Deformation Monitoring Based on Wireless Sensor Networks

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1 Introduction

high-rise buildings

dams

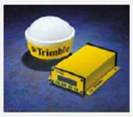
bridges

Deformation monitoring of large structures

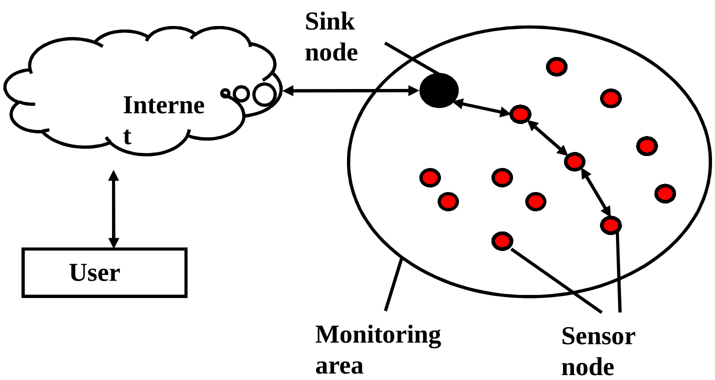
Deformation monitoring: use professional instruments and methods to measure the structures, analysis the deformation characters and make proper deformation prediction.

1 Introduction

Some current techniques

	Method type	*Precision*	*Sampling rate*	*Contact to the targets*	*Remarks*
	Inclinometer Accelerometer	High	High	Yes	Not direct results
	Fiber optic sensor	High	High	Yes need to be embedded within the structure	High sensitivity to environmental change
	Differential GPS	High	High dynamic characteristics	Yes	Influenced by multipath effect; complex process
	Total Station	High	Very low not suit to spectrum analysis	Yes need prisms	

1 Introduction



Senor node: performing some processing, gathering sensory information and communicating with other connected nodes

Sink node: head node which gathers and controls data collected by sensor nodes

***Wireless Senor Networks:** based on the development of MEMS, system on chip (SoC), wireless communications and embedded technologies*

Introduction

Advantages of wireless sensor networks for deformation monitoring:

- ***Automatic***
- ***Continuous and dynamic monitoring***
- ***Time-and-effort-saving***
- ***Low cost***

Limitations:

- ***Storage capacity***
- ***Calculation ability***
- ***Bandwidth***
- ***Energy supplement***

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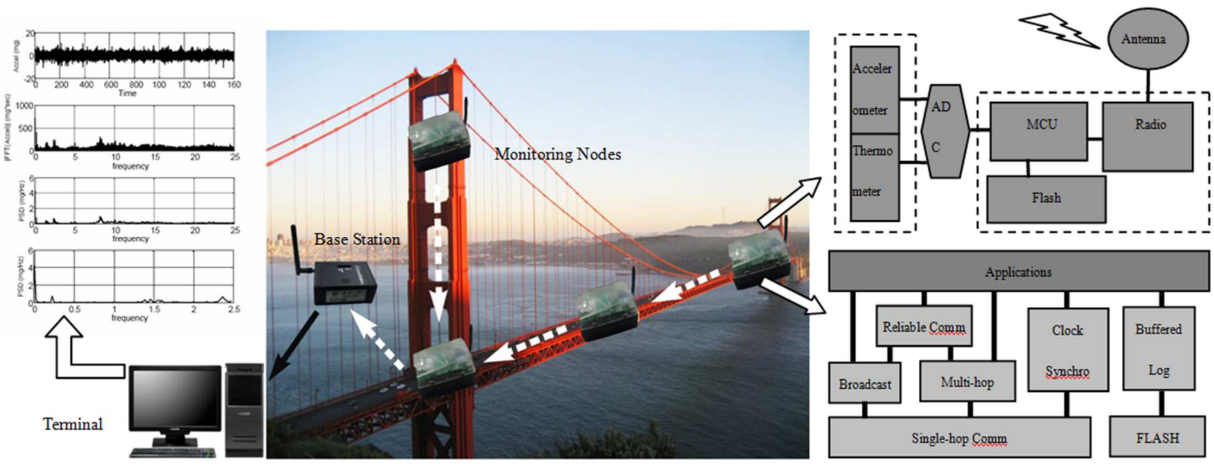
Data Acquisition

- *Hardware and software selection*
- *Data sampling*
- *Data transmission*

Data Acquisition



Deformation Monitoring Framework Based on Wireless Sensor Networks

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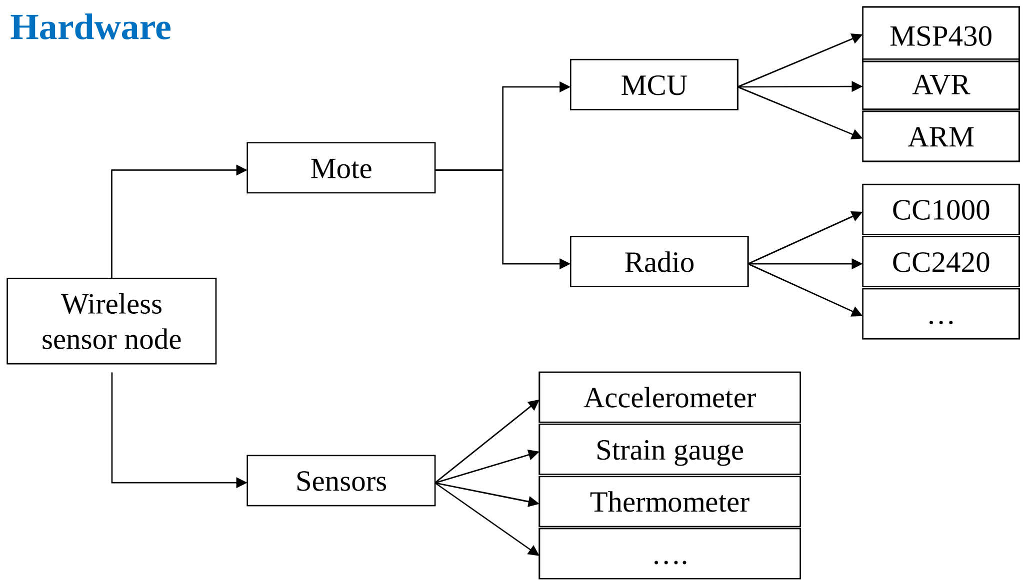
2.1 *Hardware and software selection*

Hardware



2.1 *Hardware and software selection*

Motes and Sensors in Typical Monitoring Cases

Monitoring Case	Mote	Institute	MCU	Radio	Sensors
Seismic Test Structure	Mica2	Computer Science Department, University of Southern California	Atmega128L	CC1000	Vibration card
Golden Gate Bridge	Micaz	Civil and Environmental Engineering, UC Berkeley	Atmega128L	CC2420	Dual-axis accelerometer, thermometer
Stork Bridge	Tmote-sky	Structural Engineering Laboratory, Empa Dübendorf, Switzerland	MSP430	CC2420	Dual-axis accelerometer, thermometer
Jindo Bridges	Imote2	Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign	Intel PXA271	CC2420	Triaxial accelerometer, thermometer, hygrometer etc.
Zhengdian Bridge	S-Mote	Department of Control Science and Engineering, Huazhong University of Science and Technology	MSP430F1611	CC2420	Dual-axis accelerometer, strain gauge

2.1 Hardware and software selection

Software

TinyOS:

- *Developed by UC Berkeley*
- *Open source*
- *Component-based architecture*
- *NesC language*

Contiki:

- *Developed by Swedish Institute of Computer Science*
- *Multiple task*
- *High portability*

Mantis OS:

- *Developed by University of Colorado*
- *Standard C language*

SOS:

- *Developed by University of Los Angeles*
- *Standard C language*

2.2 Data sampling

High-frequency sampling

Reason

For deformation monitoring tasks based on wireless sensor networks, continuous high-frequency sampling is needed in order to grasp the real-time deformation information of constructions.

↓

Result

Huge data volume

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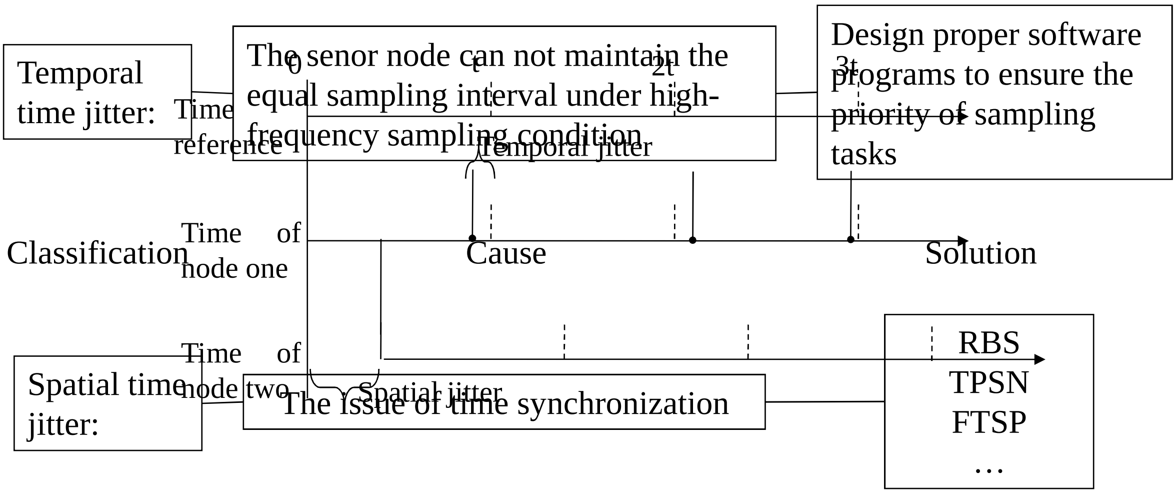
Solution

Compressive sensing, which directly samples the compressed signal, simplifies the sampling workload and leaves the complex reconstruction work to the terminal.

2.2 Data sampling

Time jitter



2.3 Data transmission

Data compression

Reason for compression:
Huge size of data and limited bandwidth

Advantages of compression:
Reduce storage space, improve the transmitting, storing and processing efficiency

Lossless compression
- Run-length coding
- Huffman coding
- Arithmetic coding

Lossy compression
- Compressive sensing
- Wavelet transform
- KL transform

2.3 Data transmission

Data loss

Cause of data loss:

Wireless transmission is more vulnerable to interference in the environment

Solution:

- Reliable transport protocol
  - Data collection — RMST,RBC,ESRT,PORT,STCP
  - Command distribution — PSFQ,GARUDA
- Recovery of lost data — Interpolation,…

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3 Vibration Data Processing

- *Data preprocessing*
  1. *Static and dynamic testing*
  2. *Temperature correction*
  3. *Data de-noising*

- *Data Analysis*
  1. *Time domain analysis*
  2. *Frequency domain analysis*
  3. *Modal domain analysis*

3.1 Data Preprocessing

Static and dynamic testing

Calibrate the acceleration sensors using a highly precise accelerometer

Temperature correction

Record real time temperature information in monitoring environment to correct the output values of the acceleration sensors

Data de-noising

Reduce or eliminate the impact of noise in data analysis.

Median filtering, Kalman filtering, Wavelet analysis and Empirical mode decomposition, etc.

3.2 Data Analysis

Time domain analysis

- Vibration signals collected by sensor nodes need to be converted into velocity and displacement signals:

$$v(t)=\int_0^t a(t)dt = v'(t)+v_0 \qquad s(t)=\int_0^t v(t)dt = s'(t)+s_0$$

- Calculate the correlation function, including autocorrelation function and cross-correlation function:

Autocorrelation $$R_{xx}(k)=\frac{1}{N}\sum_{i=1}^{N-k}x(i)x(i+k)(k=0,1,\ldots,m)$$

Cross-correlation $$R_{xy}(k)=\frac{1}{N-k}\sum_{i=1}^{N-k}x(i)y(i+k)(k=0,1,\ldots,m)$$

3.2 Data Analysis

Frequency domain analysis

Calculate the power spectral density function of the random vibration signal based on Fourier transform. It can be divided into self-power spectral density function and cross-power spectral density function.

$$S_{xx}(k)=\frac{1}{N}\sum_{r=0}^{N-1}R_{xx}(r)e^{-j2\pi kr/N}$$

$$S_{xy}(k)=\frac{1}{N}\sum_{r=0}^{N-1}R_{xy}(r)e^{-j2\pi kr/N}$$

The methods to calculate power spectral density function can be divided into non-parametric approach and parametric one.

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3.2 Data Analysis

Modal domain analysis

Analysis in modal domain is to identify the modal parameters. Modal parameters identifications can be divided into methods in time and frequency domains according to data processing mode.

- Time domain methods: Time series, Random decrement, NExT, Stochastic subspace and Modal function decomposition.

- Frequency domain methods: Peak picking method and Frequency domain decomposition method

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4 Summary

Wireless sensor networks brings new ideas for structures' deformation monitoring with the characteristics of low power consumption, low cost, being distributed and self-organized.

- ***Hardware and software*** mote, sensor, TinyOS…
- ***Data sampling*** high frequency sampling, time jitter
- ***Data transmission***. data compression, data loss
- ***Data preprocessing*** testing, correction, data de-noising
- ***Data processing*** time domain, frequency domain, modal domain

Thanks for your time

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