A Novel System-on-chip Design of Wearable ECG Signs Monitoring Node into Medical Vest

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Abstract—Intelligent fabric are fabrics with interconnections and electronics woven into them. The electronics consist of both processing and sensing elements, distributed throughout the fabric. In this paper we present a medical vest which has the wireless sensor network node for ECG signs monitoring. The system-on-chip solution chosen to transmit the body’s measured signals for further processing was the use of a wireless link, working at the 2.45 GHz ISM band. Some implementation details are explained showing how the solution can be effectively implemented and deployed into medical vest. The simultaneous recording of ECG signs is essential for the identification of disorders of the cardiac rhythm, extremely useful for the diagnosis and management of heart abnormalities such as myocardial infarction (heart attack), and offers helpful clues to the presence of generalised disorders that affect the rest of the body, such as electrolyte disturbances and drug intoxication.

Keywords— intelligent fabric; medical vest; wireless sensor network; system-on-chip; ECG

I. INTRODUCTION

An ideal medical care technology should be easy to use, reliable, and cost-effective, should provide accurate medical information to the patient and/or caregivers. Wearable medical devices should be small, lightweight, and simple to attach, while medical devices that are used in the hospital should be easy to install and permit normal movement about the living space. A patient should be able to go about a daily routine without interference or distraction. Devices that do not have these characteristics will not be widely adopted or effective. In usability studies of medical monitoring devices used by the elderly population, participants when apprehensive and lacked confidence in the devices due to the size, non-functionality when moving about, and lack of training. An emerging technology, intelligent fabric, holds the promise of creating medical care devices that will be more accepted and usable [1, 2].

In the medical domain, there are numerous projects for telemonitoring physiological data. Traditionally, personal medical monitoring systems, such as Holter monitors, have been used only to collect data for off-line processing. Systems with multiple sensors for physical rehabilitation typically feature many wires between the electrodes and the monitoring system. These wires may limit a patient’s activity and level of comfort, thus potentially affecting the reliability of the measured results. Therefore, there has been an increasing interest in health monitoring in the wearable computing community.

Martin et al discuss in issues [3] surrounding wearable computers used for health monitoring where the devices provide real-time feedback to the patient. In particular, they describe a wearable ECG device, but provide no experimental results. A Bluetooth-enabled health monitoring system is described [4], where the authors present a PDA-based ECG monitoring system with the sensors embedded in a shirt. The analysis of the data would be done in a central computer. However the authors neither report algorithms to process the data nor experiments with real users. A wearable health-monitoring device using a Personal Area Network (PAN) or Body Area Network (BAN) could be integrated into a user’s clothing [5]. Along these lines, Paradiso describes quite preliminary work on the WEALTHY system [6], a garment with embedded ECG sensors for continuous monitoring of the heart.

In the area of wireless sensor networks, the MobiHealth European project aims to provide continuous monitoring of patients outside the hospital environment by developing the concept of a 3G-enabled BAN [7]. CodeBlue [8] is a wireless infrastructure intended for deployment in emergency medical care, integrating low-power wireless vital sign sensors, PDAs and PCs. Some of their research interests include the integration of medical sensors with low-power wireless networks, wireless ad-hoc routing protocols and adaptive resource management.

However, all the above projects have made use of either simple resistive/capacitive elements or woven-in planar circuits. None of the medical vest, reported so far in the literature, approaches the wireless sensor network node design from a system-on-chip design perspective. In this paper, we outline an approach to investigating the use of intelligent fabric for monitoring people that suffer from heart arrhythmias; and therefore, living a normal life while feeling safe at the same time.
II. MEDICAL VEST PROTOTYPE

Fig. 1 shows an overview of the whole medical vest for ECG monitoring, consisting of the following components: five textile electrodes [9, 10] (RA, LA, V, RL, LL, conventional 5 lead placements of standard Holter ECG indicated in the Fig. 2), the wireless sensor network node, the base fabric and the textile-based interconnect. The vest itself is made of very elastic fabric to ensure good contact of the electrodes to the wearer’s skin.

Since the medical vest has to be water resistant and electrically isolated the node system-on-chip and an additional 5mm thin lithium-ion accumulator were molded-in using silicone to avoid a decrease in flexibility.

III. WEARABLE WIRELESS SENSOR NETWORK NODE

A. Architecture of Wireless Sensor Network

Wireless sensor networks are an emerging technology consisting of small, low-power, and low-cost devices that integrate limited computation, sensing, and radio communication capabilities. This technology has the potential to have enormous impact on many aspects of medical care. Sensor devices can be used to capture continuous, real-time vital signs from a large number of patients, relaying the data to handheld computers carried by physicians or nurses. Wearable wireless sensor network nodes can store patient data such as identification, history, and treatments, supplementing the use of back-end storage systems and paper charts. Wireless sensor networks can greatly improve the ability of first responders to triage and treat multiple patients equipped with wearable wireless sensor network nodes. Such an approach has clear benefits for patient care but raises challenges in terms of reliability and complexity. Fig. 3 shows wireless sensor network architecture for ECG signs monitoring. Wireless sensor network for ECG signs monitoring provides protocols for integrating wireless medical sensors and end-user devices such as PDAs and PCs.

The wireless sensor network nodes in a cluster are powered from batteries. To minimize energy consumption by a node and to minimize number of hops for a message, all sensor nodes prefer a single hop communications with a sink node. If, however, a single-hop path is not available, a multi-hop path can be taken. Various energy-saving routing algorithms can be applied to minimize and equally distribute energy consumption in the sensor nodes routing message from other nodes [11, 12].

A sink node controls the communication in the allocated cluster and has a less expensive and more powerful source of energy such as a power line. A sink node does not possess additional computational capabilities, but rather serves as a router of the network messages.

B. Architecture of Wireless Sensor Network Node

The system-on-chip architecture of wireless sensor node consists of four closely-interacting modules (please refer to Fig. 4). These modules are: the sensing input module, the computing module, the communication module, and the power-supply module.

The sensing input module employs textile electrodes that feel like normal fabric and were developed using of-the-shelf materials [9, 10].

The computing module is specially designed for ultra-low-power applications. It incorporates a 16-Bit RISC CPU, peripherals and a clock system. As shown in Fig. 4, it has 55KB Flash, 5KB of RAM and a clock system sourced by an internal digitally controlled oscillator (DCO) and/or two external oscillators. It also contains 5-channel 12-Bit A/D Converter.
The communication module manages the data transfer and signaling between the wireless sensor network nodes. It includes the network protocols and the radio transceiver. An IEEE 802.15.4 compliant radio can operate in 16 channels in the 2.45GHz ISM band, 10 channels in the 915MHz band (only in the US) and 1 channel in the 868MHz band (EU and Japan). The 2.45GHz band allows higher data rate and offers more channels than the other bands and thus is well suited for wireless sensor networks for medical care. Signaling in the 2.45GHz band is based on orthogonal quadrature phase shift keying (OQPSK) and direct sequence spread spectrum (DSSS). The communication module rate equals 2 Mchip/s. The transmitter and receiver have respectively a direct upconversion and low IF I/Q architecture. The transmit power can be programmed from –15 to 0 dBm in 8 steps.

C. Mixed-signal System-on-chip Design

The growing complexity of the systems that can be integrated on a single die today, in combination with the tightening time-to-market constraints, results in a growing design productivity gap. That is why new design methodologies are being developed that allow designers to shift to a higher level of design abstraction, such as the use of platform-based design, object-oriented system-level hierarchical design refinement flows, hardware-software co-design, and IP reuse, on top of the already established use of CAD tools for logic synthesis and digital place & route. However, these flows have to be extended to incorporate the embedded analog/RF blocks.

The top-down design flow for wireless sensor node is shown in Fig. 5, where the following distinct phases can be identified: system specification, architectural design, cell design, cell layout and system layout assembly.

The ultimate advantage of top-down design therefore is to catch problems early in the design flow and as a result have a higher chance of first-time success with fewer design iterations, hence shortening design time, while at the same time obtaining a better overall system design. The methodology however does not come for free and requires some investment from the design team, especially in terms of high-level modeling and setting up a sufficient model library for the targeted application. Even then there remains the risk that also at higher levels in the design hierarchy low-level details (e.g. matching limitations, circuit nonidealities, layout effects) may be important to determine the feasibility or optimality of an analog solution. The high-level models used therefore must include such effects to the extent possible, but it remains difficult in practice to anticipate or model everything accurately at higher levels. Besides the models, efficient simulation methods are also needed at the architectural level in order to allow efficient interactive explorations.

IV. INTERCONNECT TECHNOLOGY BETWEEN TEXTILES AND ELECTRONICS

Figure 4. System-on-chip architecture of wireless sensor node

Figure 5. Top-down view of the mixed-signal system-on-chip design process

Recent advances in microelectronics have enabled the manufacturing of integrated electronic circuits with millions of logic switching elements per square millimeter of silicon. Since the feature sizes of these devices are in the micrometer regime and the typical dimensions in textile and garment technologies are in the order of several millimeters, a novel technology for the electrical interconnects has been developed. The gap of the spatial dimensions can be overcome by the method that are described in the following. A polyester narrow fabric with several groups of parallel conductive warp threads has been used. In a first approach (please refer to Fig. 6-a), the endings of the conductive fabric are prepared by soldering tiny metal contact plates. The system-on-chip of wireless sensor network node is then connected by electrically isolated bonding wires. In a second step (please refer to Fig. 6-b), the system-on-chip, the wires, and the contact plates are molded for mechanical and chemical protection.

Figure 6. Interconnect concept for the integrated circuit
V. TEXTILE-BASED INTERCONNECT FOR SIGNAL TRANSMISSION

Our approach is, thus, to use conductive textiles for signal transmission. Conductive textiles already have found application in the field of electromagnetic interference (EMI) shielding and static dissipation, but there are special requirements for conductive textiles. It must be possible to process the materials using textile machinery, and the resulting materials must be robust to weaving, washing, and wearing stresses. Textile technologies have been developed to manufacture fabrics out of conductive fibers that fulfill the requirements concerning processability, resistivity, and comfort [13].

Weave based fabrication of fiber transistors directly on fibers offers an entirely new approach to providing interconnectivity [14]. By allowing transistors to be fabricated in high densities directly in fabric, this scheme would allow dynamic signal routing to be built into medical vest in a cost-effective manner. The fiber transistor device performance demonstrated here, for example, if connected in a switching network like the one illustrated in [14], could allow wireless sensor network node to sample well over five textile electrodes. But this method is adequate for most intelligent fabric applications, where response time is not likely to be critical, and many sensors used will likely have response times close to or greater than one second.

VI. ELECTROCARDIOGRAM SIGNAL PROCESSING AND ANALYSIS

The electrocardiogram (ECG) has developed into one of the most important and widely used quantitative diagnostic tools in medicine. It is essential for the identification of disorders of the cardiac rhythm, extremely useful for the diagnosis and management of heart abnormalities such as myocardial infarction (heart attack), and offers helpful clues to the presence of generalised disorders that affect the rest of the body, such as electrolyte disturbances and drug intoxication.

Recording and analysis of the ECG now involves a considerable amount of signal processing for S/N enhancement, beat detection, automated classification, and compression. These involve a whole variety of innovative signal processing methods, including adaptive techniques, time-frequency and time-scale procedures, wavelet transform, artificial neural networks and fuzzy logic, higher-order statistics and nonlinear schemes, fractals, hierarchical trees, Bayesian approaches, and parametric models, amongst others. A wavelet transform is used to provide an informative representation which is both robust to noise and tuned to the morphological characteristics of the waveform features.

VII. CONCLUSION

In conclusion, this paper has presented an initial exploration into the challenges of system-on-chip design for medical vest. We believe that low-power wireless sensors network nodes have the potential for tremendous impact in many medical applications. The research is currently being developed through several active collaborations with local hospitals and we anticipate a clinical deployment of the system in the next few months.

Finally, some additional areas that we would like to explore in future research include: (1) incorporating other sensors in medical vest, such as blood oximeter, galvanic skin response (GSR), skin temperature, motion-activity sensor, etc; (2) collaborating with medical doctors in further user studies.

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