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RESEARCH ARTICLE

Enhanced Smart Industry Wireless Sensor Networks for Smart Factory: Status, Challenges, and Perspectives

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ABSTRACT

Industrial wireless sensor networks are increased in recent years due to provide real-time monitoring, decision-making, and controlling. Industrial wireless sensor networks are used in many factories, such as food production, aircraft factories, and pharmaceutical factories. The aim of this research is to focus on the industrial wireless sensor networks in smart factory and the challenges that need to be considered in use such as its location, energy consumption, and security. The research discusses that different issues are highlighted the importance of using real-time decision-making to improve the performance of the process and provide service monitoring for industrial process improvement.

Keywords: Smart factory, wireless sensor network, energy management, digital twin model, decision-making

INTRODUCTION

Nowadays, the industrial environment is defined by increased competition, quick response times, cost savings, and production that are dependable in meeting customer demands. The new industrial paradigm known as Industry 4.0 has attracted attention on a global scale, prompting a substantial digital transformation among many manufacturers. Digital technologies have made it possible to adopt a new method for data-driven strategy decision-making processes, where knowledge extraction is dependent on the analysis of big amounts of data from factories equipped with sensors.[1]

Many challenges face smart factory construction, one of the most important challenges is the integration of existing devices in the manufacturing system with new digital technologies, especially when there is no compatibility between the devices or their systems need to upgrade. If there is no compatibility, new equipment's needed to implement in a smart factory that makes it costly.[2]

The main contribution of this research includes;

- Identify the smart factory architecture and the smart industry wireless sensor networks (SIWSN) technologies.
- Study different challenges relate to the use of the SIWSN.
- Develop different decision-making approaches in a smart factory.

The remainder of this research described the following: We present smart factory architecture and protocols; then, the challenges of SIWSN are presented and evaluated, and the decision-making approach is explained. Finally, we conclude the work and future works.

SMART FACTORY ARCHITECTURE

Many smart factory architectures and models are proposed in the literature,[3,4] with limited components. In Fortoul-Diaz *et al*.,[5] the smart factory architecture includes six main elements to cover the most related components. A brief description of each one includes the following:

Cyber-Physical Systems

It is an interface between the physical and the digital environment for data transformation using wired/wireless protocols to communicate with sensors and actuators. The IoT components send/receive information and instructions for automated devices through different protocols such as MQTT and HTTP.

Edge Computing (EC)

It executes processes near the source data, runs local real-time routines, communicates with the cloud, and distributes services

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through edge nodes. The EC will divide the workload and computing between different edge devices in the network system.

Artificial Intelligence (AI)

It makes decisions and recognizes patterns using deep learning and machine learning for data classification.

Cloud Computing (CC)

It is a collection of configurable computing resources that require only a few resource configurations to run services such as internet of things platform and distributed database.

Data Analytics

It is an important stage in smart factory to analyze data and have reports for future development. It requires data collection and selects the useful information. Reports will create a visualization of information through dashboards in real-time and find statistical calculations such as mean or average and analytical calculations such as linear regression.

Cybersecurity

It secures information and maintains secure connections between system components of a smart factory by employing different encryption/decryption technologies.

Figure 1 shows the smart factory architecture when the elements are interconnected together. This architecture integrated all the important elements that are needed to configure a smart factory architecture.

PROTOCOLS FOR SIWSN

SIWSNs have different protocols and technologies. Table 1 shows the SIWSN protocols and its specifications.[6-8] Each of these technologies has its own strengths and weaknesses, making them suitable for different use cases and applications.

LITERATURE REVIEW FOR SIWSN CHALLENGES

Sensor technology is important in smart factory and Industry 4.0 since sensors provide real-time and high performance.[9] In the literature, the SIWSN is used with different issues related to:

Localization for SIWSNs

Choosing the location of wireless sensor network in the factory is important. In Wi *et al.*,[10] they integrate the wireless sensor network with the factory environment. They proposed a worker-oriented smart factory where the worker wears a smart band to collect information then communicate with the main control system. This method is easily used and integrated in

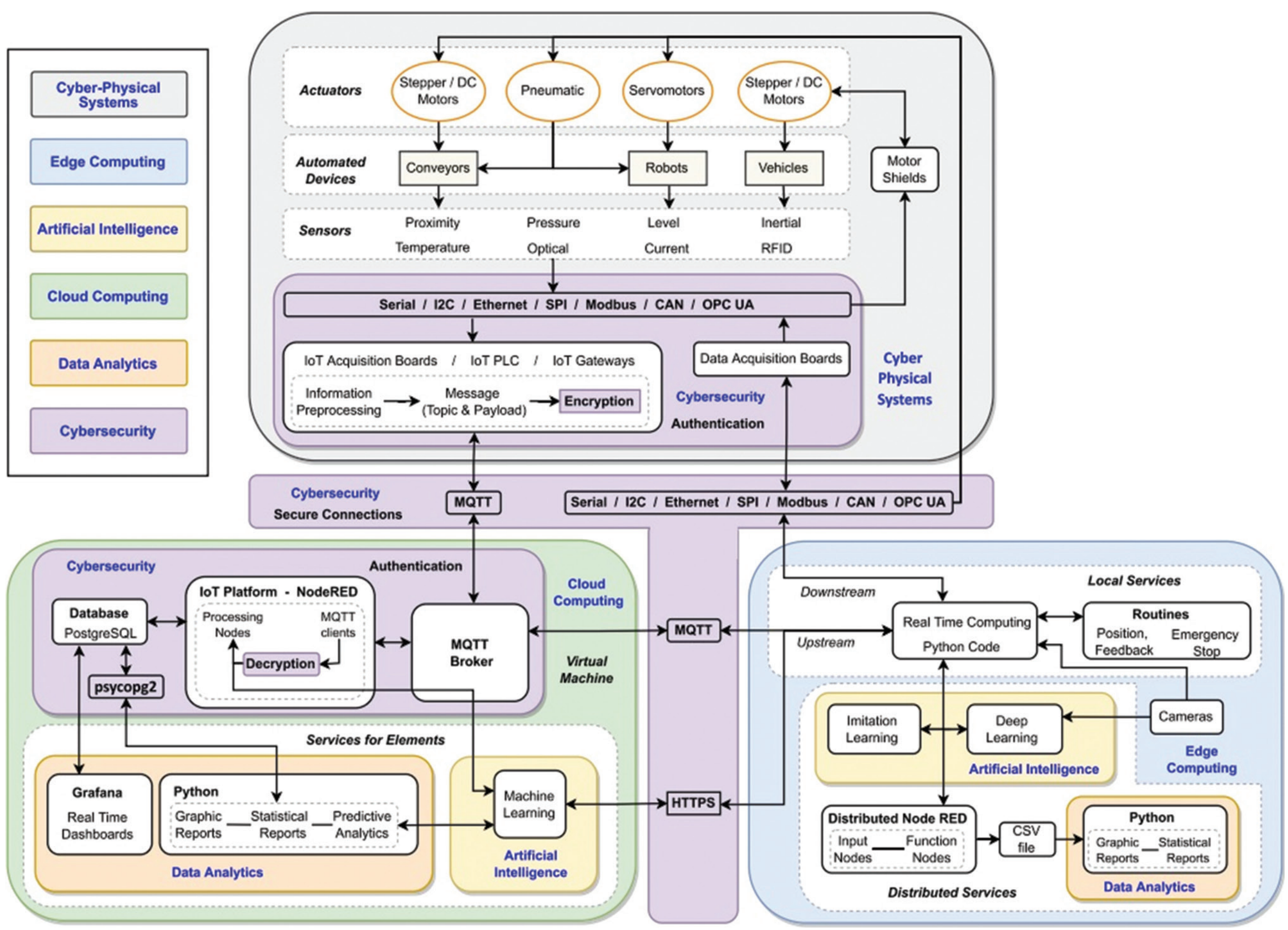

Figure 1: The elements for smart factory architecture based on open-source software[5]

Table 1: Protocols for smart industry wireless sensor networks

Protocol	Specifications	Descriptions
Zigbee	Standard: IEEE 802.15.4	Low-cost, power-efficient, limited connections
	Frequency: 2.4 GHz and 900 MHz	Used inside building/home automation with embedded sensing
		Distance range: Up to 50 m.
Bluetooth	Standard: IEEE 802.15.1	Low cost, moderate power
	Frequency: 2.4 GHz	Used with different user devices
		Distance range: <100 m.
Wi-Fi	Standard: IEEE 802.11a/b/g/n/ac	Higher data rate, Higher power consumption
	Frequency: 2.4 GHz and 5GHz	The wireless standard developed for commercial/consumer use
		Distance range: 100–200 m.

the factory since there is no need to change the environmental infrastructure of the factory.

In Kumar *et al*.,[11] the authors use the power level of the sensor nodes to choose a suitable location according to signal strength measurement. The signal strength indicator had minimum errors in the environment when using genetic algorithms.

Harmy and Mendoza,[12] specify that there are sensors nodes that are needed indoor and outdoor of the factory and they developed a special method for indoor wireless sensor localization. In the study, they concluded that the efficiency of the system is improved when the location of the sensor nodes is placed in an accurate position inside the factory using 3D localization instead of 2D methods.

Efficiency for SIWSNs

The energy management of wireless sensor networks is a big challenge in smart factories since sensor nodes have limited energy and they need to have long charge.[13,14] In Feng *et al*.,[15] they proposed a new charging strategy of wireless sensors networks and they implement scheduling plans of fast machines running to minimize the energy.

In Ashok and Kumar,[16] the authors used different methods to increase the energy of wireless sensor networks. They focus on the natural power supply to recharge wireless sensor networks from sunlight and use solar panels as renewable energy sources.

In Alanazi *et al*.,[17] the authors proposed a switch off and sleep mode for the wireless sensor nodes to minimize power and used less energy in routing. The proposed system maximizes the life of the main nodes in the virtual backbone wireless communication and provides routing protocols between the wireless sensor nodes.

In Wu and Tseng,[18] the authors proposed energy saving for sensors when they use sleep/waking modes of operation. In this proposal, the sensor is switched off most of the time and it is waking up at random or at a specific time for a limited period of time under the control of an internal timer to save the energy.

Security for SIWSN

Security for wireless sensors in factory is important because of various attacks and threats. The open environment for wireless connection needs to be secure for wireless sensors.

In Osanaiye *et al*.,[19] they proposed two phases one phase for detecting the malicious node and another phase for removing the nodes that are affected by the Jamming attack. WSN is affected by Jamming attack when it transmits a high-range signal that has the same radio frequency of WSN and disrupts sensor node function and communication.

To ensure secure data, an encryption and authentication mechanism are used. In Pandithurai *et al*.,[20] a secure cloud technology is used to process the data of sensor node using SSL/TLS encryption method to ensure secure storage for sensitive data in the cloud and during transmission.

In Ruizhong *et al*.,[21] an authentication model is used in the physical layer to recognize the legal and illegal sensor nodes in the channel. The authentication model is built around positive-unlabeled (PU) learning and bootstrap aggregating (bagging) strategy.

In Jasim *et al*.,[22] the authors used different cipher algorithms for wireless sensor networks to protect data such as LED, PRESENT, PICCOLO, SIMON, SPARX, and LEA for data confidentiality.

DISCUSSION FOR DECISION-MAKING IN A SMART FACTORY

Decision-making in a smart factory integrates data-driven approaches with various technologies such as the internet of things, AI, and machine learning.

SIWSN are used in smart factories to collect data and analyze it in edge computing and/or CC. The collected data will be analyzed to provide decision-making to improve and optimize production processes in manufacturers. Decision-making is used in manufactures related to production planning and scheduling, quality control, device monitoring and predictive maintenance before failures, and monitor the factory environment to prevent hazards.[9]

Decision-making in manufacturing is crucial for the success and efficiency of production systems. Many methods are used in decision-making for manufacturing environments. In Altuntaş,[23] a technique of precise order preference is used as a method to solve decision-making problems in manufacturing systems.

One of the important manufacturers is lithium-ion battery factory which needs decision-making to product high-quality product. The decision-making is important to develop next-generation solid-state batteries.[24]

Management needs decision-making in manufacturing companies. In Habanik *et al*.[25] the study shows an important relationship between management decision-making and worker's performance, this is done through surveys and statistical reports and tests.

Strategic decision-making systems are important to improve the quality of product and satisfy customer needs. It is used to make a balance between cost savings and product development.[26]

Each manufacturing companies try to have a high-quality product and avoid defective products. In Soares *et al.*,[27] a decision support model has been proposed to help decide the destination of defective products in mass production industries, aiming to reduce quality costs and improve overall quality.

USES OF SIWSN IN SMART FACTORY

Wireless sensor networks are used in factory for many reasons starting from building and environmental safety for workers to high product quality. Wireless sensor networks for temperature, humidity, smoak, and gas pollution are needed for continuous monitoring of the factory building to provide a safe and healthy environment for workers. Wireless sensor networks for motion detection are used to control product movements. Wireless sensor networks for color are used for products classification. Wireless sensor networks for biological, chemical, and radioactive effects are important in factories of food and medicines. Wireless sensor networks are also important for controlling electric devices and power systems.[28]

SIMULATION OF SMART FACTORY USING DIGITAL TWIN MODEL

Digital twin technology is used to simulate the real world. It is used in the manufacturing process to reduce risk and improve products.[29]

Digital twins' technology is used for the simulation of smart factory. The simulation is important in the design and implementation of the smart factory to minimize cost.[30] In Liu *et al.*,[31] Unity3d and 3Ds Max software are used to design the model. In Zhou,[32] MATLAB is the simulation software that is used to manage and control the load and energy of a wireless sensor network in a smart factory.

CONCLUSIONS AND FUTURE WORKS

In a smart factory with SIWSN, the goal is to reach to zero defect manufacturing to reduce the defect and assure a highest quality production output. The generation, distribution, and processing of industrial information are being changed by Industry 4.0. operational level of a smart factory needs benefit in safety, real-time, and data format standardization for decision-making. Successfully managing of these changes in the factory is important to achieve the digital transformation and make the business survives.

As a conclusion, the SIWSN need to have important specification to handle failures in manufacturer and solve any missing operation automatically by data collection, monitoring, and decision-making. In addition to have secure and power consuming, furthermore, the study highlighted the importance of SIWSN localization and scalability.

In the researcher's point of view, the development of smart factory is important, and its implementation becomes easy, especially when the technology with AI is available.

For future works, Industry 4.0 needs to consider sustainable manufacturing and sustainability environment and adopt standard policies to transform to Industry 5.0.

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