A Wireless System for Biopotential Acquisition: an Approach for non-Invasive Brain-Computer Interface

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Abstract—**Brain-computer interfaces (BCI) promise to be a very important tool for the handicapped people in the near future. A wireless biopotential acquisition system is proposed as a solution for true mobility during non-invasive BCI operation. Special care about noise must be taken in a signal acquisition system for biopotentials. The EEG signal amplitude ranges from a few to dozens of micro-volts and it is very low compared with the interference from mains power. Thus, a good quality signal requires an efficient interference removal. The wireless system is operating at 2.4 GHz, the maximum data throughput is 120 Kbps, the system resolution is about 4 µV, the power consumption is 0.015 W and accommodates 5 single-ended channels. The dimensions of the wireless acquisition system are approximately 5.7×4.8×2.0 cm^3.**

I. INTRODUCTION

A brain computer interface (BCI) is a real-time communication system designed to allow users to voluntarily send messages or commands without sending them through the brain's normal output pathways [1]. A BCI device allows people to communicate without movement. People can send information simply by thinking. Everybody can imagine how useful would be a system that could know accurately what the user desires to do just by reading his scalp potentials.

There are two main BCI approaches: the invasive one that is based on ElectroCorticoGraphic (ECoG) data [2] or single-neuron recording and the non-invasive one that is based on ElectroEncephaloGraphic (EEG) data [3]. In the invasive way, the signal is much cleaner of noise and the potentials locations are more evident since the electrodes are placed on the region of interest. On the one hand, the non-invasive approach is more susceptible of noise interferences and their potentials have less spatial resolution than the invasive way, on the other hand it is less traumatic and risky. Therefore the non-invasive BCI have been preferred by several implementations [4] and it is referred as BCI on this manuscript from now on.

Researchers deal with several data analysis constraints during BCI development process since the electroencephalographic (EEG) signal sources are not well known neither their brain locations [5]. Besides that, there are also some hardware limitations. Usually the EEG set-up is composed of electrodes that are plugged in a biopotential acquisition system which will amplify the EEG signal and convert it to digital format. This acquisition system is usually connected to a computer that stores and analyzes the data collected and implements a control algorithm that outputs a device command. This system architecture hampers a BCI application that requires user mobility, due to the fact that the EEG measuring device must be connected to a computer. Even in clinical applications, like epileptic patients monitoring, the data must be recorded for several hours and sometimes for several days. This mobility restriction has the potential for tilting the obtained results.

A wireless platform that monitors a user with no mobility restrictions is of most benefit on these cases. Some wireless neural measurement systems have been proposed in two different approaches: a custom micro-fabricated design [6] versus a commercial-off-the-shelf (COTS) PC technology [7]. Lately, a trade-off between the previous two approaches has been proposed. This approach able a wireless recording and telemetry system to achieve a balance between low-noise and low-power signal transmission, data communication, and networking performance [8].

The platform proposed in this study follows an approach comparable to the last one cited above. It is based on radio modules at 2.4 GHz band and on an instrumentation system prototype (to collect the EEG signals from Ag\AgCl electrodes). In order to get low-noise signals with low-power consumption, shielded electrodes as well as low noise/low power parts that are suitable for medical applications were used. This acquisition system follows some guidelines required for a safe medical device. It is battery powered.

An overview of system design, hardware and software as well as the wireless link are presented. The experimental results and system specifications are used to make a performance comparison between existing methods of wireless neural recording systems[8] and our device.

II. SYSTEM DESIGN

As any acquisition system, its design can be split in two major blocks: hardware and software.

The main goal of the acquisition system is to collect the biopotentials of the electrodes. The wireless transmission and reception are done with 2 modules (also called motes) that are described in section IV. The emitter mote runs software components that were developed to control the ADC, to handle all the communication procedures with the ADC, to build the

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data packet, to implement the medium-access control (MAC) protocol and to send the data packets wirelessly to the receiver mote. The medium-access control protocol allows high-data throughput.

The receiver module provides the connection to the PC serial port. The PC receives the acquired data through software server-client architecture applications. As mentioned above, an application is collecting data from the PC serial port and making them available through a socket connection. One or more client applications can be connected to the server application and receives all data packets in real-time. The top-level diagram of the whole setup is depicted in Fig. 1.

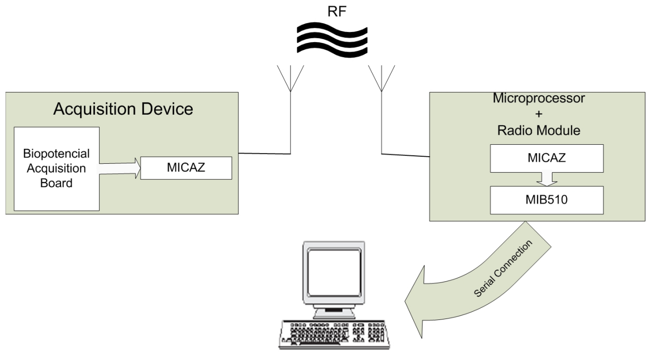


Fig. 1. System Setup Diagram

III. HARDWARE

The acquisition platform is based in a single-ended structure where each of the amplified signals is sensed differentially by a pair of electrodes. The potential of each electrode is 2.5 V level-shifted through a summing non-inverter amplifier. This amplifier scheme is based on an AD822 which is a part with 2 single-supply, rail-to-rail FET-input operational amplifiers (Opamp). They are low-power and suitable to battery-powered medical instrumentation. Its input impedance is about 100 TΩ which implements a high-impedance input stage. Each of the 5 channels (at instrumentation amplifier) is measured as a difference of potentials between itself and the reference channel of the subject (SGND). So, the Opamp output of the SGND electrode is connected to all the inverting inputs of the instrumentation amplifiers (IA). The IA in this instrumentation system is the part AD627. It works in single and dual-supply although 5 V is the only power supply potential available in this system. It allows rail-to-rail voltages and is suitable to EEG and ECG medical instrumentation applications. In this case, the IA gain is 10, even though it is configurable through a resistor. The reference potential of each channel signal at the IA output is 2.5 V, instead of the system ground, since the electrode potentials were level-shifted at the high-impedance input stage. Then the signal is band-pass filtered to eliminate the noise interference from the surrounding environment as well as the interferences induced by the other components. The filter circuit block has a band-pass filter of 0.5-100 Hz and amplifies the signal 100 times. The cut-off frequencies of the filters are configurable but they are commonly selected as 0.5-40 Hz for BCI applications. These filters are implemented again with the AD822 Opamp. The resulting signal after 2 amplifications must be in the range of ADC (AD7714) and the power supply voltage which is 0 to 5 V. This low-power ADC has a resolution conversion of 20 bits (maximum). The power supply voltage is provided by the step-up implemented by the ADP3000 from the 3 V of the 2 AA batteries.

The resulting signal from each of the 5 channels is converted to digital format using the ADC at a data sampling rate of 1000 samples/s (maximum values). It digitalizes 5 single-ended signals between the outputs of the IA and a common-reference which is the 2.5 V. The ADC data registers are available for reading through the SPI interface. This interface is implemented with 3 wires: DATA(DATA_IN/DATA_OUT), /CS (chip select) and SCLK (serial clock). The MICAz mote manages the ADC configuration registers as well as reads its data register. Then the data packets are assembled and sent by a wireless connection to another similar mote which is connected to a computer. The Fig. 2 illustrates the signal acquisition board diagram.

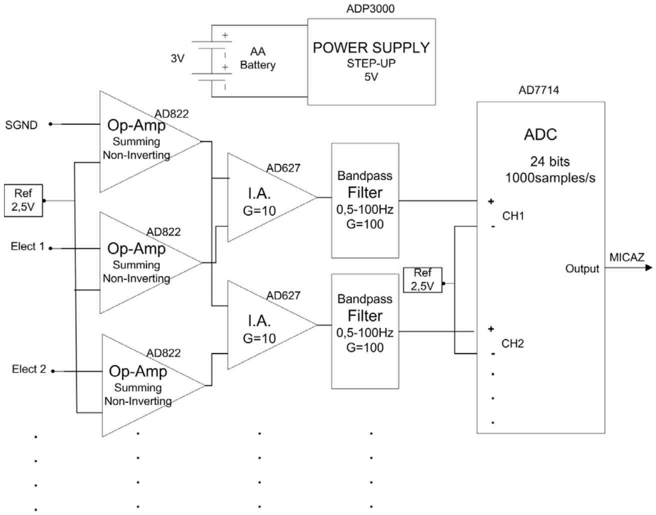


Fig. 2. Diagram of the biopotentials acquisition board.

IV. WIRELESS LINK

The wireless connection between the measurement device and a computer is based on two radio modules MICAz, several times mentioned as motes, like the one presented in Fig. 3, that are produced by Crossbow Technologies, Inc. [9]. This device is used due to its flexibility on sensor networking that able us to implement different network architectures ranging from simple peer-to-peer to more complex architectures like mesh, also known as multi-hop architectures. Each mote operation is supported by an operating system, called TinyOS, with a component-based runtime environment designed to provide support for embedded systems with a minimal amount of physical hardware to keep the system size as small as possible (Fig. 3).

Fig. 3. Micaz mote (radio module).

A MICAz mote is used as a data transmitter. This module receives the data from the biopotential acquisition board. This board is responsible for picking up the biopotentials from the electrodes, amplify, convert them to digital format and send the data to MICAz mote. The other mote is used as a receiver, and as interface to an MIB510CA (also produced by Crossbow Technology, Inc.) that provides a serial connection between the receiver mote and the computer. Fig. 4 presents the block diagram of the MICAz mote. Data is processed by an Atmel Atmega128 microprocessor with 512 kB of flash memory. This processor has analog and digital inputs/outputs that enable this module to communicate with an extra instrumentation board. I^2C and SPI interfaces are also provided. The Chipcon CC2420 radio chip, which is IEEE 802.15.4 compliant, receives or transmits the data. When the two 1.5-V dry-cell batteries are installed, the MICAz has $5.8 \times 3.2 \times 1.5$ cm^3 as dimensions. The receiver mote is plugged in a MIB510CA which extends its interface capabilities through a RS232 serial communication with the computer serial port.

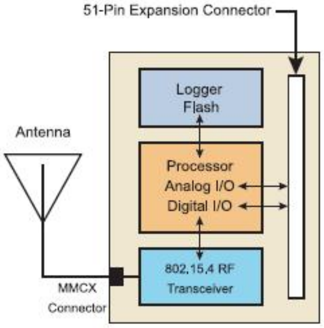


Fig. 4. MICAz block diagram.

V. SOFTWARE

The TinyOS components are developed in the nesC language that is an extension to C, designed to embody the structuring concepts and execution model of TinyOS [10].

Some components have been written to implement data-acquisition and wireless media-access control protocols for the MICAz. The receiver mote will operate on a standard TinyOS component to receive packets and broadcast them via a serial port and radio.

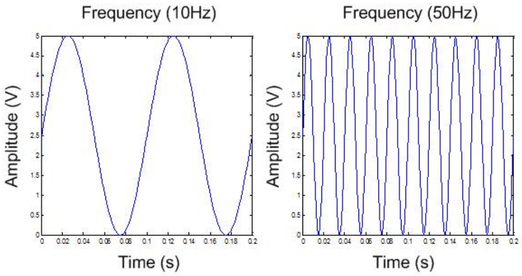
The data-acquisition component implements a five channel signal-acquisition and an algorithm that assemble each data block that will be sent. The MAC protocol is done on a buffer length basis. Each data block is composed of the header and data fields. The header has the source mote ID, the last sample number, and the cyclic redundancy check (CRC). The data field is fulfilled with 20 samples of 20 bits for every channel.

The data is collected on the computer by a C-based program that was designed to act as raw data server through a TCP/IP port and makes it available to another C-based client application that runs locally or remotely. The server-client application architecture makes this system more flexible and able one to monitor remotely the data that is being collected.

VI. EXPERIMENTAL RESULTS

A few performance tests were done with the first prototype of the proposed acquisition system. In order to evaluate the acquisition system performance in terms of bandwidth, pre-synthesized sinusoidal signals with different frequencies were injected in the channel inputs. The graphs presented in Fig. 5 able us to evaluate the hardware and software performance of the receiver block in reconstructing the acquired signal. As it can be seen in Fig. 5, the 10 Hz signal seems more sinusoidal than 50 Hz because it has more sample points per cycle.

Although this system is already battery-powered, it can not be considered a safe medical device yet. Likewise, it was not tested in real EEG acquisition tests since some human safety protection circuits need to be implemented first.



a) b)

Fig. 5. Reconstructed signals at the receiver block for 2 different frequencies: a) f = 10 Hz; b) f = 50 Hz.

TABLE I
Wireless Microsystems Performance Comparison (Adapted from [8])

Institution	U. Minho	UCLA	UCLA	Michigan	Duke	Aachen	Tokyo U.	Clev.Med.
Number of Data Channels	5	2	1	3	16	2	1	8
Telemetry Link Frequency	2.4 GHz	916 MHz	3 GHz	88-108 MHz	2.4 GHz	88-108 MHz	80-90 MHz	902-928 MHz
Communication Scheme	802.15.4	FSK	Analog FM	TDMA	802.11b	FM Stereo	Analog FM	FSK
Power Supply	3.0 V(AA)	3 V	Inductive	±1.5V	3.3V and 5V	±1.4 V	3V	9V
System Clock Frequency	7.37 MHz	4 MHz	-	70-138 KHz	66 MHz	-	-	-
Detectable Signal	4 µV	0.06-15 mV	0.015-15 mV	0.1-5 mV	-	-	-	-
Detectable Frequency	500Hz	240 Hz	10 KHz	10 KHz	-	-	-	-
Dimensions (cm^3)	5.7×4.8×2.0	2.6×2.6×1.8	1.4×1.2×0.4	1.8×1.3×0.16	5.1×8.1×12.4	2.5×1×0.5	1.5×0.8	6.4×5.1×1
Connection with probe	External	External	External	Integrated	External	External	External	External
Reference	This work	[8]	[6]	[11]	[7]	[12]	[13]	[14]

VII. CONCLUSION

This work introduces an acquisition system for biopotentials with some cut-of-edge technology parts as an approach to BCI applications. The wireless system was developed for a transmission frequency of 2.4 GHz, a maximum data throughput of 120 Kbps, the system resolution is about 4 µV, power consumption of 0.015 W and accommodates 5 single-ended channels. Its dimensions are approximately 5.7×4.8×2.0 cm^3. The developed acquisition system can be compare with other existent platforms on Table I.

As future work, further test should be done on this prototype in order to evaluate the overall performance of the acquisition system. The noise interference immunity can also be improved through an electrodes shielding drive circuit and a subject common voltage drive circuit; similar to the common right leg drive circuit on ECG acquisition systems. As a BCI tool it would also benefit from a higher number of channels, reduced dimensions and digital inputs that could be used for data synchronization on evoked-potentials.

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REFERENCES

[1] B.Z.Allison, "P3 or not P3: Toward a Better P300 BCI." 2003.

[2] E.C.Leuthardt, G.Schalk, J.R.Wolpaw, J.G.Ojemann, and D.W.Moran, "A brain–computer interface using electrocorticographic signals in humans," *Journal of Neural Engineering*, vol. 1, 2004, pp. 63-71.

[3] N.S.Dias, D.Klayton, M.Liu, V.Nguyen, D.Wu, W.X.Yan, M.Yen, Y.Zhao, P.M.Mendes, J.H.Correia, P.M.Cammer, and S.J.Schiff, "Brain-machine interface for wheel chair control," *SFN Neurosc Meeting Planner*, 2006.

[4] E.Donchin, K.M.Spencer, and R.Wijesinghe, "The Mental Prosthesis: Assessing the Speed of a P300-Based Brain–Computer Interface," *IEEE Transactions on Rehabilitation Engineering*, vol. 8, no. 2, pp. 174-179, June2000.

[5] N.S.Dias, P.M.Mendes, and J.H.Correia, "Subject age in P300 BCI," Arlington, Virginia, *Proc. 2nd IEEE Int Conf Neural Eng*, 2005, pp. 579-582.

[6] P.Irazoqui-Pastor, I.Mody, and J.W.Judy, "Transcutaneous rf-powered neural recording device," *Proc 2nd Conf EMBS/BMES Conf,* 2002, pp. 2105-2106.

[7] I.Obeid, M.A.L.Nicolelis, and P.D.Wolf, "A multichannel telemetry system for single unit neural recordings,"*J. Neur. Methods,* vol. 133, 2004, pp. 33-38.

[8] S.Farshchi, I.Mody, and J.W.Judy, "A TinyOS-Based Wireless Neural Interface," *Proc 26th Int. Conf. EMBS*, 2004, pp. 4334-4337.

[9] "Crossbow Technology, Inc.," *http://www.xbow.com.*

[10] D.Gay, P.Levis, D.Culler, and E.Brewer, "nesC 1.1 Language Reference Manual," 2003.

[11] P.Mohseni and K.Najafi, "A wireless FM multi-channel microsystem for biomedical neural recording applications," *IEEE SW Symposium on Mixed Signal Design*, 2003, pp. 217-222.

[12] A.Nieder, "Miniature stereo radio transmitter for simultaneous recording of multiple single-neuron signals from behaving owls,"*Journal Neuroscience Methods,* vol.101, 2000, pp. 157-164.

[13] S.Takeuchi and I.Shimoyama, "An RF-telemetry system with shape memory alloy microelectrodes for neural recording of freely moving insects," *1st Int EMBS Conf Micro-Tech,* 2000, pp. 491-496.

[14] M.Modarreszadeh and R.N.Schmidt, "Wireless, 32-channel, EEG and epilepsy monitoring system," *Proc 19th Int. Conf. IEEE EMBS*, 1997, pp. 1157-1160.