Possibilities and Limitations of Wireless Sensor Systems

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Abstract

Wireless sensor systems open up a wide range of new measurement applications in different fields of applications in medical, industrial and research environment. Typical applications of sensing, data processing and communication can be found in ambient assisted living projects and condition monitoring scenarios. Self-contained energy supply and wireless communication, which both enable a very flexible topology and a cost-effective implementation in existing environments, allow covering these scenarios. Miniaturized wireless sensors, designed using advanced packaging technologies, can be placed where wired infrastructure is cost- and maintenance intensive. But these enablers are also limiting factors due to restrictions regarding communication range and data rates as well as energy density. In many applications, e.g. medical services, aspects like data security and system reliability are critical issues which have to be addressed by the hardware and software design. Therefore, methods and concepts for energy saving and increasing communication reliability have to be applied.
This paper gives an overview of possibilities and limitations of wireless sensor systems and their optimization potential. Several public and industrial research projects have been realized at the Fraunhofer IZM.

Introduction

Wireless sensor networks have been researched and developed for years. Commercial wireless measurement solutions for simple parameters, e.g. temperature, pressure or humidity, are aviable today. Used as an active tire-pressure monitoring system integrated in the air chamber, used for capturing heating costs, or monitoring the food chain, wireless sensors open up new application fields. Measuring is a pre-condition of process automation and process control.
In comparison to wired sensors, wireless sensors provide a reduction of installation costs. It is expected, that miniaturized self sufficient wireless sensor nodes can be easily adapted to the existing infrastructure or build up an own infrastructure by their networking ability. Measurement systems without wires are often used in conjunction with moving and rotating parts.
We want to discuss the possibilities and limitations of wireless sensors in this paper. The next section summarizes some common aspects and their corresponding challenges in development. We try to outline the limitations. The subsequent section shows possibilities of wireless sensors in different applications. Before we conclude our paper and give an outlook on future work.

Common aspects and challenges

Compared to wired systems wireless sensor nodes are limited in their communication range and their lifetime for example. Communication and energy consumption have a strong correlation which is discussed in the following sections. The following aspects must be considered according to the application, which has to be realized:

Mobility

Wireless sensors support the mobility of measurement. The places, where parameters have to be measured, are manifold. For example, moving objects, goods or machine parts, can be monitored with an attached sensor node. This enables a real-time control of critical parameters like temperature or humidity in transport scenarios or logistic applications. Also vital parameters on human body can be sampled in real life situations with the help of wireless sensors. Advanced packaging technologies for sensors and system electronics enable the miniaturization and user-defined form factors. Both are required to measure at any place. Often, measurement on moving parts is bounded on limitations in sensor’s weight and volume.

Self sufficiency

In most cases, wireless sensors have to be self sufficient. Especially sensors on moving objects have to fullfill this requirement. Lifetime is one of the critical issues in sensor networks due to maintanance. Exchanging batteries in applications with many sensors, e.g. large sensor networks, is expensive,. The devices must operate for years to keep the costs under control.

Energy

The energy budget is the crucial question in wireless sensor design. While advanced packaging technologies promise very compact electronics for sensor and signal conditioning, the components for power-supply usually dominate the volume and weight in system design. This includes energy generating components, energy storages, as well as voltage conditioners. Low-power solutions are necessary for sensing, signal processing and wireless transmission. They support the size reduction of the overall system.

A long life time is hard to achive if constraints in volume or weight also exist. The two main possibilities to reach the requirements are

a) reducing the energy consumption, and

b) increasing the energy density of power supplies.

Dynamic frequency and voltage scaling are well-known practices to reduce the power demand of signal processing parts. Little effect can be drawn by reducing the switching activity of data and instruction streams. It is evident to enable system parts only when required.

Non-linear effects of temporary electrochemical energy storages make modeling and simulation of the system behavior necessary to get more accurate information about the energy budget and the lifetime.

Energy harvesting can be used to realize a nearly unlimited time of operation. Mechanical, optical or thermal power in the environment of the sensor can be transformed into electrical power. In respect to the place of installation light, vibration, rotation or temperature gradients can be utillized. A lot of research activities are in progress to provide reliable self powered sensors.

Communication

Wireless sensor nodes use some kind of radio broadcast communication. If the sensor is not a transmit-only transponder, but can also receive messages from its neighbours, very large networks can be spannend with a huge gain of communication range and coverage. Other sensors can be used as relais stations to increase the communication range.

One of these concepts is called meshed networks with multihop functionality (see Figure 1). The realibility of such a sensor network is increased dramaticly because of different routes, which can be chosen for the data packet transfer through the network – it can be compared with the structure of the internet.

Data transmission is not limited to transport the measured information. The sensor nodes can be configured with the help of a bidirectional data link. Configuration information can be transmitted from a basestation or wireless gateway to the sensor nodes of interest.

Different communication standards for the integration of wireless sensor networks into an industrial environment are available. But with the mobility aspect mentioned above, there are also big challenges to establish a communication link in a reliable and energy efficient way. This point is one of the most addressed issues in actual research work. Communication parameters have to be adjusted dynamically due to the non-deterministic effects in a changing environment.

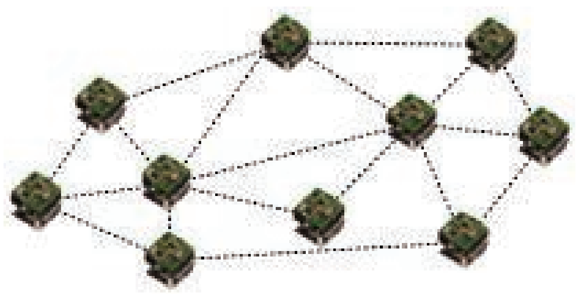

Figure 1 Meshed network. Different routes can be used to transport the information across the network.

The communication and medium access is one of the important factors in the energy budget. In the 2.4GHz ISM band with approximately 0dBm radiation power it is not important if the sensor node sends data or is in the receiving state. If the sensor is in the receiving state but no data transmission from another node is intialized one speaks of the idle listening problem. It is one of the greatest needs in the optimization process to eleminate idle listening time.

Regarding an increased reliability the environment is one of the most important influences on an communication channel. But with a changing environment and coexistence of different other wireless infrastructure access points there is an emerging risk to destroy the signal level integrity. Therefore, different approaches to error detection and error correction have to be applied in the upper protocoll layers.

In the industrial environment the communication interface has to coexist with other wireless technologies without interferences. So one can use a sub gigahertz ISM-band to communicate on a licence free frequency without interfering with WLAN and DECT. In lower frequency bands the communication consumes less energy and lifetime can be optimized but the data rate is lower than in higher frequency bands. Established communication protocols give more flexibility on the topology and the data link but consume more resources on the sensor nodes.

Localization

A further issue has to be addressed: the localization. Often it is necessary to know, where the sensor value was taken. The sensor value is only useful with information about its location. It is obvious, that mobile sensors require some kind of dynamic localization ability. Static sensor nodes can be programmed with their location in an early setup phase, but they also benefit from a dynamic localization due to reduced installation costs.
One well known possibility to get the location is the usage of satellite navigation systems like GPS. But these mechanism require satellites in the line of sight, i.e. it can be only used in outdoor applications. Todays solutions require lots of energy, which makes them unhandy for small wireless sensors.
So, different approaches from triangulation to correlation of tens of anchor nodes to derive localisation information from the different communication channels exist, which can be also applied to indoor systems. Differences in the archievable resolution in space, ranging from a fraction of hundred of meters to a fraction of one meter, can be can be observed. This is also influenced by the environment and the available computation power on the mobile sensor node.

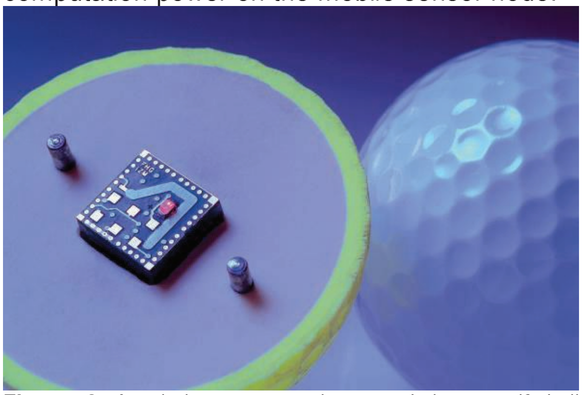

Figure 2 A wireless sensor integrated in a golf ball measuring acceleration forces during chipping. (Fraunhofer IZM)

Possibilities in different application fields

Let's take a closer look at different application fields. Without making claim to be complete, we present some applications, which are already available or discussed in the field of applied research.

Medical and home care

In medical scenarios, like ambient assisted living, the items mentioned above enable monitoring and assisting a patient in an uncompromising environment. Wireless sensors applied to the body can measure vital parameters and send these medical data to a hospital. These information can be evaluated by a doctor, who can give advice to the patient via modern communication technologies.

Industrial production

A multitude of application scenarios is still in research state. The manufacturing quality control is one of the most vital fields. It is expected, that wireless sensor systems can help to reduce production and maintainance costs. In the following section the possibilities of wireless sensor networks are discussed in detail.
The vision of a self organizing production is evaluated in the public funded research project SOPRO[1]. Every workpiece and machine is equiped with a robust wireless sensor node. Data exchange between these nodes and machines shall enable a dynamic planning process of the next manufacturing steps. Fabrication conditions for the workpieces, like their material and next manufacturing steps like drilling, milling or transport logistics, are stored in the memory on the nodes.
With an agent based communication framework time and cost critical issues during the production are organized decentrally. Conflicts of ressources can be resolved with priorities and a market based handling aproach. The wireless sensor nodes are playing a key role in this scenario. They enable decentralistic communication and decisions. Equipped with different sensors they inject additional information about the status of machine tools, material and progress information. This can be analyzed through the agent framework and changes in the production can be made in real time. The harshness of the industrial environment has to be addressed by a robust communication topology and protocol. Because of the need of a high miniaturization there is a minimum of available energy for every node.

Condition monitoring

Condition-monitoring is a requirement for a condition-based maintenance of manufacturing and industrial facilities. The upcoming approach displaces the preventive strategy of shutting down, checking, and repairing machines in predefined periods of time, which lead to a waste of remaining operating time and exchanging faultless parts. A condition-based maintenance reduces costs but requires the regular monitoring of condition.

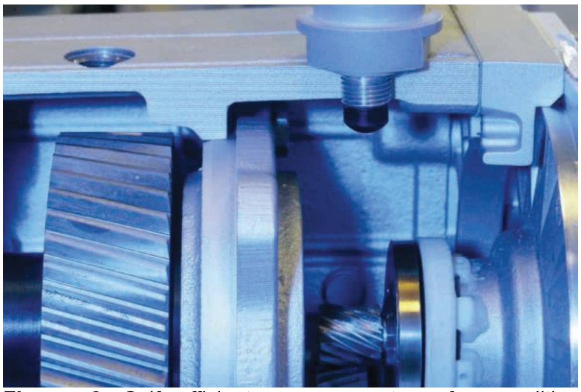

Figure 3 Self-sufficient sensor system for condition monitoring in closed machine parts. (Fraunhofer IZM)

We developed energy harvesting sensors for condition-monitoring in multiple projects. Figure 3 shows battery-less sensors integrated in a rotary shaft seal. Temperature and rotation-speed measured in oil environment are wirelessly transmitted to a receiver. The required energy is harvested from the rotary motion.

In Figure 4 another condition monitoring scenario is depicted, where the vibrations of electric engines are monitored. This wireless sensor system is powered by the thermal gradient between the motor surface and the environment. The frequency spectrum, which is software-derived from the measured vibration, is the base for diagnosting wearouts and defects.

Wireless metering

In the context of building automation and cost optimization wireless sensors can be placed at the points of energy consumption used to identify the potential of saving resources. In this scenario the big advantage of a wireless infrastructure is evident. In current research work energy harvesting plays a key role for self powered systems without any batteries, which would have to be replaced.

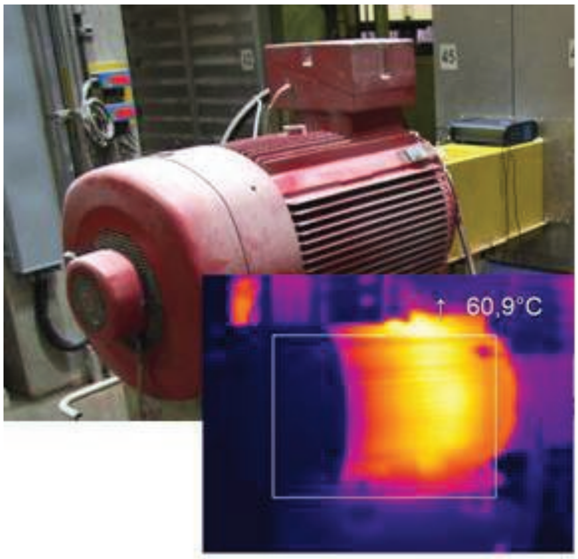

Figure 4 Condition monitoring system for vibration analysis powered by temperature gradient. (TU-Berlin / Fraunhofer IZM)

Conclusion and future work

Wireless Sensor networks cover a huge amount of different sensor applications with advantages in size, infrastructure costs and flexibility. But there are also limiting factors that have to be concidered. Therefore methods and concepts for energy saving and increasing communication reliability have to be applied. In applications like medical services aspects like data security and system safety are critical issues, which have to be addressed by the hardware and software design.

The Fraunhofer IZM realized different projects in these application fields and has an excellent expertise in hardware and software co-design.

Acknowlegments

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