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Ultra Low Power Capacitive Sensor Interfaces

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Contents

Foreword

The increasing performance of smart microsystems merging sensors, signal processing and wireless communication promises to have a pervasive impact during the coming decade. These autonomous microsystems find applications in sport evaluation, health care, environmental monitoring and automotive systems. They gather data from the physical world, convert them to electrical form, compensate for interfering variables or non-linearities, and either act directly on them or transfer it to other systems. Most often, these sensor systems are developed for a specific application. This approach leads to a high recurrent design cost. A generic front-end architecture, where only the sensors and the microcontroller software are customized to the selected application, would reduce the costs significantly.

This work presents a new generic architecture for autonomous sensor nodes. The modular design methodology provides a flexible way to build a complete sensor interface out of configurable blocks. The settings of these blocks can be optimized according to the varying needs of the application. Furthermore, the system can easily be expanded with new building blocks. The modular system is illustrated in a Generic Sensor Interface Chip (GSIC) for capacitive sensors. Many configuration settings adapt the interface to a broad range of applications. The GSIC is optimized for ultra low power consumption. It achieves an ON-state current consumption of 40μA. The system maintains a smart energy management by adapting the bias currents, measurement time and duty cycle according to the needs of the application (parasitic element reduction, accuracy and speed). This results in an averaged current consumption of 16μA in a physical activity monitoring system. The activity monitoring system is implemented in a miniaturized cube. It consists of a sensor layer (GSIC and accelerometer), a microcontroller layer and a wireless layer. The bidirectional wireless link (from the sensor node to the computer) makes it possible to display the data in real time and to change the interface settings remotely. So, the smart autonomous sensor node can adapt at any moment to environmental changes. The GSIC is also successfully tested with other accelerometers and pressure sensors. Hence, the developed GSIC is a significant step towards a generic platform for low cost autonomous sensor nodes.

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Chapter 1

INTRODUCTION

The drive towards an intelligent environment has lead to an increased need for intelligent and independent sensors. Possible forecasts predict these autonomous sensors to work as small distributed units, that can collect data over a longer period of time [War01, Asa98, Rab02]. According to this vision, they should meet the following challenging criteria:

- highly miniaturized. So, they can be worn or implanted without any discomfort for the user.
- versatile. The sensors will be able to operate without any intervention of the user.
- maintenance free. The nodes can supply their own energy. Hence, they need to combine Ultra Low Power (ULP) electronics (sensor interfaces, microcontroller and communication front-end) with an efficient energy generation and storage.
- low cost.

The emerging opportunities of these autonomous sensors will give the first impulse to several new applications such as intelligent prosthesis, sport evaluation, observation of livestock and measurement of weather patterns. The last decade, a tremendous progress has already been made in such smart microsystems. Some impressive realizations are a wireless multisensor medical microsystem [Tan02] and a very low power pacemaker system [Won04].
The multisensor medical microsystem integrates a microsensor array, the signal processing electronics, a wireless transmitter and batteries in a miniaturized capsule of 16 mm (diameter) by 55 mm (length). The sensor array contains a dissolved oxygen sensor, a pH-sensitive Ion-Selected Field Effect Transistor

(ISFET), a standard PN-junction silicon temperature sensor and a dual electrode direct contact conductivity sensor. The complete system dissipates only 6.3 mW for a minimal life cycle of 12 h.
The implantable pacemaker system monitors the heart's rate (how fast it beats) and rhythm (the pattern in which it beats), and provides electrical stimulation when the heart does not beat or beats too slowly. The pacemaker IC contains amplifiers, filters, ADCs, battery management system, voltage multipliers, high voltage pulse generators, programmable logic and timing control. The IC has 200 k transistors, occupies 49 mm^2 and consumes 8μW. This enables a lifetime of 10 years on a lithium iodine battery.

Most of these sensor systems were tailored towards the requirements of one specific application. This design approach is inflexible and requires several iteration steps for new sensor applications. It usually results in an intolerable high design cost for low and medium quantity market products. An ULP generic multisensor interface would reduce the costs significantly, since one can use the same interface chip for several applications. Hence, the recurrent design costs are eliminated and the time to market is shorter. Furthermore, the front-end can be adapted during operation. Hence, we can adjust the system to changes in the environment (e.g. enter a low power mode, when the available supply energy is getting low). Moreover, a generic interface is capable of reading out several sensors in different time intervals. So, we can combine the information from different sensors to compensate for cross-sensitivities (e.g. compensation of the temperature dependency).

Several research groups have already developed generic sensor interface architectures [Yaz00, Mas98, VDG96]. Most of these systems were designed for industrial applications, which do not need the lowest power consumption. As a consequence, their power dissipation is still too high (in the order of mW's instead of the required tens of μW) to permit autonomous functioning over a longer period of time.

This work aims to combine the flexibility of generic sensor interfacing with ultra low power consumption. The developed modular design methodology provides a flexible way to build a complete sensor interface out of configurable blocks. The settings of these blocks can be changed according to the varying needs of the application. Furthermore, the system can easily be expanded with new building blocks. The modular system is illustrated in a Generic Sensor Interface Chip (GSIC) for capacitive sensors. The GSIC is tested with several micromachined pressure sensors and accelerometers. Moreover, the GSIC is used in a miniaturized demonstrator for physical activity monitoring.

The outline of the presented work is as follows:

- In chapter 2 an overview of the most important design aspects for autonomous sensor nodes is given. The different building blocks are discussed