Study on a Sensor Network System with a Self-Maintenance Function for Plant Monitoring System

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ABSTRACT

This paper presents a new network-based concept of real-time plant monitoring based on the wireless sensor network. The wireless sensor network is a novel technology to perform distributed sensing tasks, especially for applications such as environmental monitoring, smart spaces, medical systems and etc. The advances in MEMS technology, sensing technology and wireless communications have enabled the development of real time, detailed, wide-range, low-cost, low-power and multifunctional wireless sensor network. On the other hand, semiconductor devices like ICs suffer from radiation damage. We must consider this effect for applying wireless sensor network devices to nuclear power plants. Radiation may produce one-time noise signals in the sensor network, or it may damage the wireless sensor network device. Therefore monitoring system will be unreliable for nuclear power plants in ordinary way of composing wireless sensor networks.

In this study, we develop a new concept of a robust wireless sensor network, that has a tolerance against both the partial node’s failure and packet errors; realized by a Self-Maintenance function. The Self-maintenance function is a function that enables an artifact to find, diagnosis and fix the trouble automatically and maintain itself. So far some approaches have been tried to realize robust monitoring system by applying the idea of multiplex system, based on “2 out of 3”, but this requires a large amount of the hardware and is not suitable for sensor network systems. Here, we designed a sensor network system with Self-Maintenance function based on qualitative reasoning technique for robust wireless sensor network system, and an instrument network based on ZigBee has been set up for investigations. It is found that ZigBee-based instrument networks are robust but susceptible to interference from traditional way of sensing.

Key Words: ZigBee, wireless instruments, sensor networks, health monitoring

1. INTRODUCTION

Structural health monitoring (SHM) [1] is a vast, interdisciplinary area of research whose literature spans several decades. Wireless sensor networks promise cheap and dense instrumentation for structural monitoring [2]. Recent work has demonstrated the feasibility of continuous structural data collection using a wireless network [3, 4, 5]. For these characteristics of wireless sensor networks, it could be a great application and solution for real time monitoring of nuclear power plant. Real time monitoring enables safe operation of nuclear power plants and
also, wireless sensor networks frees operators from worrying about fire caused by cable deterioration.

In other hand, since inside a nuclear power plant are under radiation field, ionizing radiation can cause unwanted effects in semiconductor devices such as flipping the state of memory cells. These unwanted changes are known as soft errors and are the most common type of single event upsets (SEUs). While statistically unlikely during the operating lifetime of even the largest field programmable gate array (FPGAs), circuit components within programmable logic devices (PLDs) such as configuration memory cells, user memory, and all those components made by semiconductors can be affected. When wireless sensor networks are implemented in nuclear power plant for structural health monitoring in ordinarily way (as we do in non-radiation field), soft errors may lead us to miss detection of failures.

In this paper, we describe the design and evaluation of self-maintenance sensor network, a sensor network system that has a tolerance against soft errors and partial nodes failure. The system has tolerance against SEUs, able to detect sensor node’s damage perfectly and avoid false-positives and false-negatives and realizes reliable real time monitoring.

2. SELF-MAINTENANCE ALGORITHM

Although rapid advancement of the technology, still living body is superior to artifacts in some respects. The difference frankly appears to the mechanism of “Production” and “Maintenance.” In other words, while living body has functions of form production and restoration, an artifact depends on outside of itself for this function. If an artifact had composition like the living body, composed of a numbers of cells, an artifact might be able to achieve the function like Self-Restoration. Therefore, for artifacts that are consisted of homogenous units, like sensor networks, we considered supplement will be one of a method for maintaining artifacts. The most fundamental function of sensor networks are maintained by supplementing damaged node with other nodes. Before implementing this self-maintenance algorithm into wireless sensor network in real world, we held a simulation in computers and designed wired device for testing.

2.1. Damage detection

Detecting a failure of a sensor node is the most important part of the self-maintenance sensor network system. It is impossible to estimate a failure from just looking at one sensor's value. We cannot tell whether the irregular value is caused by a damage of where it is monitoring (plant) or sensor itself. The system with accurate decision of node’s failure is strongly required for avoiding false-negative and false-positive. In our system, damage detection of sensor is based on the idea of model-based reasoning, that “nodes close to each other should some relationship.” Failure can be detected when sensors are connected into a network and handling those comprehensive output from the sensors. That is to say, verify whether sensor is working correctly or not by comparing value of it’s neighbor sensors and detect it’s failure. In other words, sensor's reliability is determined by sharing the information of each sensors and handling those information by network consisted of sensors. Consequently, we consider the system will be able to detect sensor's failure by giving a parameter “reliability index” to each sensor. Figure 1 describes the concept reliability index.
2.2. Reconfigurable Network

When broken sensor is detected, the system will exclude the sensor from the network and reconfigure the network with only healthy nodes. This function enables to minimize the damage of the network from a partial failure. Without this function, damaged sensor node will cause packet collisions and it will effect to entire network.

2.3. Simulation Result

In this simulation, we inspected it about the case that could happen frequently. A concrete example will be given to help clarify the system we designed so far and its result is shown in below. 16 nodes are placed and 1 of them is damaged by radiation (Fig.3-1). SEUs are occurring in the damaged sensor, and irregular value is coming. The red graph in Fig.3-2 is the output from damaged sensor, and it is outputting random values every time. Partial failure of network nodes will be a cause of false-negative the power plant.
Fig. 3-3 is a graph after applying self-maintenance function to the network. Node in failure was detected correctly and wrong outputs are excluded from monitoring system. The result proved that it works when failure rate is 1/16 (6.25%). Since it is known that under 1000Gy of radiation, CMOS chip made from 0.15µm SOI process, the error bit rate will be 2.2% in average [5], the self-maintenance function is effective enough under those condition.

2.4. Wireless Device

From the simulation we held, we found there are enough possibility to place wireless sensor network into radiation condition by applying our self-maintenance algorithm. Therefore, we designed wireless sensor network device with ALTERA’s CPLD, 10bit digital temperature sensor, and Xbee wireless module. Since these are made through 0.18µm CMOS processes, that is larger process than 0.15µm, we consider that it has more tolerant against radiation.
At this moment, we could only implement temperature sensor to the device, but we can also add vibration sensors, pressure sensors, strain gauges and noise sensor for health monitoring in many directions. Moreover, distributed processing system and this radio frequency module, called Xbee is manufactured under ZigBee protocol, the maximum size of the network will be up to 65000 nodes. The new health monitoring system followed by enormous number of sensors will enable a efficient innovational way of managing nuclear power plants.

3. CONCLUSIONS

In this paper we found a new fault tolerance algorithm for wireless sensor network. Our design and validation of self-maintenance system suggests that, sensor networks made of semi-conductors have enough possibility to be used for avoiding SEUs caused by radiations. We conjecture that the self-maintenance wireless sensor network architecture might be great applicable to nuclear power plant monitoring system, but have deferred an examination of this question to future work.

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REFERENCES