WiBeaM: Design and Implementation of Wireless Bearing Monitoring System

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2. Background
   - Types of Bearing Defects
   - Existing Methods
   - Necessity of Automated System
   - Proposed Solution
   - Theory of Bearing Measurement

3. Related Work

4. Design Overview
   - Operation Cycle of Motors
   - Hardware Selection
   - Software Selection

5. Implementation
   - Implementation Details
   - Software Implementation

6. Performance
   - Single Vs Multihop
   - Data Transfer
   - Vibration Measurements

7. Future Work
Wireless Sensor Networks

A collection of sensor nodes that are deployed to perform a specific action.

Characterestics/Challenges of WSN

- Small Processing power.
- Limited Memory.
- Radio to transmit /Receive data.
- Ability to run on batteries.
Wireless Sensor Networks

A collection of sensor nodes that are deployed to perform a specific action.

Characteristics/Challenges of WSN

- Small Processing power.
- Limited Memory.
- Radio to transmit /Receive data.
- Ability to run on batteries.
Condition Based Maintenance

To Monitor and assess the health of an equipment

Common Parameters Measured

- temperature
- vibration
- various other machine specific parameters
WiBeaM

Bearing Monitoring
WiBeaM

Thesis Definition

Develop a cheap and reliable sensor network application to monitor the bearing vibration of induction motors in a ship

Thesis Goals

- Find a suitable vibration sensor
- Form a network of sensor nodes
- Ensure reliable transfer of data
- Storage of measured readings on the node
- Conserve the battery power
- Process the measured signal and capture relevant vibration data
Background

Types of Bearing Defects

Defects in Ball Bearings
- Outer race defect
- Inner race defect
- Ball defect
Existing Methods

Manual Methods

Automatic/semi-automatic Methods

- Shock Pulse Measurement
- Vibration measurement
- Stator Transient current analysis
Necessity of Automated System

Drawbacks of Manual Methods

- Large number of machinery
- Hidden costs
  - More man hours expended
  - No lead time
  - Book keeping
  - Costly Hand held scopes
Proposed Solution

- Develop a network of Wireless Sensor Nodes
- Should measure the vibrations automatically
Theory of Bearing Measurement

Outer, inner and ball race defects

\[ F_{ord} = \left\{ \frac{N \cdot RPM}{2} \right\} \times \left\{ 1 - \left( \frac{d_{ball}}{D_{pitch}} \right) \times \cos\alpha \right\} \]

\[ F_{ird} = \left\{ \frac{N \cdot RPM}{2} \right\} \times \left\{ 1 + \left( \frac{d_{ball}}{D_{pitch}} \right) \times \cos\alpha \right\} \]

\[ F_{ball} = \left\{ \frac{RPM}{2} \right\} \times \left\{ \left( \frac{D_{pitch}}{d_{ball}} \right) - \left( \frac{d_{ball}}{D_{pitch}} \right) \times (\cos\alpha)^2 \right\} \]
## Related Work

### Structural Monitoring
- Monitor Structures

### Habitat Monitoring
- Great Duck Island

### CodeBlue
- Application for hospital care

### North-sea Deployment
- Similar to what we have done

### BriMon
- Bridge Monitoring System for railway bridges
## Comparison Table

<table>
<thead>
<tr>
<th></th>
<th>Habitat Monitoring</th>
<th>WISDEN</th>
<th>North Sea Deployment</th>
<th>BriMon</th>
<th>CODEBLUE</th>
<th>WiBeam</th>
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</thead>
<tbody>
<tr>
<td><strong>Deployment</strong></td>
<td>Long Term</td>
<td>Short Term</td>
<td>Long Term</td>
<td>Long Term</td>
<td>Long Term</td>
<td>Long Term</td>
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<tr>
<td><strong>Hardware</strong></td>
<td>Mica2</td>
<td>Mica2 MicaZ</td>
<td>MicaZ</td>
<td>Tmotes Telos</td>
<td>Mica2 MicaZ</td>
<td>Tmotes</td>
</tr>
<tr>
<td><strong>System Replaced</strong></td>
<td>manual</td>
<td>wired</td>
<td>Expensive wireless</td>
<td>manual</td>
<td>Medical Electronics</td>
<td>manual</td>
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<tr>
<td><strong>Architecture</strong></td>
<td>Tiered</td>
<td>Flat</td>
<td>Tiered</td>
<td>Tiered</td>
<td>Tiered</td>
<td>Tiered</td>
</tr>
<tr>
<td><strong>Sensor</strong></td>
<td>Temperature Pressure</td>
<td>Accelerometer</td>
<td>Accelerometer</td>
<td>Accelerometer MemS</td>
<td>Pulse oximeter EKG</td>
<td>Accelerometer MemS</td>
</tr>
<tr>
<td><strong>Compression</strong></td>
<td>YES</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
<td>NO</td>
</tr>
</tbody>
</table>
Design Overview

Operation Cycle of Motors

- Important - Fire fighting system, AC Plant, Ref plant etc.
- Less Important - Cooling motors, Fuel supply motors for Engines
- Unimportant - Ventilation, Sewage Motors
Duty Cycle

- Motors are run in a cycle of 6 hours on/off in a day
- Nodes may wakeup once in every four hours and check for activity
- One measurement in a day is sufficient
- Latency upto one day is acceptable
### Design Overview

#### Hardware Selection

**Comparison between various Accelerometers**

<table>
<thead>
<tr>
<th>Accelerometer</th>
<th>Power</th>
<th>Range</th>
<th>Freq Band</th>
<th>Sensitivity</th>
<th>Noise</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADXL105 MEMS</td>
<td>2 – 5V</td>
<td>±5g</td>
<td>0 – 12Khz</td>
<td>225 – 275mv/g</td>
<td>225mg</td>
<td>14USD</td>
</tr>
<tr>
<td>CXL04 XBow</td>
<td>±5V</td>
<td>±4g</td>
<td>0 – 100Hz</td>
<td>500mv/g</td>
<td>10mg</td>
<td>185USD</td>
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<tr>
<td>SKF CMSS786A</td>
<td>18 – 30V</td>
<td>±80g</td>
<td>0.5 – 14Khz</td>
<td>95 – 105mv/g</td>
<td>20mg</td>
<td>120USD</td>
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<tr>
<td>CMCP-1100</td>
<td>8 – 12V</td>
<td>±50g</td>
<td>0.3 – 10Khz</td>
<td>100mv/g</td>
<td>4 – 8ug</td>
<td>130USD</td>
</tr>
<tr>
<td>Wilcoxon 786A</td>
<td>18 – 30V</td>
<td>80g</td>
<td>30Khz</td>
<td>100mv/g</td>
<td>not specified</td>
<td>185USD</td>
</tr>
</tbody>
</table>

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**WiBeaM: Wireless Bearing Monitoring System**

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## Hardware Selection

**Comparison between various Sensor Nodes**

<table>
<thead>
<tr>
<th>Model</th>
<th>Radio</th>
<th>Data Rates</th>
<th>RAM</th>
<th>Processor</th>
<th>I/O Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tmote Sky</td>
<td>2.4Ghz</td>
<td>250kbps</td>
<td>10KB</td>
<td>msp430</td>
<td>10 Pin</td>
</tr>
<tr>
<td>Intel</td>
<td>Bluetooth</td>
<td>750kbps</td>
<td>64KB</td>
<td>ARM7TDMI</td>
<td>USB-slave mode</td>
</tr>
<tr>
<td>Mica2</td>
<td>916MHZ</td>
<td>38.4kbps</td>
<td>4KB</td>
<td>Atmega128</td>
<td>51-pin</td>
</tr>
<tr>
<td>Micaz</td>
<td>2.4Ghz</td>
<td>250kbps</td>
<td>4KB</td>
<td>Atmega128</td>
<td>51-pin</td>
</tr>
</tbody>
</table>
Design Overview

Operating System

TinyOS
- Component based operating system
- Developed by U/C at Berkeley
- Has lot of sample applications and code
- Freely downloadable
Design Overview

Software design

Figure: Layered design
Design Overview

Overall System design

![Diagram of WiBeaM: Wireless Bearing Monitoring System]
Hardware Implementation

![Image of hardware implementation]

**Figure:** Circuit diagram of the ADXL105 sensor.
Implementation Details
Implementation Details

Data Measurement

Software Implementation

WiBeaM: Wireless Bearing Monitoring System

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23/36
Reliable Data Transfer

Software Implementation

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Flash Storage

Software Implementation

WiBeaM: Wireless Bearing Monitoring System
Power Consumption

Software Implementation
Performance Analysis

Singlehop Vs Multihop

PG Lab Layout – Topview
(CSE Dept IIT Kanpur)

Base Station

Node 1

Node 2

Node 3

Node 4

Node 5

Printer Room

12 Mtrs

12 Mtrs
### CC2420 Transmit Power Vs Power Consumption

<table>
<thead>
<tr>
<th>TinyOS Power Value</th>
<th>Transmit Power (dBm)</th>
<th>Current Consumption (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>0</td>
<td>17.4</td>
</tr>
<tr>
<td>27</td>
<td>-1</td>
<td>16.5</td>
</tr>
<tr>
<td>23</td>
<td>-3</td>
<td>15.2</td>
</tr>
<tr>
<td>19</td>
<td>-5</td>
<td>13.9</td>
</tr>
<tr>
<td>15</td>
<td>-7</td>
<td>12.5</td>
</tr>
<tr>
<td>11</td>
<td>-10</td>
<td>11.2</td>
</tr>
<tr>
<td>7</td>
<td>-15</td>
<td>9.9</td>
</tr>
<tr>
<td>3</td>
<td>-25</td>
<td>8.5</td>
</tr>
</tbody>
</table>

**Table:** Source - CC2420 Datasheet
### Powers After running Power Negotiation Algorithm

<table>
<thead>
<tr>
<th>Node ID</th>
<th>Transmit Power(dBm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-25</td>
</tr>
<tr>
<td>2</td>
<td>-9</td>
</tr>
<tr>
<td>3</td>
<td>-12</td>
</tr>
<tr>
<td>4</td>
<td>-18</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>
## Data Transfer with 4 nodes

<table>
<thead>
<tr>
<th>Delay (msec)</th>
<th>Throughput (kbps)</th>
<th>%Packet Loss (per file)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>17.5</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>23</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>8</td>
</tr>
<tr>
<td>1</td>
<td>35</td>
<td>9</td>
</tr>
</tbody>
</table>

**Table:** Throughput and Packet loss at various delay intervals
Testbed for Trials
Vibration Measurements

Measurement Settings

- Sampling Frequency = 20KHz
- No of data points measured = 4096
- \[ \delta F = \frac{1}{(\delta T \times N)} \]
- \( \delta F \) is the desired frequency resolution
- \( \delta T \) is the time between two samples (depends on the sampling rate)
- \[ \delta F = \frac{1}{(50 \times 10^{-6} \times 4096)} = 4.88 \text{Hz} \]
- No of Frequencies checked = 7
- No of measurements obtained at each frequency = 5
Vibration Measurements

Figure: Vibration readings measured with ADXL105

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Future Work

- Data Compression
- Packaging
- Industry Trials
- Site Survey
- Security
- Low power operation (switch off Microcontroller)
- User Interface
Conclusion

- Wireless solutions are ideal to ships environment
- Extendable to other equipment like Engines and Generators etc
Questions?

Please ask, it may improve the standard of my work