WIDEBAND WIRELESS LINK FOR BCI CONTROL
100 kHz – 8/16 Channel for High Resolution EEG

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Abstract: This work presents a solution to obtain a wireless biopotential acquisition system with high data rate. Wireless systems are currently emerging with the possibility of being used for monitorization of several physiological parameters. However, most of the solutions are based on standard wireless systems. Besides the wireless throughput limitation, those systems are also limited in their software solutions and data acquisition capabilities. A trade-off solution between commercial of-the-shelf and custom design was explored by interfacing a MICAz with external instrumentation, while maximizing the rate of communication. The wireless system is being used for BCI control, operates at 2.4 GHz (Zigbee compliant), with a data rate of 250 Kbps for wireless link, and up to 1 Mbps for serial communication. Signals down to about 23 µV can be detected, and 8/16 single-ended channels are provided with 100 kHz sampling rate.

1 INTRODUCTION

The use of wireless sensor networks to assist in biomedical applications is being pursued by many researchers and will become available as soon as the required sensors and network solutions are made available (Schwiebert *et al.* 2001). However, before turning it into reality there are a few challenges to overcome.

The system must have low power consumption and the network nodes must operate under limited computation. Also, since these systems must operate in the human body, they do have some material constraints. Moreover, continuous operation is required, with high robustness and fault tolerance capability (Schwiebert *et al.*). Recently, the widespread availability of low power sensor devices with physiological monitoring ability is pushing researchers to include them in smart suits that can be used to monitor biological signals in different situations. Their application ranges from monitorization embedded in space suits (Simons *et al.* 2004), to monitorization during jogging activity (Marculescu *et al.* 2003).

However, the requirements of sending only cardiac or respiratory rhythm data are not enough anymore for modern monitorizing systems. Today, in many monitorization devices, it is necessary to route all the acquired data for storage and further processing. The development trend on physiological data acquisition is demanding more and more available bandwidth. As an example, the Brain-Computer Interface (BCI) operation, demands several electroencephalogram (EEG) channels with large bandwidth, which leads to large information amounts handling for feature and artefact extraction.

BCI is trusted to be a very useful tool for impaired people, both in invasive and non-invasive way. Although subjects using invasive approaches usually show evidence of better device control than non-invasive method users, it is barely preferred due to the high risk involved in its research and practical implementation. BCI has the potential to enable people to control a device with their brain signals. In several studies, different BCI approaches have been tested that enable impaired people to communicate and control specific devices (Wolpaw et al. 2000).

This paper will start with the presentation of the hardware platform that was used in this work. Afterwards, the requirements for physiological data acquisition for BCI are introduced, as well as the required hardware modifications. After highlighting the limitations of the available platform, a solution is proposed to overcome them and the obtained results are presented.

2 WIRELESS BCI

The BCI system is mainly made by four software/hardware modules: (1) EEG signal acquisition, (2) features extraction, (3) translation algorithm, and (4) actuator and feedback system.

The system that is being used for BCI records EEG data using a Labview platform, which receives data from a BrainProducts® Quickamp through a socket connection. The Data are digitized at 250 Hz and passed through a 6th order (48 dB per octave) band-pass Butterworth filter of 1-50Hz. This platform extracts the subject specific features, provides feedback and graphical interface to subject.

There are many challenges to be solved before BCI systems can show their full potential. A wideband low-power wireless acquisition platform is of most relevance for BCI operation. Fig. 1 shows a possible solution for a wireless BCI system. The presented solution uses a ZigBee link to transmit the EEG signals.

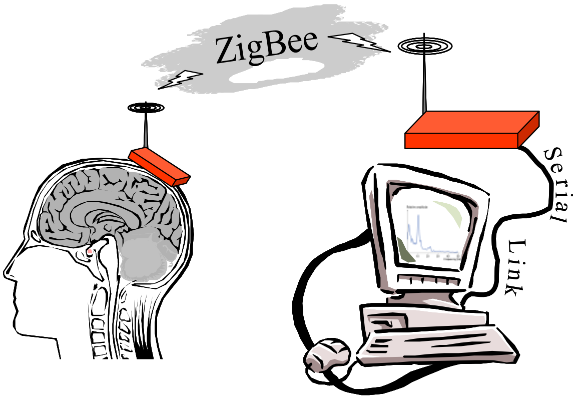

Figure 1: Wireless BCI system under development, (red modules are the target of this work).

2.1 Wideband BCI

A BCI is usually based on the ongoing rhythms of EEG signals. Those rhythms are the so called delta (0.5-4 Hz), theta (4-7.5 Hz), alpha (7.5-13 Hz), beta (15-20 Hz) and gamma waves (20-42 Hz). A bandwidth of 100 Hz would suffice for the acquisition of these potentials. However, during BCI operation, the reactivity of a rhythm to a mental task is usually identified in power spectra that are calculated using the FFT algorithm.

A good BCI control, from the user point of view, is a system with real time feedback. Any action will happen as soon as the user thinks about it. To obtain this, the system should collect as much data as possible in the shortest period of time, limited by the spectral resolution required. In this way, for a specific time window, the higher the number of sampled points, the higher is the spectral content in the calculated spectra. Once 1000 samples per second are recorded, the FFT of a 1 s time window achieves 1 Hz resolution in the frequency domain, together with a spectral content up to 1000 Hz. This sampling rate able the acquisition system to track surface EMG (2-500 Hz bandwidth) signals in order to detect task related muscle activity (Prutchi and Norris, 2004), since a BCI system is supposed to operate in the absence of muscle activity.

BCI systems can be greatly improved if more complex and faster algorithms can be used but this would require routing all the available data to a powerful computing system. The acquisition systems are, due to power saving requirements, very limited to perform this task.

2.2 Wireless Platform

One key element required to implement a wireless BCI system is the wireless platform. There are many solutions to implement it but the MICAz is a very popular one. This platform allows easy implementation of a wireless sensor network formed by individual wireless nodes. Fig. 2 a) shows the node core available for system development. This core includes the microcontroller, the ADC with 10 bits resolution, the ZigBee wireless interface, and the serial interface.

The microcontroller is the ATMEL Atmega128, running the TinyOS operating system. The micro provides access to the ADC, allowing data acquisition at 76.9K samples/s, with a resolution of 10 bits, from a maximum of 7 differential or 8 single-ended channels. The acquired data can then be routed trough the wireless ZigBee link, which allows a throughput of 250 kbps. The other option is to route the data through the serial interface. It uses a RS-232 link with the maximum data rate of 115.2 kbps.

2.3 Data Acquisition

The system can use three different node types, as shown in Fig. 2. The first is the standard wireless platform (Fig. 2-a)), which has a microprocessor with a built in analogue-to-digital converter (ADC). This device allows a maximum data transfer rate of 115.2 kbps. This limitation comes from the serial port connection (RS232), where the PC USART is limited to this speed.

When more resolution is required, it is necessary to use an external ADC. This is required for high resolution EEG and ECG, e.g., to enable the

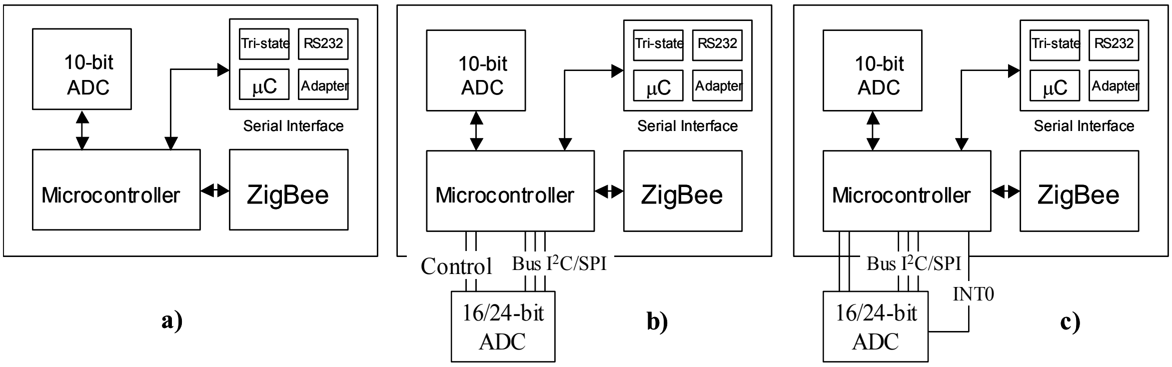

Figure 2: Wireless nodes involved in the physiological data acquisition. a) with internal ADC; b) with external ADC driven by software interrupt; c) with external ADC drive by hardware interrupt.

recording of EEG signals for BCI. For the second node type it the AD7714 ADC was selected for external operation, connected to the Mote I2C bus using a serial link with the SPI port available in the ADC. This solution allows 16 or 24 bits of resolution, with a maximum sampling frequency of 1028 samples/s. However, the data acquisition from the external ADC requires the use of commands from the operating system, the TinyOS. Due to operating system timings, the maximum sampling speed is 4000 samples/s. In this way, it was necessary to implement the third solution, which is a modified version of solution two. Instead of implementing all the external ADC control by software, the time critical tasks were implemented using hardware interruptions. With the third node type it is possible to sample the analogue channels at 8K samples/s, with 16 or 24 bits of resolution. The system limitation is on channel switching, made by software, which takes 3 ADC conversion periods to change between channels, due to resettling of the sigma delta modulator and digital filter.

To overcome this switching limitation, the use of the ADS8345 is proposed. It is an 8-channel, 16-bit, sampling Analog-to-Digital (A/D) converter with a synchronous serial interface. This ADC allows data acquisition from 8 channels at 100 kHz. The channel switching time is only 500 ns, and typical power dissipation is 8mW at a 100kHz throughput rate.

2.4 Data Routing

After solving the problem of data acquisition, it is required to send the EEG data to the host station. This requires a wireless link and a RS-232 link. The first hop will be the wireless link, a ZigBee link with a data rate of 250 kbps. If we consider sampling at 1 kHz, 8 channels, and 16 bits per sample, we have an overall data rate requirement of 128 kbps. This means that the wireless link will be enough to support it.

After receiving the data, the base station needs to route it to the processing unit, a PC. This is done using the RS-232 interface. This means we have a bottleneck in the system since the RS-232 will allow a maximum data transfer rate of 115.2 kbps. However, the microcontroller Atmega128 allows the configuration of his RS-232 port to operate at 921.6 kbps, and it is also possible to use a RS-232 to USB interface, having the possibility to achieve a maximum data rate of 1 Mbps. Considering this, the bottleneck will be on the ZigBee link, but we have then a bandwidth of 250 kbps.

3 PLATFORM PERFORMANCE

3.1 Data Acquisition

In the second solution (fig. 3 b)), the bottleneck is the software driven interruption. To test the maximum sampling frequency, a timer was implemented and each sample was sent together with its time stamp. We have found that the smallest sampling time, Ts, is about 1s (with a 2.5 MHz crystal). Thus, it is not a timer problem, since when the Ts was reduced below 1ms, the system started to fail on the delivering of some data points. In this way, the system does not allow to obtain all the signals at maximum sample rate. The third solution (fig. 2-c)), with the hardware driven interruption, was able to read 16 bit samples at a maximum data rate of 1028 samples/s. This makes an overall bit rate of 131584 bps, which is not a problem for the ZigBee link. However, the data was not reaching the host station, despite the serial configuration of almost 1 Mbps.

3.2 Serial Link

To test the maximum speed possible with this link, it was used the solution of Fig. 2-c) and the INT0 line was used to trigger the data transmission. Instead of sending data from the ADC, the data was generated and transmitted through the system. To detect the wrong samples, each sample was generated from the previous, by adding a fixed amount. In this way, each time a sample was missed, the difference between two consecutive samples allowed the detection of a missing sample. The results are shown in Fig. 3 and Fig. 4. It shows the effect of increasing the sample rate, with the nonzero values representing instants where data packets (of 10 samples) were lost.

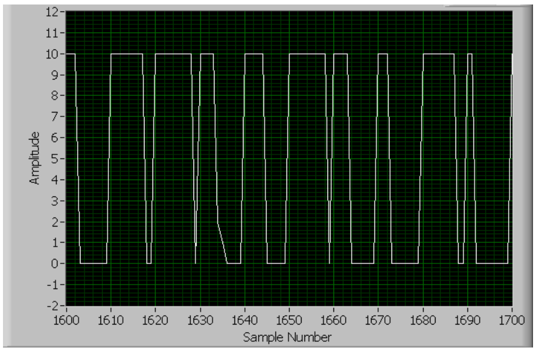

Figure 3: Error plot when data is sampled at 3.95 kHz.

The previous figure shows the received samples when the interrupt signal was set to 3.95 kHz. This corresponds to a total bit rate of 113.76 bps. From the plot, we can see that some data values are corrupted but the system is able to proceed with the transmission of correct values.

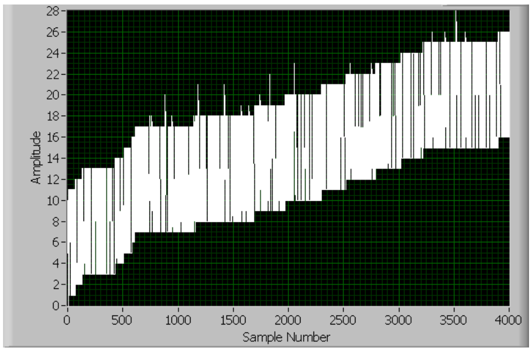

Figure 4: Error plot when data is sampled at 4.3 kHz.

In the previous plot, the overall data rate is 123.84 kHz and we can see that the system is not able anymore to recover and transmit correct values.

The microcontroller associated with this block, which controls the programming steps of the main microcontroller, also allows 1 Mbps and was not the problem. The bottleneck resides on the voltage adapter, responsible for the conversion between PC voltage levels to the micro voltage levels.

This is the MAX3223, which guarantees only 120 kbps of throughput. Our proposal is to use the MAX3223E, fully compatible with the available board, which guarantees a 250 kbps throughput. If required, another adapter for achieving higher data rate can be used. However, the ZigBee link will limit data rate to 250 kbps.

4 CONCLUSIONS

A solution to obtain a high date rate wireless link for physiological data acquisition was presented, operating at 2.4 GHz, with a minimum detectable signal of about 23 µV, and power consumption of 15 mW. The solution is based on a MICAz mote and is used for external ADC management as well as transmitting the acquired data via wireless link to another mote connected to a computer's serial port. The written TinyOS components detect the end of conversion by the ADC via external interrupt, avoiding sampling jitter, and perform read and write operations on its registers through the SPI interface.

This solution was tested for BCI control applications. With the proposed solution it is possible to acquire data from 8/16 channels at 100 kHz sampling frequency, with a data rate limit of 250 kbps.

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