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A low power wireless node for contact and contactless heart monitoring

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ABSTRACT

Ubiquitous vital signs sensing and processing are promising alternatives to conventional clinical and ambulatory healthcare. Novel sensors, low power solutions for processing and wireless connectivity are creating new opportunities for wearable devices which allow continuous and long term monitoring, while maintaining freedom of movement for the users. This paper presents a low-power embedded platform with novel high sensitivity electric potential dry surface sensors that can be used in either contact or non-contact mode to measure biomedical signals. The proposed low power system is optimized to compute the heart rate and respiratory rate close to the sensors. This approach reduces the amount of data that needs to be transmitted to a host device. It allows also the platform to be autonomous and wearable or even be used in cars for applications such as driver drowsiness detection. Experimental measurements show the acquisition and the processing of data from sensors and the low power consumption achieved with the node in different modes of operation.

1. Introduction

Technology advancements of sensors, low power mixed-signal/RF circuits, wireless communication and embedded systems have enabled the design of compact, low power, high performance and low cost distributed sensing solutions better known as Wireless Sensor Networks (WSNs). WSN are covering an ever-increasing range of applications, such as surveillance, building monitoring, sports/fitness and, of particular interest, applications for health care. Wireless wearable health-monitoring systems have enjoyed increased interest from industry and research community alike during recent years [1–3]. As the world elderly population is increasing, governments are spending on healthcare significant amounts of money. This has created the need to monitor patients health status while they are out of the hospital to decrease the cost and at the same time increase the comfort and wellbeing of the patients which can be in a familiar environment. Wearable devices are also very attractive for sports, fitness and wellness and entertainment market to measure sports performance, daily activity, sleep patterns, and other related parameters. To address this demand, recent research efforts focus on wireless, unobtrusive, mobile, and easy to wear solutions to make the monitoring process more user-friendly and hence easier to be accepted. Wearability and wireless communication are important factors for any application that aims to achieve real-time, continuous and unobtrusive monitoring since the presence of wires may limit the user activities and level of comfort and also influence significantly the measurements. These systems are perfectly suited to be integrated within a telemedicine platform and wearable monitoring providing information technology that will be able to support early warning of abnormal conditions, prevention of serious consequences and in general health and body information [1,13,14]. As stated above, wireless wearable systems bring several advantages when compared to traditional wired health monitoring systems. The freedom of movement due to the wireless connectivity is the most obvious and important advantage for the users. In fact, the system can unobtrusively sense and process the vital signs of the person anywhere and anytime for as long as it is needed (often limited to a number of days of continuous monitoring). Another important advantage for the users is the tracking of their health conditions without frequent visits to the clinician, and to have alerts in case of a critical situation. As an example, patients that suffer from conditions where the symptoms present themselves in the form of seizures (i.e. epilepsy) can now avoid to be hospitalized for days for continuous monitoring [4]. For this reason a large number of novel body sensors are proposed by several companies [5,6]. These sensors can meet the requirements of a

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wireless sensors node especially in terms of high accuracy, small-scale factor, high integration, multisensory versatility and low-power consumption.

Common sensing biomedical parameters includes skin temperature, body motion, heart rate, blood pressure, respiration rate, electrocardiography (ECG) for the heart health, Electromyography (EMG) for the muscles control, electroencephalography (EEG) for the brain signals, oxygenation signals, and internal temperature[8–16].

The most widely used sensors to detect vital sign and health monitoring are the Electrocardiography (ECG) which provide useful information about the cardiovascular system. High sensitivity electric field sensors in this domain are starting to be used for detection of ECG-like signals to cover different types of applications ranging from forensics and healthcare to IC inspection and automotive safety systems [6]. These sensors can work without any skin preparation or the use of conductive gels required when using conventional wet electrodes, moreover can work also in contactless manner where the skin contact is not possible, for example in-car application where the electrodes are embedded in the driver's seat. Finally, these sensors can work attached/deployed in more wearable parts on the body such as on the arms, fingers and legs. These features together with the high sensitivity and high quality of the signal and low power consumption make these sensors the most promising candidates to be used in wearable biomedical parameters.

On the other hand, strict requirements for weight, cost and size, power and functionality became key challenges for every wearable wireless sensor node. To meet the first of these challenges, ultra low power design is required. These systems have to be supplied from batteries which need to last days(typically) or even months. Power restriction impacts on the complete node design, imposing constrains on computational resources, sensors and transceivers. Moreover functionality requirements impact on the biomedical information reliability and eventually on the platform quality. Thus, a hardware software co-design is required to achieve all the challenges.

This paper presents a wearable wireless sensors node which is able to support medical and health care applications. The node platform is developed to host novel commercial dry-surface electric potential integrated circuit (EPIC) sensors from Plessey Semiconductors optimized for ECG acquisition [7,20]. The proposed analog front end is optimized to reduce the noise of ECG signal in contact and noncontact mode and it is a critical part to have high quality data and algorithms accuracy. The core of the designed node is an ultra low power microcontroller, which samples the signal performing an Analog to Digital Conversion (ADC) and then processes the resulting data into information. The wireless connectivity is provided by two different radios: a Bluetooth Low Energy (BTLE) radio which is used to transmit the information to a remote host or a Smartphone and an ultra low power IEEE 802.15.4 radio (CC2500 by TI/ChipCon). The node is built with energy performance in mind, for these reasons power management in hardware and software is present to avoid any waste of energy. The heart rate(HR) and respiratory rate(RR) algorithms implemented directly on board are presented in this paper.

The remainder of this paper is organized as follows: Section 2 describes recent related work to the wireless body sensors node. Section 3 presents the hardware architecture of the node and its components. Section 4 details the proposed approach, describing the data processing. Section 5 describes the implemented approach, along with measurements, comparative evaluation, and validation. Section 6 concludes the paper.

2. Related works

Wearable wireless devices have recently increased the versatility and popularity of systems designed for monitoring human biomedical parameters to support a wide range of application in healthcare, sports, fitness and entertainment. In this field, research is focused specially on the wearable wireless sensor network (WSN) and Wireless Body Sensor Network(BSN). As for the WSN, the sensors nodes are designed to meet the requirements of long term operations and continuous health monitoring and can provide an early warning system or real-time emergency alerting that can be life saving. The small size required for the nodes, the low power resources and limited computing abilities are hard constraints for nodes that are supposed to have long-term life while maintaining continuous sensing.

The most popular runtime data processing in literature are for EEG, EMG, ECG monitoring. The papers [6–17] present different approaches and applications. The nodes architectures are very similar of each other and are comprised mainly of the sensors, the electronic circuit for analog to digital conversion, a microcontroller and a radio. The most used radios for the wireless connectivity with a host (typically a PC or a Smartphone) are usually Bluetooth (or recently Bluetooth Low Energy), Zigbee, or other low power radio, usually in the ISM band and using the IEEE 802.15.4 standard. In previous works researchers focused mainly on the design of sensor nodes for ECG or EEG acquisition and processing. In recent years academic and industrial researchers are proposing wearable devices which can process the data autonomously. Current trends in wireless ECG monitoring systems have produced an innovative and versatile approach to wearable textile-based monitoring systems, ECG data have been collated using smart clothes [18,19,21]. The most important modules of smart wearable monitoring technology are the wearable biomedical sensors which are attached directly on the patient or to electrode-embedded wearable garments. Wireless sensors that measure vital parameters are the most important emerging devices for improving the quality of care whilst reducing costs. In [21] a wearable ad-hoc solution for heart rate is presented. This solution is very interesting and impressive for ultra-low power of only few of μA. The NFC radio is used for the communication to cut further more the power consumption. However it lacks of flexibility and scalability, as it is not possible to modify the firmware and to use another algorithm or radio transceiver. From the analysis of these works it is notable that modern wireless technologies have a very high level of available integrated resources. These resources facilitate data manipulation and processing but on the other hand they bring very high peak power consumption that negatively impacts the well-known issue of lifetime of battery-operated devices. When added to the power consumption of the radio and microcontroller, the body sensor nodes reach quickly very high energy consumption. Nevertheless, any wearable sensing node requires accurate data processing. Many authors have investigated methods to obtain the interested measurements from physiological signals. Possible approaches vary from digital filtering techniques [23–26] to more complex techniques such as continuous wavelet transform (CWT) [28–32] and Variable-Frequency Complex Demodulation (VFCDM) [33,34].

Each method has benefits and drawbacks and it is outside the scope of this paper to give a detailed review of them. However, it is of interest to note that the more complex techniques while giving improved estimation have a higher computational complexity that is hard to justify when the interest of the application is to have a generic range and/or to track trends rather that a precise reading. Moreover, the computational cost makes these methods impractical for an implementation on ultra low power sensors. As the previous related works show, the power consumption is the key challenge of the wearable and wireless devices since the stricter constrain is the energy availability.

The node proposed in this paper has been designed to reduce the power consumption through hardware and software co-design.