Real Time Visualization of Structural Response through Wireless Communication using MEMS Sensors

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Background ~ Structural Monitoring

- Cable-based data acquisition systems present some difficulties for structural health monitoring
- Cabling and electromagnetic interference
- Early damage detection (even invisible)
- Effective, economical and long-term structural inspection and maintenance
Rapid advances of **MEMS** technologies such as mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro fabrication technology.

**Advantages of MEMSAccelerometer**

- Small
- Low-cost
- Low Power Consumption

**MEMSnet**
http://www.memsnet.org/

**Analog Devices**
http://www.analog.com/
Objective

Development of a reliable and robust devices with MEMS accelerometer and wireless transmitter for the structure monitoring in a field environments
Preliminary Study

✓ Experimental Setup

✓ ADXL202E Unit
✓ Shaker Test

✓ Silicon Designs (SD) 2210-002 Unit
✓ SD Unit Technical Flow
✓ Shaker Test
✓ Impact Experiment

http://www.silicondesigns.com/
Experimental Set Up
**ADXL202E**

- Most Popular MEMS Accelerometer
- Low Cost & Low Power Consumption
- 2 Axis; ±2g

**ADXL202E MEMS Accelerometer**

- Battery Room: 4"
- Main Board of Sensor: 2-1/2"
- Micro Controller
- RS232 Port

**Transmitter & Receiver Unit**
Shaker Test of ADXL202E Sensor Unit

- Noise level is too high for bridge health monitoring
- RMS = 3.0mg

Shaker test at 2Hz 10mg

Linearity Curve
Silicon Designs SD-2210-002

- Low Cost & Low Power Consumption
- 1Axis; ±2g
- Bigger Mass than ADXL 202E
- Wide Range of Output Voltage; ±4V against ±2g

http://www.silicondesigns.com/
Silicon Designs Sensor & Receiver Unit

Sensor Unit

Receiver Unit

2 ½“

4 ½“

Antenna

9V

Micro Controller

FM Receiver

Serial Port

Receiver

Sensor Unit

Receiver Unit

9V Battery

Micro Controller

Serial Port
Sensor Unit & Receiver Unit Data Flow

**Sensor**

- 9V Battery
- Micro Controller
- FM Transmitter
- 5V Regulator
- SD Sensor

**Receiver**

- 9V Battery
- FM Receiver
- Micro Controller
- 5V Regulator

**Flowchart Details**

- **SD 2 Voltage AON,AOP**
- **Calculation the difference between AON and AOP**
- **Decide the Pulse Width**
- **PWM Output**
- **FM Transmitter**
- **Antenna**

**Antenna**

- **FM Receiver**
- **Input Capture Interrupt**
- **Count the Pulse Width**
- **Serial Output**
- **RS232C**

**Serial Port**

- **Tx**
- **Rx**

**Laptop Computer**
Real-time Data Acquisition System

**Hardware**
- 1 Axis; ±2g
- Transmit Range up to 400 ft
- Powered by 9V Battery
- Connected by RS232C Cable

**Software**
- Read the Serial Port
- Real-time Visualization
- 200Hz Sampling
- Data Logger system

Real-time Visualization Software
Noise Level of SD Sensor Unit

- Reduce 50% noise comparing with ADXL202E Unit
- RMS = 1.5mg

Shaker test at 2Hz 10mg  Linearity Curve
Steel Truss Bridge at UCI
**Experimental Setup**

**3 type Accelerometers**
- **✓** Seismic Piezoelectric Accelerometer PCB 393C
- **✓** Silicon Design Wireless Sensor Unit
- **✓** ADXL202E Sensor Unit and Transmitter Powered by UPS

- **✓** Data Acquisition at 10 m Away from Sensors
- **✓** Impact Test at the Center of Bridge

Data Acquisition at 10 m Away from Sensors
**Experimental Results Time Domain**

**Seismic Piezoelectric Accelerometer PCB 393C**

<table>
<thead>
<tr>
<th>Measurement Range</th>
<th>2.5g pk</th>
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</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>0.1mg</td>
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<tr>
<td>Sampling Rate</td>
<td>60Hz</td>
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**Silicon Design**

<table>
<thead>
<tr>
<th>Measurement Range</th>
<th>+2g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>1.5mg</td>
</tr>
<tr>
<td>Sampling Rate</td>
<td>200Hz</td>
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**ADXL 202E**

<table>
<thead>
<tr>
<th>Measurement Range</th>
<th>+2g</th>
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<tbody>
<tr>
<td>Resolution</td>
<td>3mg</td>
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<tr>
<td>Sampling Rate</td>
<td>50Hz</td>
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Experimental Results Frequency Domain

**Seismic Piezoelectric Accelerometer PCB 393C**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
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<tbody>
<tr>
<td>1</td>
<td>4.12</td>
</tr>
<tr>
<td>2</td>
<td>6.00</td>
</tr>
<tr>
<td>3</td>
<td>13.63</td>
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</table>

**Silicon Design**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
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<tbody>
<tr>
<td>1</td>
<td>4.08</td>
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<tr>
<td>2</td>
<td>6.12</td>
</tr>
<tr>
<td>3</td>
<td>13.17</td>
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</table>

**ADXL 202E**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>4.20</td>
</tr>
<tr>
<td>2</td>
<td>5.96</td>
</tr>
<tr>
<td>3</td>
<td>13.57</td>
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</tbody>
</table>
Bridge Response Under Jumping Load Simulation with SAP 2000

Construction Design on Paper

SAP 2000 3D Model (to scale of actual bridge)
Modal Analysis

<table>
<thead>
<tr>
<th>Mode</th>
<th>Natural Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1</td>
<td>5.04 Hz</td>
</tr>
<tr>
<td>Mode 2</td>
<td>6.19 Hz</td>
</tr>
<tr>
<td>Mode 3</td>
<td>10.80 Hz</td>
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<tr>
<td>Mode 4</td>
<td>11.01 Hz</td>
</tr>
<tr>
<td>Mode 5</td>
<td>13.13 Hz</td>
</tr>
</tbody>
</table>

- Mode 1: Vertical Mode
- Mode 2: Lateral Mode
- Mode 3: Vertical Mode
- Mode 4: Local Mode
- Mode 5: Torsional Mode
**Time History Analysis**

- **Loading**

  Impact load simulated by rectangular function

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**Time** vs **Acceleration (mg)**

- Time (s) range: 0 to 8
- Acceleration range: -80 to 80

**Load (kg)** vs **Time (s)**

- Load range: 0 to 120
- Time range: 0 to 4500

**Power Spectral**

- Damping Ratio = 0.01
- Damping Ratio = 0.02
**Summary**

- ADXL202E is popular, low cost, and low power consumption. It is good for detection of larger acceleration such as severe earthquakes.

- Silicon Design SD-2210-002 shows better performance than ADXL202E in noise level. SD-2210 can measure much smaller acceleration. It provides a good sensor option for bridge health monitoring.

- SD-2210 is integrated with wireless transceiver module in a sensor system. **Real-time visualization on laptop computer** is demonstrated for the first time in the field test.

- In the field test, cable based traditional accelerometer is also used. Comparison show the reliability of wireless device and data acquisition system for bridge health monitoring.

- Results of structural analysis by SAP 2000 show the validity of the experimental results.
**Future Plan**

**Near Future Plan**

Apply developed sensor units to Caltrans’ highway bridges for ambient vibration experiment

Power consumption is a problem to be solved. By using a 9V battery in a sensor unit, the battery power can run out in 5 hours.

**Long-term Future Plan**

Apply Bluetooth module for Multiple wireless communication

Solar Power for the power consumption problem
Caltrans’ freeway bridges

West St. On-Ramp
Jamboree Rd. Overcrossing
UCI

Jamboree Rd. Overcrossing

West St. On-Ramp
References


2. High Performance Wireless Research and Education Network (HPWREN), http://hpwren.uscd.edu


Acknowledgment

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