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Deploying Wireless Sensor Networks with Fault-Tolerance for Structural Health Monitoring

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Abstract—*Structural health monitoring (SHM) systems are implemented for structures (e.g., bridges, buildings) to monitor their operations and health status. Wireless sensor networks (WSNs) are becoming an enabling technology for SHM applications that are more prevalent and more easily deployable than traditional wired networks. However, SHM brings new challenges to WSNs: engineering-driven optimal deployment, a large volume of data, sophisticated computing, and so forth. In this paper, we address two important challenges: sensor deployment and decentralized computing. We propose a solution, to deploy wireless sensors at strategic locations to achieve the best estimates of structural health (e.g., damage) by following the widely used wired sensor system deployment approach from civil/structural engineering. We found that faults (caused by communication errors, unstable connectivity, sensor faults, etc.) in such a deployed WSN greatly affect the performance of SHM. To make the WSN resilient to the faults, we present an approach, called FTSHM (fault-tolerance in SHM), to repair the WSN and guarantee a specified degree of fault tolerance. FTSHM searches the repairing points in clusters in a distributed manner, and places a set of backup sensors at those points in such a way that still satisfies the engineering requirements. FTSHM also includes an SHM algorithm suitable for decentralized computing in the energy-constrained WSN, with the objective of guaranteeing that the WSN for SHM remains connected in the event of a fault, thus prolonging the WSN lifetime under connectivity and data delivery constraints. We demonstrate the advantages of FTSHM throughextensive simulations and real experimental settings on a physical structure.*

INTRODUCTION

The new advances in sensor device technologies make wireless sensor networks (WSNs) effective and economically-viable solutions for a wide variety of applications, such as environmental monitoring, scientific exploration, and tar-get tracking. Civil structures, including bridges, buildings, tunnels, aircrafts, nuclear plants, among others, are complex engineering systems that ensure society's economic and industrial prosperity. Structural health monitoring (SHM) systems are implemented for these structures to monitor their operations and health status. WSNs are becoming an enabling technology for SHM that are more prevalent and more easily deployable than current wired systems. Examples include the Golden gate bridge in the US, bridge monitoring in India, and Guangzhou new TV tower (GNTVT) inChina .

The objectives of SHM are to determine health status (i.e., damage, which is a remarkable change around a sensor location) of a structure, and provides both long-term monitoring and rapid analysis in response to unusual incidents, e.g., earthquakes, load, etc. In practice, it is often difficult to achieve these objectives in WSN-based SHM, due to requirements of SHM and severe limitations of WSNs .

One of the fundamental requirements of SHM is sensor location optimization. According to deployment methods from civil/structural/mechanical engineering, wired sensors are usually deployed at strategic locations to achieve the best estimates of structural health status. These methods do not support sensor deployment anytime or any-where in the structure. They also require significant domain knowledge along with SHM complexity. Generic random, uniform, or grids-based WSN deployments may not be suit-able for SHM. Bearing these in mind, we first focus on deploying a set of N wireless sensors (called primary sensors) in a set

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of locations of a structure by using the most widely accepted sensor location optimization method from the engineering domains, EFI (EFfective Independence).

Since generic WSN deployments are not bounded by the engineering-like requirements, locations of sensor or relay nodes can be planned to prolong network lifetime by ensuring connectivity and reliable data delivery. In contrast, a notable fact in SHM is that once a set of N sensors are deployed (no matter if N is a few or many) and analysis of structural physical properties is carried out by a base station (BS), data from each sensor location must be collected for SHM. Thus, at first sight, wired networks seem a more reliable and stable choice than WSNs. There are severe constraints inWSNs, such as error-less communication, fault tolerance, energy, bandwidth, etc. There are more chances that the deployed WSN for SHM is prone to faults (e.g., getting separated into multiple components) for various reasons: (1) physical structural modeling constraint; (2) irregular communication or unstable connectivity; (3) sensors' debonding faults; (4) quick energy depletion of some sensors (they may only be the points by which other sensors transmit data);(5) there is irregular communication distance—transmitting data from a sensor to another sensor, or the BS over large structures is not reliable.

If any of the fault types occur in WSNs, two problems arise: how to continue obtaining monitoring information and how to guarantee sensor fault tolerance in SHM. Without these answers, we are unable to know at some moment: is a structure going to crash? The fault tolerance problem has been studied extensively in diverse applications of WSNs by researchers in the computer science (CS) community. This is ignored in the SHM applications.

We consider the problem of detecting possible repairing points (RPs) in the WSN. We present an approach, called FTSHM (fault-tolerance in SHM), to repair the network before itstarts operations, so as to guarantee a specified degree of fault-tolerance. FTSHM searches the repairing points or locations in clusters, and places a set of backup sensors at those points by satisfying engineering requirements. In fact, searching the RPs is a prediction of future network failure points (e.g., separable points, isolated points, and critical middle points), which is a promising idea (to search such points and tackle them in advance). To search highly possible RPs, we think of this searching in a distributed manner: it involves only local communication between neighbors in a cluster, and limits searching to clusters (i.e., cluster by cluster).

Another fundamental requirement of SHM is structural damage identification. Existing SHM algorithms work on the raw data of multiple sensors at a high frequency (X00 times per second, $X = 1\,2\,...$). Each sensor works actively for a long period of time, say, from 10 minutes to hours, subjected to severe constraints on radio bandwidth and energy usage. Given these constraints, it is typically not possible to acquire data continuously from all nodes in a global BS [5], [17], [18]. As a result, SHM applications strive to acquire the most "interesting" data (e.g., when there is an event of an earth-quake or of damage in a structure) while wasting resources on "uninteresting" data [19]. To prolong the WSN lifetime, theenergy cost of each sensor for monitoring must be carefully considered. We present an energy-efficient SHM algorithm, called Damage-Indicator. This runs on each sensor and then provides a light-weighted indication of damage in a cluster in a decentralized manner. If there is no indication found in the cluster, the "uninteresting" data transmission toward the BS can be reduced.

The major contribution of this paper is four-fold:

- We formulate the problem of placing a small set of backup sensors into a deployed WSN with primary sensors, and design the FTSHM to address the problem, which is no easy task, as it incorporates multi-domain knowledge.
- To make the WSN resilient to the faults, we propose a backup sensor placement (BSP) algorithm that includes several sub-algorithms.
- To make the resource-constrained WSN easier to use for SHM, we propose an SHM algorithm, Damage-Indicator, showing how a traditional entralized SHM framework can be transformed into a decentralized one.
- We conduct a comprehensive evaluation of FTSHM. In simulation studies, we use data sets collected from the GNTVT system (a SHM project of Hong Kong PolyU) . In a real-world deployment, we utilize integrated Imote2 sensors that run on TinyOS. The effectiveness of FTSHM is compared with that of existing approaches.

EXISTING SYSTEM

- The paper discusses wireless sensor network

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and its application to wearable physiological monitoring and its applications. Also the problems associated with conventional wearable physiological monitoring are discussed.

- ➢ The conventional physiological monitoring systems are bulky to be used for wearable monitoring.
- ➢ The gels used in the electrodes dry out when used over a period of time, which lead to increase in the contact resistance and thereby degrading the signal quality. Let we see the drawbacks

DISADVANTAGES

- Bulky.
- It's not trusted one.
- Not wearable one.
- Cause irritation & rashes.

PROPOSING SYSTEM

- Structural health monitoring(SHM) systems are implemented for these structures to monitor their operations and health status.
- WSNs are becoming an enabling technology for SHM that are more prevalent and more easily deployable than current wired systems.
- Here the sensors are used to detect the patients condition and WSN is used to send the variations.
- Using this module doctor can monitor the variation in his room itself.

ADVANTAGES

- Wearable health care system
- Portable.
- Accuracy.
- More efficient.
- No more irritation & rashes, feel smoothness.

Block Diagram

TRANSMITTER

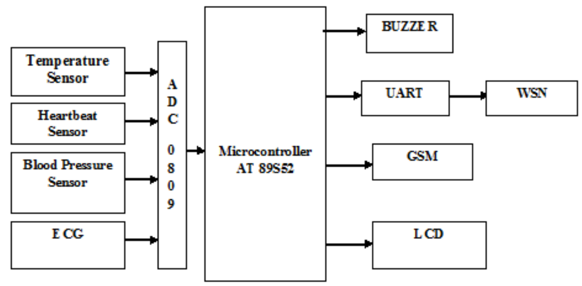

Fig.1Transmitter of Structural Health Monitoring (SHM)

RECEIVER

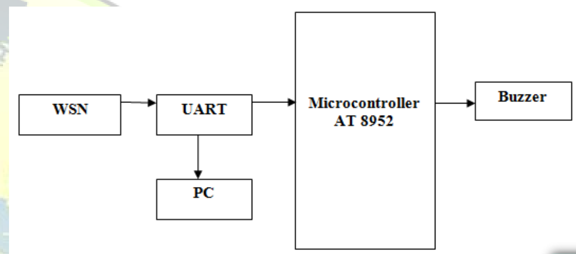

Fig:2Receiver of Structural Health Mon itoring (SHM)

ATMEL 89S52

The AT89S52 is a low-power, high-performance CMOS 8-bit microcontroller with 8K bytes of in-system programmable Flash memory. The device is manufactured usingAtmel's high-density nonvolatile memory technology and is compatible with the industry-standard 80C51 instruction set and pinout. The on-chip Flash allows the programmemory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with in-system programmable Flash ona monolithic chip, the Atmel AT89S52 is a powerful microcontroller which provides ahighly-flexible and cost-effective solution to many embedded control applications.

ATMEL 89S52 PIN DIAGRAM

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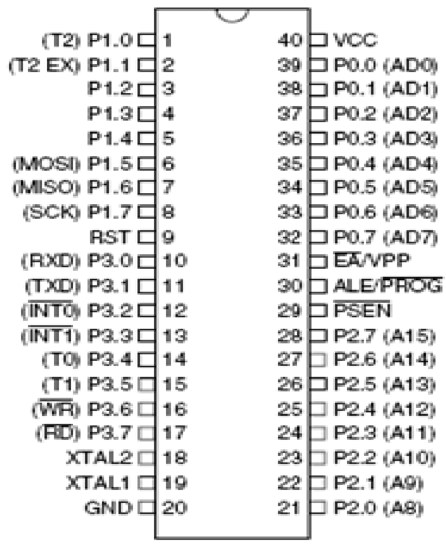

Fig.3 Pin diagram of ATMAL 89S52

PIN DESCRIPTION

VCC

Supply voltage.

GND

Ground.

PORT 0

Port 0 is an 8-bit open drain bidirectional I/O port. As anoutput port, each pin can sink eight TTL inputs. When 1sare written to port 0 pins, the pins can be used as high-impedance inputs.

Port 0 can also be configured to be the multiplexed low-order address/data bus during accesses to externalprogram and data memory. In this mode, P0 has internalpullups.

Port 0 also receives the code bytes during Flash programming and outputs the code bytes during program verification. External pullups are required during programverification.

PORT 1

Port 1 is an 8-bit bidirectional I/O port with internal pullups.The Port 1 output buffers can sink/source four TTL inputs.When 1s are written to Port 1 pins, they are pulled high bythe internal pullups and can be used as inputs. As inputs,Port 1 pins that are externally being pulled low will sourcecurrent (IIL) because of the internal pullups.

In addition, P1.0 and P1.1 can be configured to be thetimer/counter 2 external count input (P1.0/T2) and thetimer/counter 2 trigger input (P1.1/T2EX), respectively, asshown in the following table.Port 1 also receives the low-order address bytes duringFlash programming and verification.

Port Pin	Alternate Functions
P1.0	T2 (external count input to Timer/Counter 2), clock-out
P1.1	T2EX (Timer/Counter 2 capture/reload trigger and direction control)
P1.5	MOSI (used for In-System Programming)
P1.6	MISO (used for In-System Programming)
P1.7	SCK (used for In-System Programming)

Table.1 Port 1 pins and it's functions

PORT 2

Port 2 is an 8-bit bidirectional I/O port with internal pullups.The Port 2 output buffers can sink/source four TTL inputs.When 1s are written to Port 2 pins, they are pulled high bythe internal pullups and can be used as inputs. As inputs,
Port 2 pins that are externally being pulled low will sourcecurrent (IIL) because of the internal pullups.
Port 2 emits the high-order address byte during fetchesfrom external program memory and during accesses toexternal data memory that use 16-bit addresses (MOVX @DPTR). In this application, Port 2 uses strong internal pullups when emitting 1s. During accesses to external datamemory that use 8-bit addresses (MOVX @ RI), Port 2emits the contents of the P2 Special Function Register.

Port 2 also receives the high-order address bits and somecontrol signals during Flash programming and verification.

PORT 3

Port 3 is an 8-bit bidirectional I/O port with internal pullups.

The Port 3 output buffers can sink/source four TTL inputs.When 1s are written to Port 3 pins, they are pulled high bythe internal pullups and can be used as inputs. As inputs,Port 3 pins that are

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externally being pulled low will sourcecurrent (IIL) because of the pullups.

Port 3 also serves the functions of various special featuresof the AT89S52, as shown in the following table.

Port 3 also receives some control signals for Flash programming and verification.

Port Pin	Alternate Functions
P3.0	RXD (serial input port)
P3.1	TXD (serial output port)
P3.2	$\overline{\text{INT0}}$ (external interrupt 0)
P3.3	$\overline{\text{INT1}}$ (external interrupt 1)
P3.4	T0 (timer 0 external input)
P3.5	T1 (timer 1 external input)
P3.6	$\overline{\text{WR}}$ (external data memory write strobe)
P3.7	$\overline{\text{RD}}$ (external data memory read strobe)

Table.2 Port 3 pins and it's functions

RST

Reset input. A high on this pin for two machine cycles whilethe oscillator is running resets the device. This pin drivesHigh for 96 oscillator periods after the Watchdog times out.

ALE/PROG

Address Latch Enable (ALE) is an output pulse for latchingthe low byte of the address during accesses to externalmemory. This pin is also the program pulse input (PROG) during Flash programming.

In normal operation, ALE is emitted at a constant rate of1/6 the oscillator frequency and may be used for externaltiming or clocking purposes. Note, however, that oneALE pulse is skipped during each access to external datamemory.

If desired, ALE operation can be disabled by setting bit 0 ofSFR location 8EH. With the bit set, ALE is active only during a MOVX or MOVC instruction. Otherwise, the pin isweakly pulled high. Setting the ALE-disable bit has noeffect if the microcontroller is in external execution mode.

PSEN

Program Store Enable (PSEN)is the read strobe to external program memory.When the AT89S52 is executing code from external program memory, PSENis activated twice each machinecycle, except that two PSENactivations are skipped duringeach access to external data memory.

EA/VPP

External Access Enable. EAmust be strapped to GND inorder to enable the device to fetch code from external program memory locations starting at 0000H up to FFFFHNote, however, that if lock bit 1 is programmed, EAwill beinternally latched on reset. EAshould be strapped to VCCfor internal program executions.This pin also receives the 12-volt programming enable voltage (VPP) during Flash programming.

XTAL1

Input to the inverting oscillator amplifier and input to theinternal clock operating circuit.

XTAL2

Output from the inverting oscillator amplifier.

SPECIAL FUNCTION REGISTERS

A map of the on-chip memory area called the Special Function Register (SFR) space is shown in Table 3.

Note that not all of the addresses are occupied, and unoccupied addresses may not be implemented on the chip.Read accesses to these addresses will in general returnrandom data, and write accesses will have an indeterminate effect.
User software should not write 1s to these unlisted locations, since they may be used in future products to invokenew features. In that case, the reset or inactive values ofthe new bits will always be 0.

INTERRUPTS

The AT89S52 has a total of six interrupt vectors: two external interrupts (INT0and INT1), three timer interrupts (Timers 0, 1, and 2), and the serial port interrupt. Each of these interrupt sources can be individually enabledor disabled by setting or clearing a bit in Special FunctionRegister IE. IE also contains a global disable bit, EA, whichdisables all interrupts at once.

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0F8H									0FFH
0F0H	B 00000000								0F7H
0E8H									0EFH
0E0H	ACC 00000000								0E7H
0D8H									0DFH
0D0H	PSW 00000000								0D7H
0C8H	T2CON 00000000	T2MOD XXXXXX00	RCAP2L 00000000	RCAP2H 00000000	TL2 00000000	TH2 00000000			0CFH
0C0H									0C7H
0B8H	IP XX000000								0BFH
0B0H	P3 11111111								0B7H
0A8H	IE 0X000000								0AFH
0A0H	P2 11111111		AUXR1 XXXXXXX0				WDTRST XXXXXXXX		0A7H
98H	SCON 00000000	SBUF XXXXXXXX							9FH
90H	P1 11111111								97H

Table.3 Special function rgister space

FEATURES OF ATMEL 89S52

- 256 bytes of RAM(Random Access Memory)
- 32 I/O(Input/Output)lines
- Three 16-bit timer/counters
- A full duplex serial port
- Clock circuitry
- 40 Pin IC

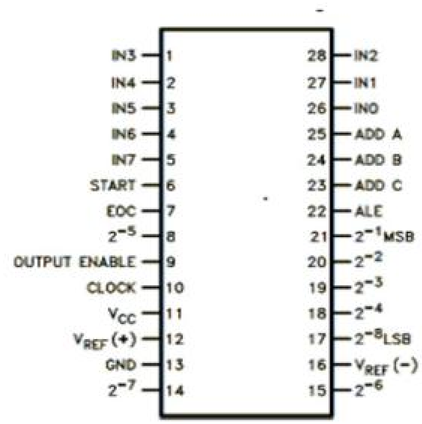
WSN

A Wireless Sensor Network(WSN) is a wireless network consisting of spatially distributed autonomous devices using sensors to monitor physical or environmental conditions. A WSN system incorporates a gateway that provides wireless connectivity back to the wired world and distributed nodes .some of the available standards include 2.4GHz radios based on either IEEE 802.15.4 or IEEE 802.11(wi-fi) standards or proprietary radios, which are usually 900MHz.

ADC (0809/0808)

The ADC converts analog voltage level to a digital number.Digital number can be effectively handled by microcontrollers.The 8-bit A/D converter uses successive approximation as the conversion technique.

ADC PIN DIAGRAM



SENSORS USED

In this paper ,there are four types of sensors are used such as temperature sensor,blood preasure sensor,heart beat sensor and ECG.Temperature sensor sense the temperature of human body.Blood preasure sensor helps to determine the preasure of the patient.Heart beat sensor used to monitor the heart beat of the human's body.Each of the above mentioned sensors are analog sensor that produces variable electrical signals.

UART

A Universal Asynchronous Receiver / Transmitter (UART) is used to implement serial communication. It is a standard piece of hardware, although manufactures makes slightly different versions that may have some functionality beyond the standard UART functionality.

CONCLUSION

In this paper, our intention was to demonstrate a new way of incorporating the requirements of both

WSN and SHM, and to make use of traditional engineering methods in the WSN. We found that it is worthwhile to place a small number of backup sensors around the repair points in the WSN to have a better performance. We believe that such an idea (of the backup sensor placement) can also be used in generic WSN applications. Besides, we proposed an SHM algorithm exploiting sensor decentralized computing in the resource constrained WSN. Through extensive simulations and a real implementation using integrated Imote2 sensors, we validated the effectiveness of our approach. The validation shows that structural health monitoring using WSNs can be meaningless, if the requirements of WSNs (e.g., fault tolerance, energy-efficiency) are not seriously considered.

This work leaves at least two open issues in the multi-domain research area. One issue is to develop algorithms for SHM application-specific sensor fault detection and recovery. Another issue is to develop a SHM-specific scheduling technique for the backup sensors that will wake up one or more backup sensors in the areas of interest (e.g., damaged area) in the case of a sensor fault/failure. This may help to meet both coverage and connectivity requirements in a WSN-based SHM system.

ACKNOWLEDGMENT

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