A PORTABLE ECG DEVICE IN A HOME CARE ENVIRONMENT USING BURST TRANSMISSION

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Abstract: This article presents a wireless microcontrolled system for ECG home monitoring. The main particularity of the system is related to the data transmission strategy, which is intermittent to save battery power. In order to evaluate the potential of the strategy proposed to diminish power consumption, a comparison of the transmission time spent is made between a theoretical estimation and the experiments.

1 INTRODUCTION

Chronic heart patients need continuous monitoring due to the probability of a new event occurring that is harmful to their health. These patients could have better chances of recovery, mainly for psychological reasons, if they were able to be monitored at home instead of in a hospital. Also, the number of patients hospitalized could be reduced without affecting the quality of the medical care.

In that context, it is important to create conditions to allow for safe, efficient and reliable home monitoring, reducing costs and restrictions to the patient's activity and comfort.

Home monitoring is viable in the current technological environment. Even though transmission failure must still be addressed, current wireless technology allows for increasingly reliable links. Moreover, size, cost and power consumption of electronic components are lower than ever.

There are several applications for monitoring systems with wearable medical sensors. (Reisner, Shaltis and McCombie, 2004). Home patient monitoring is one of them. Different approaches have been proposed, such as: sending the data through the phone network using mobile phones (Istepanian, Woodward and Richards, 2001), (Boquete, Bravo, Barea, Ascariz and Martín, 2005); providing a terminal for the patient themselves to view data and register events (Segura-Juaréz, Cuesta-Frau, Samblas-Pena and Aboy, 2004); transmitting data through the Web (Fensli, Gunnarson and Gundersen, 2005); allowing direct use by nearby medical staff (Paim, Correa and Marques, 2004).

Existing works using wireless transmission keep the transceiver on all the time. This practice does not take advantage of the fact that the data being transmitted is usually much less than the data transmission rate.

This work presents a portable device able to acquire and transmit electrocardiogram (ECG) signal using a wireless link through a remote computer. It has been conceived in the context of a project called Telecardio, whose aim is to monitor cardiac patients at home (Andreão, Pereira-Filho and Calvi, 2006).

Our main contribution is related to the data transmission strategy. The data is stored in a memory, and only then the transceiver is activated to send all the data in a burst. This reduces battery consumption, improving the critical features of battery size, weight, and duration. These features are critical because the patients will need to carry the equipment (and the batteries) at all times, and interrupt their routine to change batteries.

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2 MONITORING SYSTEM

The proposed device for home ECG monitoring (Bumachar, Andreão and Segatto, 2006) extends battery life by transmitting in bursts. It consists in:

- A battery-powered, microcontrolled acquisition device to be carried by the patient at all times, which pre-amplifies then samples their ECG, stores it and transmits periodically;
- A receiving station that receives the data and does some processing (such as filtering, segmentation and automatic analysis), then retransmits it through the internet;
- A telemonitoring server that can receive the data of several patients, sort it, store it and make it available to authorized parties.

The system is illustrated in Figure 1.

In order to control all these tasks, an algorithm has been developed to be run in the microcontroller, as follows.

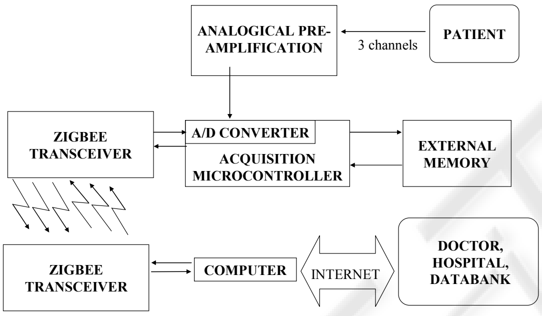

Figure 1: Monitoring system.

2.1 Microcontroller Algorithm

The embedded microcontroller spends most of the time idle, to save power. Every sample period, it is interrupted by an internal timer and samples the three A/D (analog-to-digital conversion) channels, obtaining three 12-bit samples. This data is organized in bytes and stored in internal memory, and then there is a return to inactivity.

This cycle repeats until there are 42 samples, or 63 bytes. Then a 1-byte counter is added as a header, completing a 64-bytes data vector, which is stored in the external memory using the I2C serial interface, freeing the internal memory for further samples.

The microcontroller counts these writing operations to keep track of the amount of data and, therefore, the amount of time stored. When 30 seconds of ECG are completed, the microcontroller wakes the transceiver from its sleep mode, which can take a few milliseconds. If a new data vector is completed in that time, it is properly stored in the external memory.

When the transceiver becomes active, the microcontroller repeatedly attempts to contact the receiving station until receiving an answer. The station can send to the microcontroller a transmit request or a repeat request.

After receiving a transmit request, the microcontroller will read from the external memory the oldest data packet and transmit it; after a repeat request, it will retransmit the last packet. A data packet is defined as 16 data vectors, or 1024 bytes.

While the microcontroller handles the transmission, sampling continues through interruptions, but the microcontroller no longer becomes idle. The internal memory is monitored and its content is transferred to the external memory, unless the later is being read for transmission. To avoid data loss in this situation, the internal memory buffer size is defined with a margin. Similarly, the external memory has a large margin to stand eventual wireless transmission failures.

Finally, after several transmissions, there will be no packets left in the external memory. Then, the microcontroller will answer the next transmission request with an ending request, and the receiving station will send an ending confirmation. The microcontroller will return the transceiver to sleep mode and begin data accumulation again, reinitiating the cycle.

2.2 Prototype

A prototype of the monitoring device was able to sample, packet, store and transmit three channels of pre-amplified signals.

The microcontroller, memory and transceiver used were Analog Devices' ADuC841, Microchip's 24AA515 and MaxStream's XBee respectively.

Despite the non-volatility of the memory being unnecessary, a serial EEPROM memory was selected instead of faster RAM memory because it requires less power – only the EEPROM page being written requires power, whereas RAM consumes power all the time just to maintain data.

Figures 2, 3 and 4 show the prototype.

This prototype works with a single-channel pre-amplifier to raise the very low biometric ECG signal to voltage levels that could be accurately sampled by the microcontroller's A/D converter. Since two other amplifiers are not yet available, the same amplified signal is sampled by all three channels. The amplifier contains lowpass filters and a Right-Drive-Leg terminal (which prevents amplifier saturation).

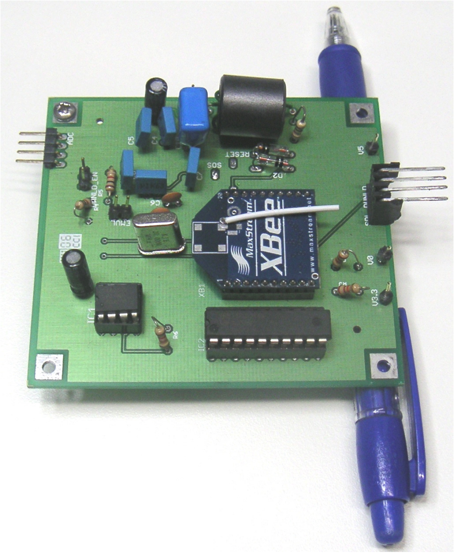

Figure 2: View of side one of the prototype.

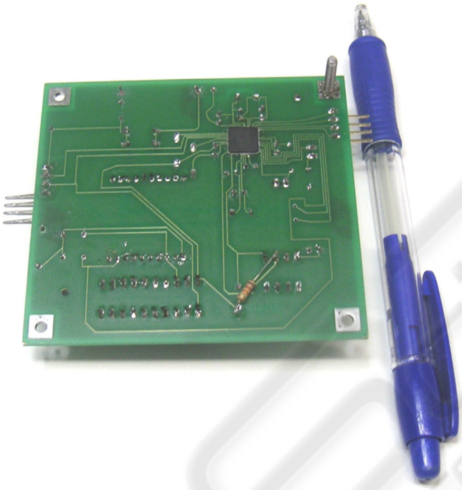

Figure 3: View of side two of the prototype.

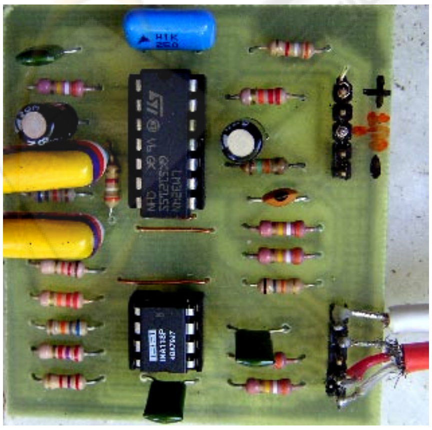

Figure 4: Single-channel amplifier.

3 TRANSMISSION TIME

The data storage time is the duration of each data storage phase, in which the acquisition device does not transmit. It has been fixed at 30 seconds.

The transmission phase lasts the time necessary to transmit all the samples taken during the transmission and storage phases.

There are three interfaces to be considered that can influence the transmission time: the I2C serial interface between the microcontroller and the memory, the UART serial interface between the microcontroller and the transceiver, and the ZigBee rf link between the transceiver and another transceiver at the receiving station.

3.1 Theoretical Minimum

The bottleneck of the transmission, theoretically, is the UART serial interface, with a rate of 115,2 kbps. Disregarding transmission overhead, acknowledgements, and processing delays (such as servicing interrupts), the transmission time will be given by the following equation:

$$T = \frac{30 \times 256 \times 3 \times 12}{115200 - 256 \times 3 \times 12} = 2{,}61 \qquad (1)$$

where 30 is the data storage time in seconds, T is the desired transmission time, 256 is the sampling frequency in Hertz, 3 is the number of A/D channels being sampled, 12 is the number of bits per channel, and 115200 is the bottleneck rate in bits per second. As a result, the desired transmission time T is 2,61 seconds, which corresponds to the transmission phase occurring 8% of the time, as shown in the following equation:

$$TP(\%) = \frac{2{,}61}{30 + 2{,}61} = 8\% \qquad (2)$$

3.2 Experimental Value

The I2C interface was implemented in software on the microcontroller's (master's) side. At first, was assumed that it was not the bottleneck, but it was so inefficient that it became the actual bottleneck, determining the transmission time of 19 seconds. Consequently, I2C interface implementation was improved, by having a timer do some counting previously done by executing useless processor instructions. However, after the I2C improvement, the device stopped functioning properly. Most data would get through to the receiving station, but not all, at a distance too short for link failure.

The device worked properly when an arbitrary delay was inserted between transfers of each byte from memory to transceiver. This delay was then calibrated to its approximate minimum value that would still allow for proper functioning.

The resulting transmission time was 5,5 seconds. It is more than double the theoretical, ideal value. It corresponds to the transmission occurring 15,5% of the time.

3.3 Discussion

The acquisition device was not able to function with transmission time lower that 5,5 seconds, that is, it did not function properly without deliberate delays that increased the transmission time to 5,5 seconds.

The microcontroller code keeps the I2C interface from getting ahead of the UART interface, that is, the next byte is read from the memory only after the last byte is forwarded to the transceiver.

The UART interface is very much slower than the rf link, and the former shouldn't overwhelm the latter. However, the transceiver was configured not to wait for any number of bytes to form an rf packet, that is, as soon as a byte is received by the UART, it is put in an rf packet with significant overhead. (This configuration is necessary to transmit one-byte control messages used for reliability.) Therefore, if assembling the packet takes too long, perhaps the transceiver's transmission buffer overflows.

At the receiving station's side, the rf link, being faster then the UART interface, could overwhelm it This shouldn't happen since all the data coming through the rf link has passed by the UART interface at the acquisition device. However, non-uniform delays due to rf packet assembling and disassembling could cause the receiving buffer to overflow.

4 CONCLUSIONS

This work presented a wireless microcontrolled solution for an ECG home monitoring system application. It was based in the concept of battery power saving through intermittent data transmission.

It was observed that in practice the transmission time is much higher than the ideal theoretical minimum. Further experimentation is necessary to discover whether it can be reduced.

The use of intermittent data transmission has opened another strategy to reduce battery consumption by setting the power-down modes of the microcontroller and transceiver, but that wasn't achieved with this prototype. For example, if the storage phase power consumption can be ten percent of the transmission phase power consumption, then the total consumption as a percentage of the transmit-all-the-time consumption will be 24%.

Therefore, it is useful to use intermittent transmission instead of transmitting all the time.

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