WIRELESS SENSOR NETWORKS IN NUCLEAR PLANTS

By

Eng. Mohamed Yehia Ahmed Habash

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE in
Electronics and Communication Engineering

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Title of Thesis:

Wireless Sensor Networks in Nuclear Plants

Key Words:
WSN; Validation of Sensor Readings

Summary:

In this thesis, a system based on a WSN to monitor the radiation level around and inside a nuclear power plant is designed and investigated using the Castalia Simulator. A new approach for validating the sensor reading and detecting a new event is proposed. The fault detection algorithm is applied at the cluster-head, and is based on the idea that the sensor data tends to be correlated in both time and space By using the idea of Triple Modular Redundancy, three reference sensor nodes are used in each cluster. We use the two out of three voting mechanism to select a good sensor as a reference for checking the correctness of other sensors in the same cluster.

The event detection algorithm is applied at the sink node and exploits the historical data maintained at the sink node.

The simulation results show that the proposed fault detection algorithm outperforms other existing algorithms in terms of fault detection accuracy/ false alarm rate, number of received/ sent messages per node, fault detection processing time, and energy consumed

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Nomenclature

ADC	Analog to digital converter
AI	Analog Input
BAN	Body Area Network
BN	Beacon Node
BS	Base Station
CDMA	Code Division Multiple Access
CH	Cluster-Head
CM	Clutser-Member
DA	Detection Accuracy
DSP	Digital Signal Processor
FAR	False Alarm Rate
FDI	Fault detection and Identification
FTQM	Fault Tolerance by Quartile Method
FT	Faulty Sensor
FSDA	Faulty Sensor detection Accuracy
GD	Good Sensor
LEACH	Low Energy Adaptive Cluster Head
LF	Local Faulty

LG	Local Good
MANET	Mobile Ad hoc Network
NPP	Nuclear Power Plant
NT	Neighbors Table
PDA	Personal Digital Assistant
RNS	Residue Number System
SHM	Structural Health Monitoring
SN	Sensor Node
SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access
TMR	Triple Modular Redundancy
VCR	Video Cassette Recorder
VoIP	Voice over Internet Protocol
WSN	Wireless Sensor Network

Abstract

A Wireless Sensor Network (WSN) consists of spatially distributed sensor nodes that cooperatively monitor physical or environmental conditions, such as radiation, temperature, sound, vibration, pressure, motion, relative humidity, or pollutants. These sensors are small in size and communicate with each other, typically over a Radio Frequency (RF) channel. Due to the small size and wireless communication, nodes may be placed very close to the observed phenomena. As these sensor nodes may be deployed and operated in hostile environments, it might be difficult or dangerous for humans to enter these areas such as in nuclear plants. Therefore, sensor nodes are expected to operate for periods ranging from days to years without any human intervention. At the same time these sensor nodes are subject to various types of faults such as sensing faults.

In nuclear premises, the sensor reading plays a key role in the assessments of the system state. The indication of an abnormal state may be the result of a sensor failure rather than a system failure. Failure to identify the source of the indication of an "abnormal state" and take appropriate corrective action could result in expensive and unnecessary system shutdowns or, worse still, accidents that endanger both system and personnel. So, it is very important for a monitoring and diagnostic system to distinguish between the case where a sensor failure and not a system fault is responsible for the indication of an abnormal state.

In this thesis, a system based on a WSN to monitor the radiation level around and inside a nuclear power plant is designed and investigated using the Castalia Simulator. A new approach for validating the sensor reading and detecting a new event is proposed. We use one of the standard routing techniques to create clusters with cluster-head, and cluster-members.

The fault detection algorithm is applied at the cluster-head, and is based on the idea that the sensor data tends to be correlated in both *time* and *space*. Existence of temporal correlation means that the observed reading at one time instant are related to the observed readings at the previous time instants while spatial correlation implies that the readings from sensor nodes that are geographically close to each other are expected to be largely correlated.

By using the idea of Triple Modular Redundancy, three reference sensor nodes are used in each cluster. We use the two out of three voting mechanism to select a good sensor as a reference for checking the correctness of other sensors in the same cluster. The event detection algorithm is applied at the sink node and exploits the historical data maintained at the sink node.

The simulation results show that the proposed fault detection algorithm outperforms other existing algorithms in terms of fault detection accuracy/ false alarm rate, number of received/ sent messages per node, fault detection processing time, and energy consumed.

Chapter 1 : Introduction

In recent years, Wireless Sensor Network (WSN) has become one of the most important fields of research, due to its wide range of applications such as military target tracking and surveillance, traffic control and monitoring, natural disaster relief, biomedical health monitoring, building and structures monitoring, industrial and manufacturing automation, and hazardous environment exploration and seismic sensing. Also, thanks to the recent technological advances in wireless communications, processor, memory, radio, low power, highly integrated digital electronics, and Micro Electro Mechanical Systems (MEMS) [1], it becomes possible to significantly develop tiny and small size, low power, and low cost multifunctional sensor nodes.

A **WSN** is a wireless network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. The development of wireless sensor networks was originally motivated by military applications such as battlefield surveillance. However, the wireless sensor networks are now widely used in many industrial and civilian application areas, including industrial process monitoring and control, machine health monitoring, environment and habitat monitoring, healthcare applications, home automation, and traffic control.

Each node is a battery operated device that has a CPU to perform computation, small amount of memory to store program code and data, and a radio transceiver for wireless communication. These nodes are tightly coupled with the physical environment through sensors and actuators. Due to small size and wireless communication, nodes may be placed inside or very close to the observed phenomena.

While individual sensors have limited sensing region, processing power and energy, networking a large number of sensors gives rise to a robust, reliable, and accurate sensor network covering a wider range. These sensors cooperate with each other to collect the sensed data and send it to a sink node or a Base Station (BS) which in turn communicates these data to a central processing and storage system. A sensor