Reaping the harvest

Professor Dr Olfa Kanoun and Professor Dr Wolfram Hardt, of Chemnitz University of Technology, champion the benefits of energy harvesting in wireless innovation...

Distributed, autonomous sensor systems are subject to an ongoing process of miniaturisation. To keep the installation efforts and maintenance costs as low as possible, these systems are developed to be self-sufficient. All communication interfaces are implemented wirelessly. Consequently, a decentralised power supply of the individual sensor nodes is required. Due to the miniaturisation process and high system integration level, the dimensioning of the energy storages is challenging. Alternative strategies to conventional battery technologies are necessary to ensure a stable energy level for each system component.

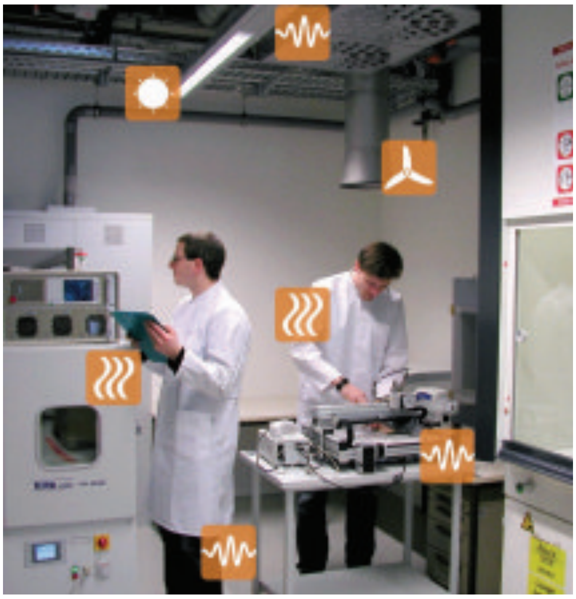
The use of modern energy harvesting technologies extends the operating time of wireless sensor systems (eg in automobiles, buildings, logistics, structural health monitoring and consumer electronics) significantly. The energy resources are simply harvested where they are needed.

Energy harvesting technology

Energy harvesting is the conversion of small amounts of ambient energy into usable electrical energy – representing a power level in the range of less than a few milliwatts. For common energy sources like solar, thermal or kinetic energy, several physical conversion principles are used. In this context, photoelectric converters, electrodynamic induction as well as the Seebeck and piezoelectric effect are established techniques. Extensive research and development activities have taken place in this field considering novel technologies for components and system solutions.

To ensure the effective operation of the sensor system and the whole wireless network, energy generation and consumption must be matched to each other. Therefore, the available energy should be scaled with the size of the transducer for a given system demand. A load can be controlled by intelligent management of different operating states and duty cycles.

The question of reliability remains a critical issue, not only because of the low level of upcoming energy, but also because of the fluctuating availability of ambient energy. Accordingly, the efficiency of the converters is strongly



Energy sources for powering wireless sensor node can be found almost everywhere. The picture above shows sources for vibration, fluid flow, light and heat harvesting in a place of work

dependent on the ambient conditions in the environment. To solve this challenge, hybrid energy harvesting systems are using the diversity of different energy sources. Here, the intelligent integration of complementary harvesting principles is the most important point to improve the system's reliability, availability and functionality. A solar cell, for example, is useless at night, but wind can still be available in the dark with high peak power.

Available energy is subject to periodic or random fluctuations. Superfluous energy should be accumulated in order to bridge the temporary gap of low energy availability. Depending on the buffering duration and the required amount of buffered energy resources, multistorage architectures combine the advantages of different technologies and at the same time bypass the disadvantages of a single energy storage unit. Accordingly, multistorage systems consist of several types of capacitors as well as batteries. These storages also support the harvester components in case of temporary increased system load, where the transducer itself would not be able to generate enough power.

Generally, different voltage levels are necessary within a system using energy harvesting. Therefore, several conversion steps between transducer and load are necessary. The impedance matching at voltage conversion has to be flexible for varying operating and environmental conditions. Adaptive tracking techniques fix the transducer's operating point at its maximum power point (MPPT).

Embedded energy management

Besides the basic technological components, an intelligent management system is important for controlling the energy flow between source, storage and load. Different functionalities of the sensor node are executed with different levels of power consumption. This includes the sensing functions as well as the wireless communication tasks. Therefore, the controller has to schedule each task dependent on the level of energy availability. In this context, the efficiency of the system design and the respective management features are essential to ensure a maximum level of reliability during the operation.

Hybrid energy harvesting systems are used in complex and dynamically changing environments. This high degree of varying conditions represents one of the key challenges in regards to efficient energy management. The management knowledge base therefore has to be extended to the node's operating system, where task scheduling incorporates priority and energetic budgets.

On the harvester level, the energy management coordinates the set of available harvester components to ensure the required energy output. Therefore, a multidimensional logic analyses the actual environmental situation and adapts the system components on demand.

On the energy storage level, the management is responsible for an intelligent partitioning of the converted energy resources. These decisions are application-specific and depend on the actual status of the overall system.

During the runtime, the wireless communication allocates major parts of the available energy resources. Miniaturised, embedded sensor system architectures, innovative communication strategies as well as an optimised communication infrastructure are necessary to realise any kind of maintenance-free long-term application. Thus, the smart integration of innovative energy harvesting technologies, situation-aware task scheduling strategies as well as topology optimisation approaches and cooperative routing approaches are the key for realising energy-efficient systems. On top of this architecture, an application-specific configuration optimises the system behaviour during the runtime.

By integrating a smart energy management into next generation energy harvesting technologies, the range of applicability to industry related emerging products will be extended significantly.

Future trends

The most important aspect for the acceptance and widespread use of smart energy harvesting architectures is the efficient collaboration of relevant interdisciplinary fields of research. These include:

- New materials and novel transducer principles: infrared solar cell, bio-harvesting;
- Low power electronics: weak inversion technology;
- Flexible harvester and electronics: printed devices;
- System integration and miniaturisation: MEMS, NEMS technology;
- Smart materials: integrated harvester and sensors, smart textiles;
- Smart energy management: energy prediction, state monitoring;
- Low power communication technologies and protocols;
- Optimised data processing: data aggregation, data fusion.

The development of hybrid energy harvesting systems enables novel and promising fields of application, like smart metering applications, and object surveillance or disaster prevention systems. Research additionally focuses on next generation manufacturing technologies, ambient assisted living, building automation and environmental monitoring. Integrated solutions in the logistics business or enhanced products in the healthcare sector represent further developments.

Even if an optimum system design is reached by application-specific energy harvesting solutions, this novel technology can be better promoted, if universal architectures with standardised interfaces are developed. Typical energy harvesting systems can be developed on a modular base using highly optimised but simultaneously adaptable components.

Energy harvesting will be the leading force in realising large, dynamic, self-sufficient wireless networks in the next 10 years. Through progress in this promising technology, future challenges in demography, climate and health issues can be overcome.

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