Deformation Monitoring Based on Wireless Sensor Networks

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Introduction
Data Acquisition
Vibration Data Processing
Summary
Introduction

Data Acquisition

Vibration Data Processing

Summary

Introduction

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

**Some current techniques**

<table>
<thead>
<tr>
<th>Method Type</th>
<th>Precision</th>
<th>Sampling Rate</th>
<th>Contact to the Targets</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclinometer Accelerometer</td>
<td>High</td>
<td>High</td>
<td>Yes</td>
<td>Not direct results</td>
</tr>
<tr>
<td>Fiber optic sensor</td>
<td>High</td>
<td>High</td>
<td>Yes</td>
<td>High sensitivity to environmental change</td>
</tr>
<tr>
<td>Differential GPS</td>
<td>High</td>
<td>High dynamic characteristics</td>
<td>Yes</td>
<td>Influenced by multipath effect; complex process</td>
</tr>
<tr>
<td>Total Station</td>
<td>High</td>
<td>Very low</td>
<td>Yes</td>
<td>Need to use spectrum analyser</td>
</tr>
</tbody>
</table>

**Sensor 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 Sensor 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
2 Data Acquisition

- Hardware and software selection
- Data sampling
- Data transmission

Deformation Monitoring Framework Based on Wireless Sensor Networks
2.1 Hardware and software selection

**Hardware**

![Diagram of Wireless sensor node](image)

- **Mote**
  - **MCU**
    - MSP430
    - AVR
    - ARM
  - **Radio**
    - CC1000
    - CC2420
    - ...
  - **Sensors**
    - Accelerometer
    - Strain gauge
    - Thermometer
    - ...

**Motes and Sensors in Typical Monitoring Cases**

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

Software

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

Mantis OS:
- Developed by University of Colorado
- Standard C language

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

SOS:
- Developed by University of Los Angeles
- Standard C language

2.2 Data sampling

High-frequency sampling

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.

<table>
<thead>
<tr>
<th>Reason</th>
<th>Result</th>
<th>Solution</th>
</tr>
</thead>
</table>
|        | Huge data volume| 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*

- **Temporal time jitter:** The sensor node cannot maintain the equal sampling interval under high-frequency sampling conditions.
- **Spatial time jitter:** The issue of time synchronization.
- **Temporal jitter:** Time reference.
- **Cause:** Temporal jitter.
- **Solution:** Design proper software programs to ensure the priority of sampling tasks.

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

Command distribution

Recovery of lost data

Interpolation,…

Data collection

Data Acquisition

Vibration Data Processing

Summary
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:

\[ v(t) = \int_0^t a(t)dt = v'(t) + v_0 \quad s(t) = \int_0^t v(t)dt = s'(t) + s_0 \]

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

**Autocorrelation**

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

**Cross-correlation**

\[ R_{xy}(k) = \frac{1}{N-k} \sum_{i=1}^{N-k} x(i)y(i+k) \quad (k = 0, 1, \ldots, m) \]

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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.
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.
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