Wirelessly powered miniature wearable vital signs monitor

M. Marzencki and B. Kaminska

CiBER Laboratory, Simon Fraser University,
Burnaby, BC, Canada, email: mjm11@sfu.ca

ABSTRACT

Wireless, wearable health and activity monitoring devices are becoming an interesting solution for early detection of health problems and remote surveillance of post-incident patients. While efficient and precise signal acquisition and processing are readily available, the biggest challenge in widespread adoption of wearable monitoring devices lies in their energy supply. The tradeoff between the device lifetime and its size implies that a device that is comfortably small has lifespan not allowing for prolonged use, especially if continuous data transfer is required. In this work, we propose a novel system that employs a long range inductive link to recharge a small battery on-board the wearable device. The application of wireless energy transfer in this case is motivated by comfort of use and reliability rather than necessity. In case of wireless power transfer, intermittent battery recharging is transparent for the user, thus very comfortable.

Keywords: wireless energy transfer, wearable sensor node, telehealth

1 INTRODUCTION

Up to now, healthcare has focused on treatment of life threatening problems, rather than their prevention. Nevertheless, it would be much more efficient and cost effective if health problems could be detected early in order to avoid dangerous complications. To this end, multiple projects aim at creating wearable health monitoring systems that would analyze in situ human vital signs and report detected anomalies. Such systems are usually bulky and uncomfortable. The recent progress in microelectronics however, opened way to introduction of miniature wearable devices that can acquire, store and wirelessly transmit the obtained data. Multiple solutions have been proposed to improve practicality of use of such systems. Miniaturization of wireless sensors [1–3] or implementation on flexible substrates [4] have been proposed to improve comfort of wearing. Several studies investigated the possibility of integrating the electronics and electrodes in fabrics [5]. As a result, all these systems can be comfortably worn and used. Nevertheless, given their small size and relatively high power consumption, their lifetime is very limited. Therefore, the biggest challenge in improving the usability of wireless health monitoring devices lies in their energy supply. Lifespan of current miniature devices is limited to several hours when continuous data transmission is required, or up to several days of data acquisition, if a comfortable size and weight are to be kept. The progress in battery technology, although fairly steady, cannot guarantee a breakthrough required by this kind of devices. Several alternative sources of energy have been proposed including kinetic [6, 7] and thermal [8] energy harvesting from the human body. Nevertheless, none of them is efficient enough or comfortably small for everyday use.

Wireless powering is one of the most promising solutions for extending lifetime of miniature wearable devices. This concept has been widely used in powering of implantable devices [9, 10] where battery replacement must be excluded. Most such systems are characterized by very short range of operation, where an external unit positioned on the subject body is communicating with an implanted device located just underneath. In wearable devices, the need for wireless energy transfer is driven by comfort of use rather than patient safety and cost of operation. In order for a wearable device to be really usable, no interaction should be required from the subject wearing the device. It is most prominent in cases where the senior population is monitored, where regular battery recharging may be an issue.

We propose to use resonant inductive coupling [11], where one end of the link is integrated into the wearable device and the other end is integrated in various common objects present in the proximity of the user, ranging from furniture (e.g. bed) to personal electronics (e.g. mobile phone). In this work, we focus on proving the viability of the concept of wireless recharging in the case of wearable sensing devices. We aim at creating a compact system that would transfer a power of 10 to 100mW over a distance of up to 50cm using resonant inductive coupling.

This work is organized as follows. After introduction, the proposed system is presented outlining its architecture, functionality and power consumption requirements. The proposed implementation follows with presentation of experimental results. A discussion outlines the most important aspects of this work and compares the results with state of the art. Finally, a conclusion closes this paper.

2 SYSTEM OVERVIEW

The concept of wireless energy transfer is based on non symmetrical energy availability in a system. We distinguish an energy rich device that transmits energy, and an energy restricted device that receives it. For example, a wearable node has to be miniaturized in order to be comfortably worn and thus can not be equipped with a big energy reservoir. It is therefore the energy receiving device as other devices in the system may not be as severely limited in size. Usually, a wearable monitoring device is accompanied by an external control and display device that has less severe requirements on size and lifetime [12]. Therefore, energy contained in the control device can be periodically transferred to the wearable sensor node to improve its autonomy. By implementing this approach, the user would be required to recharge one device only (the control device), while the other (wearable sensor node) would not need any maintenance. Furthermore, dedicated recharging devices can be installed in pieces of furniture in close proximity of which the user is often present. For example, we consider installing recharging devices in the back of a chair or inside a bed. Using these locations, the wearable device would be stationary in their proximity for efficient inductive energy transfer during periods long enough for battery recharging.

In the field of wireless power transfer, radiative methods have been successfully employed for powering of remote devices [13, 14], but if used on a mobile subject, this method requires complicated tracking mechanisms. Furthermore, the radiated power can be dangerous for human beings in the way [15] which is of special concern for wearable devices. The inductive method on the other hand uses resonant magnetic coupling, which means that energy is transferred between two strongly coupled devices and only slightly affects extraneous objects [11]. Recently, an efficient mid-range energy transfer has been demonstrated based on self resonance of very high quality factor coils [11, 16]. Power transfer of 60W at efficiencies of about 40% over two meters distance using cylindrical coils of radius 30cm and height of 20cm is reported. Similar approach was used by Zhu et al. [17] where power transfer of 50W at 60% efficiency is demonstrated over a distance of 1 meter using coils of 50cm in diameter. These works show that efficient mid-range energy transfer is achievable using very high quality electrical resonances. In our work we employ smaller coils to transfer lower power over distances of up to 30 cm.

3 HEALTH AND ACTIVITY MONITORING SYSTEM

Schematic representation of the proposed system is presented in Figure 1. It is composed of a wearable vital signs monitoring device interfaced with a base station providing power over an inductive link and optionally data transmission over a 2.4GHz RF link. The data transmission is implemented if the base station acts also as a data logger device.

3.1 Sensor Node

The proposed system uses a miniature wireless vital signs monitoring node developed in the CiBER laboratory [3]. It is capable of performing the following actions:

- streaming full one lead ECG signals,
- calculating and reporting heart rate,
- calculating and reporting position from a built-in accelerometer,
- calculating and reporting the current activity level of the subject,
- reporting temperature from a built-in sensor.

The system is build with a Texas Instruments System-on-Chip CC2510 containing an optimized 8051 microcontroller, an analog to digital converter and a 2.4GHz radio front-end. The big advantage of this device lies in its ability to use and quickly switch between numerous power saving modes, with current consumptions ranging from $190\mu A$ down to $0.3\mu A$. This simple, inexpensive, very low power and low footprint device performs all the computation and control tasks of the system. The average power consumption of the entire system is of 1.86mW during continuous ECG acquisition and periodic heart rate reporting and 16.6mW for complete real-time burst data transmission at 0dBm with missing packet retrieval.

3.2 Base Station

The wearable device transmits acquired data to a data logger device either periodically or upon request. The same data logger device can be used for wirelessly recharging the wearable device. The base station can be implemented inside various objects ranging from furniture (when data logging functionality is not required) to hand-held electronic devices (when both energy and data transfer is required). Use of the later is particularly convenient due to its extensive communication and computation capabilities and built-in big energy storage. This solution permits to simplify maintenance of the system. In fact, in such a case the user would

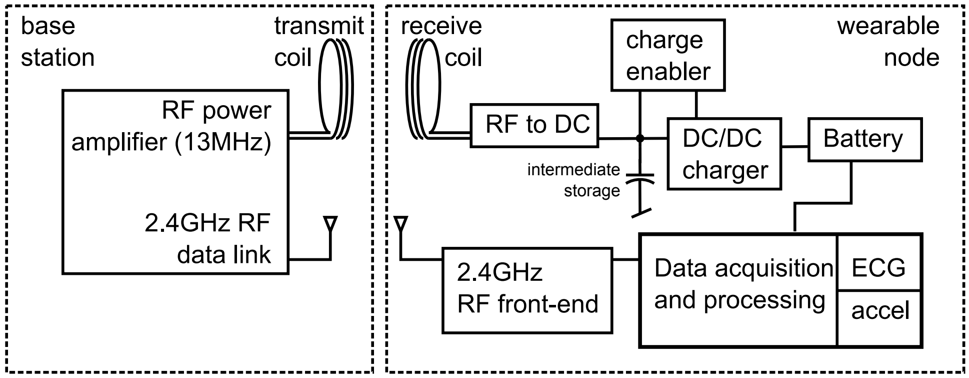

Figure 1: Architecture of the proposed system with the wearable node and the base station device acting as the energy source and optionally a data logger and control device.

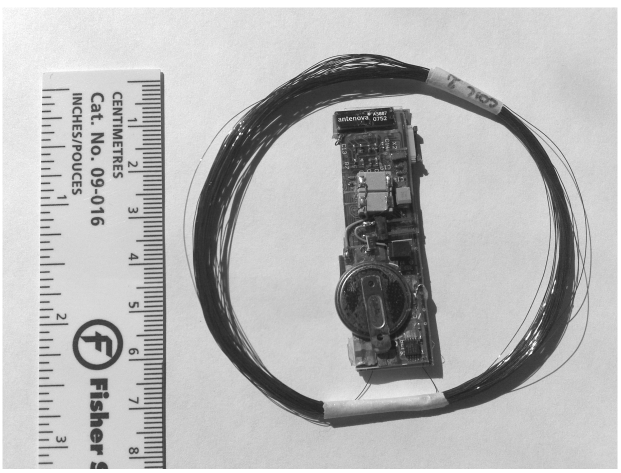

Figure 2: Miniature wearable vital signs monitoring node with wire-wound coil antenna for energy transfer

have to recharge one device only (hand-held), while the other (wearable node) would become maintenance free. Recharging of the wearable node would take place either when the control device is being used, which would be absolutely transparent to the user, or after having prompted the user to approach the control device to the wearable node triggered by a message indicating low level of energy.

4 EXPERIMENTAL RESULTS

The proposed system was built and experimentally tested in order to assess its performance for maximum distance of efficient energy transfer and relation between available power and the distance between the monitoring device and the receiver.

Figure 2 presents a photograph of the current implementation of the sensor node with integrated wire-wound coil for energy transfer.

We used standard AWG28 copper wire to create the source coil and AWG36 copper wire to create the de-

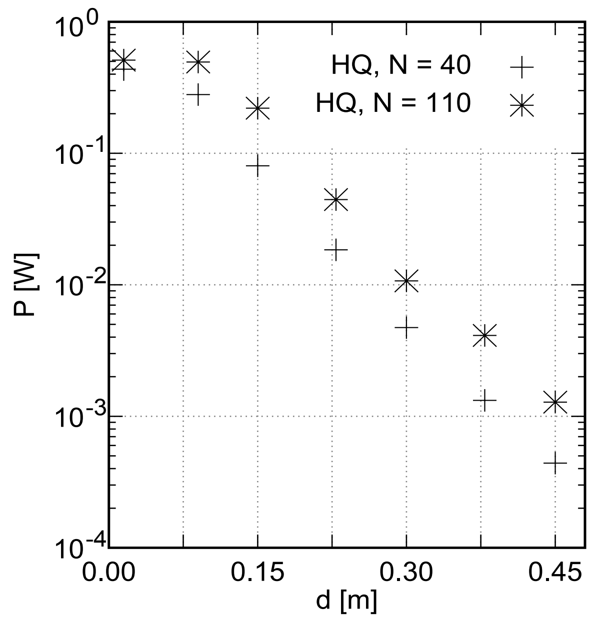

Figure 3: Power dissipated on a matched resistive load versus distance for device coils with 40 and 110 turns.

vice coil. The source coil had 60 turns and diameter was chosen equal to 10cm ($700\mu H$). The device coil diameter was 7cm (as defined for maximum values for comfortable use) and two numbers of turns were considered: 40 and 110. The data was gathered using two Fluke 8846A Precision Multimeters. The measurement procedure employed was as follows: for each distance between the device and source coils an optimal load resistance providing maximal power was sought. Thus, for each load value the frequency of operation and loading capacitor on the source coil were manually adjusted to maximize the power transferred to the load resistance on the distant device coil. The device coil was prepared with a fixed loading capacitor to have its resonant frequency close to 13MHz.

In the first place, we analyzed the amount of power that can be transferred between the base station device and a simple resistively loaded LC resonant circuit. Figure 3 presents experimental results of transferred power versus distance for the two device coils analyzed. It can be seen that the coil with more rounds (higher quality configuration) provides much higher efficiency of energy transfer. For the coil with 40 turns, the coil at $20cm$ provides a power of $4.73mW$ into a matched resistive load. For the coil with 110 turns, the power at $20cm$ is equal to $10.71mW$.

5 DISCUSSION

Providing power to miniature wearable devices is identified as the biggest challenge in their usability improvement. The presented solution consists in using inductive link for energy transfer between the wearable node and a base station device. With the recent improvements in the transfer efficiency, this solution is becoming a viable alternative to big fixed local energy sources. It is based on an assumption that the two devices used in the system, i.e. the wearable sensor node and the base station device, are highly asymmetric in the energy availability terms. While it would be very uncomfortable to replace battery or recharge the wearable device, the control device is being recharged regularly or powered from mains. Therefore, one can concentrate on maximal optimization of power consumption and energy delivery to one device, even at the expense of reducing lifetime of the other device.

The experimental results show that efficient energy transfer can be established for distances of tens of centimeters with coils of comfortable size and weight with careful tuning of operating frequency and loading. The presented system is the first reported case where long range resonant inductive coupling is used power a wearable sensor node. Compared to previous works on wireless health monitoring systems using inductive coupling, we propose a system with much longer distance of operation. In our case, the use of inductive coupling is dictated by the convenience of eliminating the need to recharge battery on the miniature wearable device rather than the possible danger for the patient as for implantable devices. Nevertheless, we believe that the reduced and simplified maintenance of the system justifies the added complexity.

6 CONCLUSION

This paper presents an innovative solution for extending lifetime of miniature wearable devices. We focus on a wearable vital signs monitoring node to analyze feasibility of the proposed solution. We have shown that the very low power consumption characteristic for modern electronic system enables to use wireless power transfer as the main energy source. The obtained results confirm that the proposed architecture can be successfully used to dramatically extend battery life of wearable devices. We show that a sensor node can be fully powered using inductive coupling and coils of comfortable size and weight when it is up to 30 cm away from the sourcing device installed in a commodity equipment (chair, bed) or in a control and display device (mobile phone). For closer distances, a small battery built into the sensor node is recharged, while for longer distances the wirelessly transmitted power reduces energy drain from the battery and thus extends the lifetime of the device.

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