automation	RF link (458 MHs), Solar Power data acquisition stations (SPSWAS)	Greenhouse control Animal feeding facilities	HVAC, Lighting, energy, access control, risk management,
Advantage/ Functions	- Improved productivity and reduce labor requirement		
Traceability system (RFID biosensor tags) Smart collars Acoustic wave systems	Hobo Pro data loggers (Onset computer corporation, Pacaset, MA)	Animal ID and health monitoring Food packaging Transportation Food inspection	Temperature, humidity, noise, light and ammonia content in the air -smart packing, automatic checkout and smart recycling, Vibration and animal behavior, bacterial concentration in food,
Advantage/ Functions	Improved security, traceability, productivity, inventory control, savings in capita and operational costs. High food monitoring quality		

Together with other forms of precision agriculture such as integration of scattered pieces of land, WSN had the ability of improving the quality of food products, enhancing sustainability, protecting the environment, and improving rural development [12]. Table II provides a comparison of main applications of wireless sensor networks in agrofood industry. Selected field of applications presents how this technology can be integrated to enhance safety and quality of food products and provide advantages such as mobility, transparency and autonomy. The WSN technology is mainly built on networked devices or utilizes networks for communication. However, much additional work still should be done for a large scale integrated communication and scalable coordination throughout the agro-food networks [13].

V. CONCLUSION

WSNs have gained increasing popularity over the last couple of years; they have helped revolutionize industrial operations starting with production to manufacturing to retailing. The agricultural sector has also seen an increased use of WSN to track the history of food products beginning from cultivation to post-harvest activities. Using WSNs, the history of food product starting from production to harvesting to marketing can be traced. The use of WSNs has seen improved food security around the globe. There are various benefits associated with WSNs despite the fact that there are still many challenges to overcome. For instance, there is a huge opposition from agronomists who believe that they have the knowledge and experience to manage fields. Further, the costs associated with acquiring and setting up WSNs is also a challenge to be addressed, particularly in developing economies where land is scattered and small scale farming is the major form of agriculture. Consolidation of such land is needed to ensure that the cost of using WSNs in agriculture is less compared with the gains. Furthermore, there is a need to address cultural issues such as the belief that food security cannot be fully achieved as well as the need for a vast campaign in a bid to educate stakeholders of the benefits of using WSN in the food production and marketing chain.

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