Wireless sensor networks: monitoring approaches and network architectures

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A continuous [structural health monitoring](SHM) with wireless sensor networks (WSN) allows to determine the condition of constructions and delivers a statement for its durability. In comparison with wire-based networks, a wireless solution is easier and faster to apply, so that the network can be adapted to the construction. It is also more cost-efficient. The health monitoring is separated by the type of data logging into event-based and time-discrete.

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Monitoring approaches

Monitoring based on MEMS

The use of [Microelectromechanical systems](MEMS) reduces the costs of health monitoring. MEMS are composed of electrical and mechanical components. The captured measurements have to be continuously transmitted via Internet or SMS-protocols. The captured information is transmitted over short distances of decimeters between particular nodes and the base station with the assistance of multi-hop networks. The base station is collecting measurement data, saves it in databanks and executes data analysis, until the data is required by the user. If errors are detected by the data analysis, an alarm notification is triggered. The central unit allows wireless administration, calibration and reprogramming of the sensors to maintain the effectiveness of the system. The data logging and signal processing unit contains a low-voltage microcontroller with integrated A/D-converter and sufficient data memory.

![Technological approach for intelligent health monitoring](image)

Time-discrete monitoring

Due to the simple implementation, time-discrete monitoring is the most common approach. The basis of this approach is the time interval between two measurements. A time signal triggers the measurement process and serves as event. The difference between time-discrete and event-based monitoring is that the time is a global value in time-discrete monitoring. The selected time intervals should vary in dependence of the measured parameters. The disadvantage of time-discrete monitoring is that the sensors are not able to capture measurements between the measuring points. Consequently impacts on the construction that occur between these measurement points cannot be detected.
**Time intervals for time-discrete monitoring** [3]

<table>
<thead>
<tr>
<th>Measurand</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Hour</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Hour</td>
</tr>
<tr>
<td>Temperature caused strain, tension or displacement</td>
<td>Hour/day</td>
</tr>
<tr>
<td>Corrosion</td>
<td>Month</td>
</tr>
<tr>
<td>Chemical attack</td>
<td>Month</td>
</tr>
<tr>
<td>pH</td>
<td>Month</td>
</tr>
</tbody>
</table>

**Event-based monitoring**

Event-based monitoring is used, when the particular measured values only occur under certain temporary impacts such as wind, snow, earth quakes and certain traffic loads. The impacts serve as causing event and trigger the measurement process, considering that the time is delivered as one of the measurement values.

The advantage of this approach is the range of potential reactions on the events. The event can trigger a combination of different reactions and thus enable particular motes, a signal analysis or an alarm notification. [3] The difficulty is to determine and interpret all critical events causing high energy consumption. Therefore, the selection is restricted to low energy consuming sensors. Some MEMS-based solutions are available and are used for monitoring rail bridges and recognizing fraction processes. To reduce the amount of measurement data in the wireless sensor network, the data analysis is partially executed in the motes itself to determine changes in the construction. A reduction of data can be realized through simple functions like maximum and minimum values or more complex analysis, such as determining the characteristic frequency. A complex data analysis of the measurements requires the implementation of more elaborate algorithms in the memory of the mote. [2]

**Analysed areas caused by occured events** [3]

<table>
<thead>
<tr>
<th>Analysed parameters</th>
<th>Event</th>
<th>Measurand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature change</td>
<td>Clima</td>
<td>Temperature</td>
</tr>
<tr>
<td>Change in relative humidity</td>
<td>Clima</td>
<td>Humidity</td>
</tr>
<tr>
<td>Cracks in pre-stressed steel, cracks in concrete, steel</td>
<td>Corrosion, Temperature, static/dynamic mechanical load</td>
<td>acoustic events, tension, strain, displacement</td>
</tr>
<tr>
<td>fatigue</td>
<td>maxinum/medium/minimum tension, strain, displacement</td>
<td></td>
</tr>
<tr>
<td>Structural behaviour caused by static impact</td>
<td>Earthquake, wind</td>
<td>Acceleration, modular form</td>
</tr>
<tr>
<td>Structural behaviour caused by dynamic impact</td>
<td>Extraordinary load</td>
<td>Tension, strain, displacement</td>
</tr>
<tr>
<td>Structural failure</td>
<td>All</td>
<td>All</td>
</tr>
</tbody>
</table>

**Process scheme for health monitoring** [2]
Existing monitoring concepts

**Smartmote**

The captured measurement data of the structural monitoring will be processed in the sensor nodes and send to the base station. The SmartmoteWS contains a MSP430 F1611 microcontroller with 10 kB RAM and 48 kB program memory. A RISC-Processor with energy save mode and low energy consumption in standby mode allows a long working period. A wireless transceiver uses the ZigBee-standard. The maximum bandwidth is 250 kbps. Because of the modular concept, the energy demand can be covered by supercapacitors or solar modules.

A variety of sensors can be used for structural monitoring - strain gauges, MEMS, accelerometers, temperature and humidity sensors. Between the sensor node and the base station SmartgateWS, distances of several hundred meters are possible. SmartgateWS is a Linux-based industrial computer with GPRS/UMTS-modem. The captured data is transmitted via Internet and saved in a SQL-databank. [4]

**Smartbrick®**

Smartbrick® is a monitoring system for applications with a small amount of sensors. The system differs from a common WSN: it contains self-referring sensors, communicating via mobile phone network GSM/GPRS. In addition to the typical characteristics, Smartbrick® uses a trigger system sensitive to the frequency domain of structural building vibrations. With an energy consumption of 66 µW, the trigger system can remain turned on without relevant influence on the battery life. The device is turned on within 150 ms, capturing dynamic events with up to eight independent sources. The maximum bandwidth is 4100S/s and the amount of saved measurements is 64k. The monitoring system is used to capture the environmental temperature, pitch of several axis and triaxial acceleration. Preconfigured inputs are available for additional sensors such as strain gauge [link], displacement transducer, force transducer, humidity sensor and laser-based displacement sensor. [4]

**CulturBee**
To monitor historical and cultural buildings, scientists from the University of Linköping, Sweden, developed a network based system named CulturBee. The system can be used under harsh environmental conditions. The wireless sensor networks can be used to measure the relative humidity or temperature. Additional sensor types can also be attached. With a sample rate of fifteen minutes, the battery lifetime is about ten years. Two different types of sensor nodes have been developed: ZigBees sensor module is able to capture the temperature and relative humidity and is used in the network as terminal device. ZigBees radio technology contains an external power amplifier and a low-noise amplifier. With an additional adapter assembly, the module can operate as a coordinator or as a router. Another application method is the use as a terminal device to allow the communication with other sensor types. Once the power is turned on, the coordinator builds a local network and connects the devices. The WSN is connected to the main remote server via GPRS/3G/Ethernet. [4]

Essebi

The monitoring system was developed by the company Essebi in Italy and contains several analog input nodes NI WSN-3202 with bidirectional 4-channels. The data transmission to the gateway meets the standard IEEE 802.15.4. A node can contain different sensors such as linear dia potentiometer, inclinometer and pressure sensors. The fourth channel is predetermined for temperature measurement. The gateway of the wireless network is connected via Ethernet to a PC. A remote access by the user via GSM modem is not possible. A connection with Faser-Bragg-Grid-sensors is possible, if a cRIO-device is used as gateway. [4]

Network architecture

Generally, the sensor nodes are distributed in a sensor field. Every node in the field is able to measure data and send information back to the gateway. The gateway is located near the sensor field and sends requests to the sensor nodes, collects measurement data, processes data and transmits the processed information via internet or satellite to the user. The type of transmission is determined by the network architecture. [6]

Single-Hop Network

In a single-hop network, every sensor node sends information directly to the gateway. This type of transmission consumes a high amount of energy. The information transfer in a wireless sensor network consumes more energy than the data mining. The energy consumption ratio of data transfer to data processing can be 1000 up to 10000. The required energy for data transfer increases exponential with the transfer distance. This type of network architecture is used with short transfer distances between nodes and gateway. [6]

Multi-Hop Network

Multi-hop networks are utilized for short transfer distances between sensor nodes. In this network type, the measurement data is transferred with the help of internodes to decrease the energy consumption for data transfer. The multi-hop architecture can be divided in two types: [6]

Flat architecture
In a flat network, every sensor node fulfills the same purpose and all sensor nodes are peers. Because of the high amount of sensor nodes, it is not possible to assign a global base station to all sensor nodes. For this reason, the data is gathered by data-based redirection. The gateway sends a request to all sensor nodes within its acquisition area. The sensor nodes only reply with the information regarding the request. The sensor nodes transmit the information via multi-hop and use the neighbor nodes as relays. [6]

Hierarchic architecture

In a hierarchic network, the sensor nodes are grouped in clusters. Every cluster node sends the information to the cluster head node. These cluster head nodes behave as relays and transmit the measurement data to the gateway. This process can lower the energy consumption of the communication and compensate the data traffic. In case of an increasing network, the scalability is improved. To compensate the data traffic between the nodes, the clustering has to be executed periodically due to the equal availability of power transmission of the sensor nodes. To reduce the amount of data and to increase the energy efficiency, the head cluster nodes are able to aggregate the data.

The sensor networks can be divided by the cluster strategy into single-hop clustering and multi-hop clustering architecture. According to the amount of layers in the clustering hierarchy, a sensor network can be divided into one-layer or more-layer architectures. The gateway connects to the task manager via internet or satellite. The design of a sensor network depends on multiple factors: failure tolerance, production costs, operational environment, network topology, energy consumption, hardware constrains and transmission media. Depending on the type of data acquisition, wireless sensor networks can be divided into three categories: homogeneous sensor networks, heterogeneous sensor networks or hybrid sensor networks: [6]

Homogeneous sensor network

A homogenous sensor network contains base stations and nodes with the same sensors. Therefore, every node can recognize the measurement data. In case of a sensor breakdown, the complete node is useless. [6]

Heterogeneous sensor network

A heterogeneous sensor network contains base stations (stationary or movable), sensor nodes and nodes with integrated advanced processing technologies and communication abilities in comparison to common sensor nodes. The data can be captured in the mobile base stations. In such networks the mobile base station moves arbitrary within the entire network, collecting measurement data directly from the sensor nodes or using neighboring sensor nodes for data transfer. If the sensor nodes are more apart from each other, the energy consumption for communication is increasing. Investigation on the networks revealed, that the data acquisition of mobile base stations can extend the operating time of the system. [5]
For a faster acquisition of data in real-time, several base stations work together. This is called a hybrid sensor network. Measurements are passed through several mobile stations. The routing algorithms for ad-hoc networks can be adopted as routing protocols. Mobile ad-hoc networks (MANET) assume that every node can move in its own velocity. Although WSN is more restricted as other wireless networks, the data transfer between the base stations can be executed with MANET protocols. If the position of the base station cannot be determined or the connection between base stations is interrupted, it is worth to adopt the methods for mobile ad-hoc networks. The communication of the mobile base station with other sensor nodes through WSN protocol and with other base stations in a hybrid sensor network is realized with the help of MANET protocols. Hybrid networks feature a longer durability and can increase the efficiency of data acquisition. [6]

![Hybrid sensor network](image)

**Literature**