Extended Wireless Monitoring through Intelligent Hybrid Energy Supply

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Outline

• Introduction – Wireless Structural Health Monitoring

• System Architecture

• Implementation – Hybrid Smart Power Unit

• System Characterization, Test and Simulation

• Conclusion
SHM is performed to manage risk. It is typically done using wired systems collecting environmental data over long periods of time. Wireless SHM systems require novel energy solutions to allow long lifetime and autonomous operation in the field. Industrial sensors and wireless communication require significant amounts of energy. This work focuses on meeting the energy demands of such systems.

### TABLE I  SENSORS SELECTED

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Electrical Interface</th>
<th>Supply Voltage</th>
<th>Average Power during Sampling (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>A(2-wire)</td>
<td>&lt;15V</td>
<td>0.2V</td>
</tr>
<tr>
<td>Displacement</td>
<td>A(3-wire)</td>
<td>&lt;60V</td>
<td>5V</td>
</tr>
<tr>
<td>Inclination</td>
<td>D(RS485)</td>
<td>5V</td>
<td>5V</td>
</tr>
<tr>
<td>Pressure</td>
<td>A(2-wire)</td>
<td>8-28V</td>
<td>12V</td>
</tr>
<tr>
<td>Moisture</td>
<td>A(4-wire) D(RS485)</td>
<td>5V</td>
<td>5V (D)</td>
</tr>
</tbody>
</table>

A: Structural Health Monitoring as early warning system can alert to improve structure stability and thus prevents structure damage or collapse.
B: Structural Health Monitoring can alert to evacuate building on time before collapse.
System Architecture

WIRELESS SENSOR NODE

DIGITAL INTERFACE

POWER SUPPLY

BOOST CONVERTER

MCU

POWER MANAGEMENT STAGE

OUTPUT DC-DC CONVERTER

RECHARGER

BATTERIES SUPERCAPs

SMART POWER UNIT

SENSOR LAYER

MAIN LAYER

POWER LAYER

GENESI Nodes

GENESI Gateway

GENESI Cloud

TCP/IP

e.g. WebDavis

Structure | Internet | Visualization

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Implementation – Hybrid Smart Power Unit

Solar Harvester Subsystem Architecture

BOOST CONVERTER OPERATED IN CONTINUOUS MODE TO STEP UP MAIN CELL VOLTAGE AND EXPLOIT MPPT

ORing diode

STORAGE CAPACITOR (SUPERCAP)

PWM SIGNAL FROM MCU

PILOT CELL TO SENSE OPEN CIRCUIT VOLTAGE
Implementation – Hybrid Smart Power Unit

Wind Harvester Subsystem Architecture
Implementation – Hybrid Smart Power Unit

Fuel Cell Subsystem

DIRECT CONNECTION FC - RECHARGE CIRCUIT (BEST SOLUTION TESTED)

ORing DIODE

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Implementation – Hybrid Smart Power Unit

Recharging subsystem
System Characterization, Test and Simulation

Bench testing

### TABLE II  ENERGY SOURCES

<table>
<thead>
<tr>
<th>Sources</th>
<th>Max Power</th>
<th>Efficiency</th>
<th>State of the art</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar</td>
<td>450mW</td>
<td>86%</td>
<td>90%</td>
</tr>
<tr>
<td>Wind</td>
<td>10mW</td>
<td>83%</td>
<td>84%</td>
</tr>
<tr>
<td>FC (Li-Ion Battery)</td>
<td>500mW</td>
<td>86%</td>
<td>80-90%</td>
</tr>
</tbody>
</table>

### TABLE III  MEASURED POWER CONSUMPTION: TELOSB VERSUS GENESI MAIN LAYER

<table>
<thead>
<tr>
<th>Operational Mode</th>
<th>TelosB</th>
<th>GENESI Main Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM (TRX Off)</td>
<td>2.15 mW</td>
<td>7.56 mW</td>
</tr>
<tr>
<td>LPM3</td>
<td>17.82 µW</td>
<td>12.9 µW</td>
</tr>
<tr>
<td>AM + TX (0dBm)</td>
<td>60.06 mW</td>
<td>62.37 mW</td>
</tr>
<tr>
<td>AM + TX (-25dBm)</td>
<td>31.68 mW</td>
<td>31.68 mW</td>
</tr>
<tr>
<td>AM + RX</td>
<td>66.66 mW</td>
<td>72.6 mW</td>
</tr>
</tbody>
</table>
System Characterization, Test and Simulation

Solar Panel Characterization

Wind Turbine Characterization
System Characterization, Test and Simulation

Energy Model

\[ E_{bat}(t) = E_{bat}(t-1) + E_{sol}(t) + E_{wind}(t) + E_{FC}(t) - E_{Node}(t) \]

\[ D = \frac{t_{on}}{T} \]

\[ T = t_{on} + t_{off} \]

\[ t_{on} \geq t_{wakeup} + t_{acquire} + t_{communicate} \]

Power Traces

**TABLE IV GENESI NODE POWER CONSUMPTION**

<table>
<thead>
<tr>
<th>Devices</th>
<th>Consumption (mW) (3.3V)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Active (mW) Measured</td>
</tr>
<tr>
<td>Main Layer (AM)</td>
<td>7.56</td>
</tr>
<tr>
<td>Sensor</td>
<td>8.7</td>
</tr>
<tr>
<td>Radio Tx</td>
<td>62.37</td>
</tr>
<tr>
<td>Radio Rx</td>
<td>72.6</td>
</tr>
<tr>
<td>MCU SPU (1Mhz)</td>
<td>1.29</td>
</tr>
</tbody>
</table>
System Characterization, Test and Simulation

### Simulation

#### TABLE V  MODALITIES SIMULATED

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Duty Cycles</th>
<th>Sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Node</td>
<td>Radio (Tx=Rx)</td>
</tr>
<tr>
<td>Critical</td>
<td>0.75%</td>
<td>0.75%</td>
</tr>
<tr>
<td>Alarm</td>
<td>1.5%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Normal mode</td>
<td>0.05%</td>
<td>0.05%</td>
</tr>
</tbody>
</table>

#### Results

![Graph showing fuel cell activation and deactivation over time](image)

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Conclusion

The design, implementation and characterisation of a prototype hardware platform that achieves energy autonomy for low duty cycle wireless structural health monitoring applications have been presented. The development of an advanced Smart Power Unit, with hybrid energy harvesting capability and electrochemical fuel cell integration; coupled with intelligence and interoperability, represents a significant improvement over the current state-of-the-art. The platform was designed for ultra-low power operation, with less than 1mW in sleep mode to achieve continuous operation using only one 800mAh battery, one fuel cell, solar and wind harvesters. Interfaced with the appropriate wireless sensor network hardware infrastructure, the platform is provably suitable for long-term wireless structural health monitoring.

Experimental results demonstrate that, even with an extra MCU to provide additional novel features, overall efficiency is still comparable with state-of-the-art of harvesting solutions, giving very high energy conversion efficiency up to 86%, and a low quiescent current of only 5μA. Simulation has shown that the platform can comfortably operate energy-autonomously for duty cycles up to 0.75% using the harvesters alone, and with the invocation of the fuel cell can achieve extended lifetime for a duty cycle of 1.5% (which equates to 6 samples collected and transmitted per hour).
References

References

References


• Horizon Fuel Cell Technologies Pte Ltd (2010) Introducing the MiniPAK “Personal Power Center”.


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