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Energy Efficient Hardware Architecture for Data and Computation Intensive Wireless Monotoring

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Abstract:

Wireless Sensor Networks (WSNs), in addition to enabling monitoring solutions for numerous new applications areas, have gained huge popularity as a cost-effective, dynamically scalable, easy to deploy and maintainable alternatives to conventional infrastructure-based monitoring solutions.

A WSN consists of spatially distributed autonomous wireless sensor nodes that measure desired physical phenomena and operate in a collaborative manner to relay the acquired information wirelessly to a central location. A wireless sensor node, integrating the required resources to enable infrastructure-less distributed monitoring, is constrained by its size, cost and energy. In order to address these constraints, a typical wireless sensor node is designed based on low-power and low-cost modules that in turn provide limited communication and processing performances. Data and computation intensive wireless monitoring applications, on the other hand, not only demand higher communication bandwidth and computational performance but also require practically feasible operational lifetimes so as to reduce the maintenance cost associated with the replacement of batteries. In relation to the communication and processing requirements of such applications and the constraints associated with a typical wireless sensor node, this thesis explores energy efficient wireless sensor node architecture that enables realiz ation of data and computation intensive applications.

Architectures enabling raw data transmission and in-sensor processing with various technological alternatives are explored. The potential architectural alternatives are evaluated both analytically and quantitatively with regards to different design parameters, in particular, the performance and the energy consumption. For quantitative evaluation purposes, the experiments are conducted on vibration and image-based industrial condition monitoring applications that are not only data and computation intensive but also are of practical importance.

Regarding the choice of an appropriate wireless technology in an architecture enabling raw data transmission, standard based communication technologies including infrared, mobile broadband, WiMax, LAN, Bluetooth, and ZigBee are investigated. With regards to in-sensor processing, different architectures comprising of sequential processors and FPGAs are realized to evaluate different design parameters, especially the performance and energy efficiency. Afterwards, the architectures enabling raw data transmission only and those involving in-sensor processing are evaluated so as to find an energy efficient solution. The results of this investigation show that in-sensor processing architecture, comprising of an FPGA for computation purposes, is more energy efficient when compared with other alternatives in relation to the data and computation intensive applications.

Based on the results obtained and the experiences learned in the architectural evaluation study, an FPGA-based high-performance wireless sensor platform, the SENTIOF, is designed and developed. In addition to performance, the SETNIOF is designed to enable dynamic optimization of energy consumption. This includes enabling integrated modules to be completely switched off and providing a fast configuration support to the FPGA.

In order to validate the results of the evaluation studies, and to assess the performance and energy consumption of real implementations, both the vibration and image-based industrial monitoring applications are realized using the SENTIOF. In terms of computational performance for both of these applications, the real-time processing goals are achieved. For example, in the case of vibration-based monitoring, real-time processing performance for tri-axes (horizontal, vertical and axial) vibration data are achieved for sampling rates of more than 100 kHz.

With regards to energyconsumption, based on the measured power consumption that also includes the power consumed during the FPGA's configuration process, the operational lifetimes are estimated using a single cell battery (similar to an AA battery in terms of shape and size) with a typical capacity of 2600 mA. In the case of vibration-based condition monitoring, an operational lifetime of more than two years can be achieved for duty-cycle interval of 10 minutes or more. The achievable operational lifetime of image-based monitoring is more than 3 years for a duty-cycle interval of 5 minutes or more.