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Real-time EEG signal processing based on TI's TMS320C6713 DSK

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Abstract

As one of the most powerful DSP products of Texas Instruments, the TMS320C6x DSPs have been used in a variety of areas in industries for real-time signal processing applications (e.g., communication, radar system, hearing aid etc.), and in research agencies for developing advanced algorithms and prototyping of a DSP system for specific applications. In education, the C6x DSPs were also widely used as a tool for bridging the gap between the digital signal processing theory and practical applications. The hardware-based laboratories have been successfully integrated into the digital signal processing course at many universities. However, most labs were designed only for very common signal processing problems such as the FIR/IIR filter design, FFT and so on. In this paper, a system for real-time EEG (electroencephalograph) signal acquisition, processing and presentation was proposed and will be implemented with the Texas Instrument's TMS320C6713 DSK being used as the hardware platform. As a practical application of C6713 DSK in biomedical signal processing, this project is designed as a complement of the current DSP laboratories of the Digital Signal Processors course for senior level undergraduates/graduates in Biomedical Engineering Technology Program (BMET) at the university. After the completion of the project, students are expected to be able to understand the scheme of a real world DSP system, process EEG signals for specific applications and gain the experience in processing the real world signals. In addition, this project is also intended for preparing the motivated high level students for future career in biomedical signal processing areas.

I. Introduction

As a core course of the BMET at the department of Engineering Technology at the xxx University, the **Digital Signal Processors (ENTC 4347)** introduces both the basic and advanced digital signal processing theories as well as the hands-on experience of developing signal processing applications on the DSP board. A variety of research works on the education of the Digital signal processing have proven that the introduction of the DSP board into the education not only helped the students understand the abstract and complex DSP concepts and algorithms, but also brought the sufficient practical skills in real-time implementation of DSP algorithms[1]-[5]. That is why the digital signal processors were introduced into our DSP educations. As many other universities, the current course laboratories covered the very basic digital signal processing problems such as FIR/IIR (Finite Impulse Response/ Infinite Impulse Response) filters design, Fast Fourier Transforms and so on. Although some author proposed advanced DSP laboratories related to specific applications such the biomedical signal processing, those labs still laid on the level of off-line data acquisition [3]. To help students understand the scheme of a real world DSP system (from data acquisition, signal processing, to output presentation), gain the experience in processing real world signals and to encourage the motivated undergraduate students to involve in some research projects as a beginning researcher, an EEG (Electroencephalograph) signal acquisition, processing and presentation system based on the TI's TMS320C6713 DSK hardware was proposed and will be developed as a pilot study. In the future, this project will be merged into the current DSP course laboratories to benefit the future students in studying the DSPs, and also will be upgraded as a future research project which will involve more students who are ambitious in the digital signal processing careers.

The TI's TMS320C6713 DSK was chosen as the platform of our project mainly because of the two reasons. First, the Texas Instrument Company is the company with leading technology of the development and production of DSP processors, education and training based on TI's DSPs will make the students have a good chance to meet the most advanced DSP technologies when entering their jobs. The second reason is that TMS320C6713 DSP is a feature-rich, high-performance device that is widely used in industries. The educational platform, TMS320C6713 Digital Signal Processing Starter Kits (DSK) is a low cost development platform which is ideal for educational purpose. The DSK comprises a small circuit board containing a TMS320C6713 floating-point digital signal processor (DSP) as well as other supporting functional units. It comes bundled with the Code Composer Studio C/C++ Integrated Development Environment (CCS IDE) for easy program developing, debugging and execution [6]. In addition, the CCS includes the Real-time Data exchange (RTDX) allowing for PC host based file I/O, graphing and other analysis tools which are useful for signal display and FFT analysis. A lot of third party software such as the MATLAB link for CCS developments tools and LABVIEW which have powerful displaying and data analysis tools also support the problem design in DSPs. The frameworks code of DSP written in C provides a software platform allowing the developer to concentrate on the implementation of DSP algorithms [1]. The framework code is standard and easy to make modification according to different applications. Once the framework is understood, the students can easily proceed to writing C code to implement DSP algorithms.

EEG signal carries the information of brain activities which in turn can be estimated and predicted by extracting the information contained in the EEG signals through well-developed signal processing algorithms [7]. In recent years, EEG signal plays an important role in the diagnosis of brain and mental diseases, anesthesia depth monitoring, sleeping test, as well as the brain machine interface and so on. Most of the applications require the real time processing of the EEG signal for the purpose of diagnosis, monitoring and control. EEG signals can be recorded by placing some electrodes properly on human's scalp [7-8]. However even well placed and designed electrodes are used for EEG signal recording, many kinds of noises could be recorded. Noise in EEG may include: eye movement, patient or object motion artifacts, EMGs (electromyogram) which is an electrical signal caused by the muscle motion, power line interface. So noise cancelation should be before any other EEG signal processing algorithms. In addition, the EEG signal spectrum will demonstrate different characteristics when the subjects are in distinct status such as deep/light anesthesia, deep/light sleeping etc. [8]

The EEG signal was chosen as the target signal to be processed in the proposed project because this is a DSP course mainly for BMET students at the University. EEG signals found many applications in the biomedical field, so learning how to acquire, identify, and process the EEG signals and the operation of the corresponding instruments and devices are very important and meaningful for a BMET student. This project can partially assistant the students in achieving such kind of goals.

The remaining of the paper is organized as the following: the second section will give details about the system hardware and software. The third section introduces some background information about EEG signal processing. The forth section will discuss the plans of how to implement the system and make it work. The last section will be the summary of the main points of this paper.

II. Hardware and Software of the System

The complete system consists of:

1) an EEG data acquisition device,
2) a host PC that runs the software (Biopac Hardware API, MATLAB, CCS) for program developing, results displaying, and data exchange with the DSP and data acquisition devices,
3) a TMS320C6713 DSK board as well as its supplements for implementing the EEG signal processing algorithms.

a. EEG signal acquisition device

There are a great amount of commercially available EEG signal acquisition devices in the market, the price of them ranges from a few hundred dollars to being over 10 thousand dollars depending on the functionality of the devices such as the number of acquisition channels, the available embedded signal processing functions etc. For education purpose, it is not practical to use the very expensive instruments. Instead, those devices which are inexpensive while still works well for data acquisition are always our first choice. Therfore, two EEG data acquisition instruments will be considered in our project: The MP36 biomedical signal acquisition system of Biopac System Inc. (around $3,000, available in our lab but serves for another course in the BMET program). Another EEG acquisition device in consideration is Modular EEG which costs around 3 to 5 hundred dollars but you have to buy the components and design your own device. There is a lot of information on internet discussing how to make a Modular EEG device [9]. This device is less expensive and affordable by our grant (our project is financially supported by the university student-faculty collaborative grant).

Figure 1 Four channel modular EEG

Figure 2 Biopac MP36 4 channel biomedical signal acquisition system

b. TMS320C6713 DSK board

The TMS320C6713 DSK board is a complete DSP system [6]. The board is with an approximate size of 5×8 in.. The board diagram and the board areshown in Figure 3 and Figure 4.

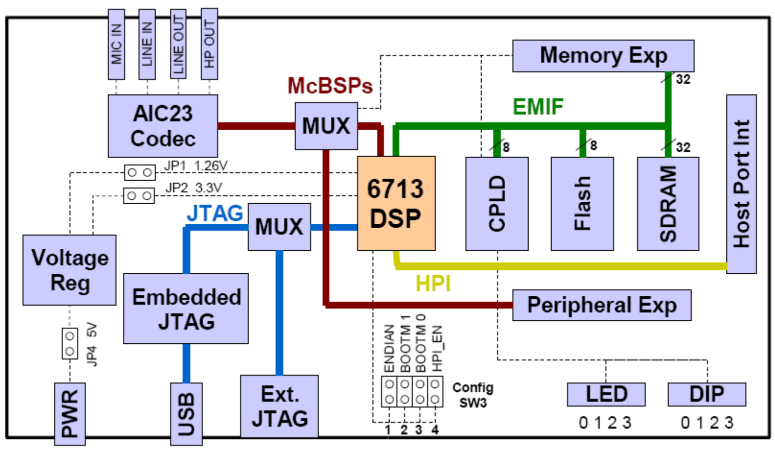

Figure 3 A basic block diagram of C6713 DSK

The C6713 DSK comes with a full compliment of on-board devices that suit a wide variety of application environments. Key features include:

- A TMS320C6713 DSP operating at 225MHz. It is based on the VLIW architecture, which is very well suited for numerically intensive applications.
- An AIC23 stereo codec for A/D and D/A conversion.
- 16 Mbytes of synchronous DRAM.
- 512 Kbytes of non-volatile Flash memory (256 Kbytes usable in default configuration).
- 4 user accessible LEDs and DIP switches.
- Software board configuration through registers implemented in CPLD.
- Standard expansion connectors for daughter card use.

- JTAG emulation through on-board JTAG emulator with USB host interface.

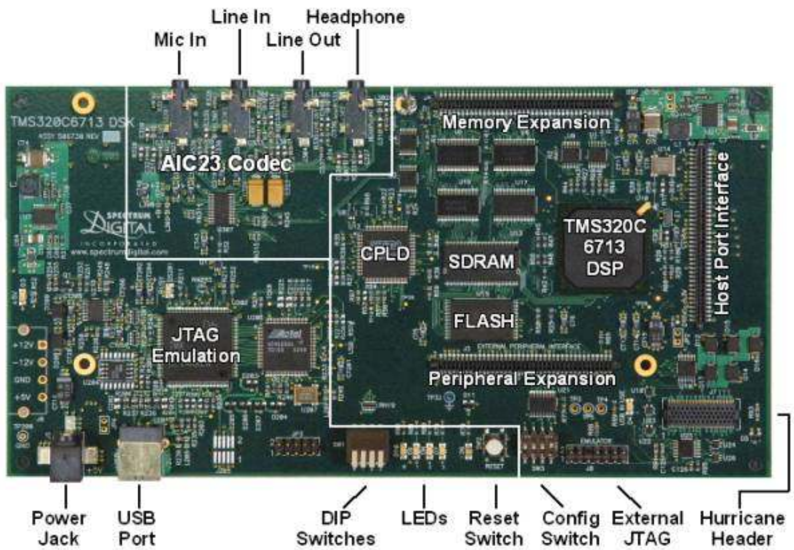

Figure 4 TMS320C6713 DSK board

III. EEG signal analysis

Since EEG is the product of synaptic activity on the pyramidal cells in the superficial cortex, it can be recorded by the properly arranged electrodes placed on the scalp. The EEG activity can be described by those descriptors such as waveform, repetition, amplitude, frequency, distribution, phase relation, timing, persistence and reactivity [7]. In many application field, the most frequently used descriptor for EEG is frequency. In frequency domain, EEG signal is usually divided into 5 groups or frequency band [8], see Table 1.

Table 1 Five EEG frequency bands

Band	Delta or δ	Theta or θ	Alpha or α	Beta 1 or β_1	Beta 2 or β_2
Freq. range	Under 3.5Hz	3.5 to 7 Hz	7 to 13Hz	13 to 30 Hz	30 to 50 Hz

Many research works have proven that the EEG frequency bands will change with the patient physical status, so EEG parameters derived from the frequency bands can serve as an important index of patient status. For this reason, real time EEG spectrum analysis will be one of the purposes of our project. In this project, students will practice to program to derive the EEG parameters in frequency domain which involves the Fast Fourier transform, power spectrum calculation and picking up the individual frequency band components.

Another purpose of our project is the removal of the noise contained in the recorded EEG signals. Because EEG signals have very low amplitude, it is easily contaminated by the noises during acquisition process. Some typical noises are: motion of patient under recording, eye movement, the power line interference, and electromyogram (EMG) [8]. Existence of those noises will seriously affect the estimation, predication and even diagnose of disease in medical. Hence, noise cancelation must proceed any other EEG signal processing. The simplest while still efficient method for EEG noise cancelation is filtering. The students will learn how to properly design and implement a filter (low-pass, band-pass, or high-pass filter) to remove noises.

IV. Implementation of the system

So far, we have introduced the system hardware and software, as well as the tasks of our project. Now, we will discuss how to implement the system and make it work. The first step is properly connecting the system hardware, then, set up the communication interface between the hardware. Finally, develop and implement EEG signal processing algorithms with both CCS and MATLAB.

The system hardware connection is shown in Figure 5. Both of the EEG acquisition devices and DSK board were connected to the host PC through USB cables. The interfacing block diagram is shown in Figure 6.

Figure 5 Connection of system hardware

When the system is running, the EEG signal is acquired and delivered to the host PC. Then the data will be transferred to DSP to process. Finally, the processed EEG signals will be returned to the host PC for displaying. Most of the EEG acquisition devices offer the interfacing methods for the third-party software such as MATLAB, LABVIEW etc. For Biopac devices, the Application Programming Interface (API) is available to permit third-party software programs to communicate with an MP150, an MP36, or an MP35 for basic data acquisition [10]. In our project, MATLAB was used as the third-party software to read the acquired EEG signal from the MP36 device.

There are three different interfacing methods between MATLAB and CCS [6]:

1) Using the "Link for CCS" in MATLAB;
2) Creating a header file in MATLAB and importing it to CCS;
3) Simulink;

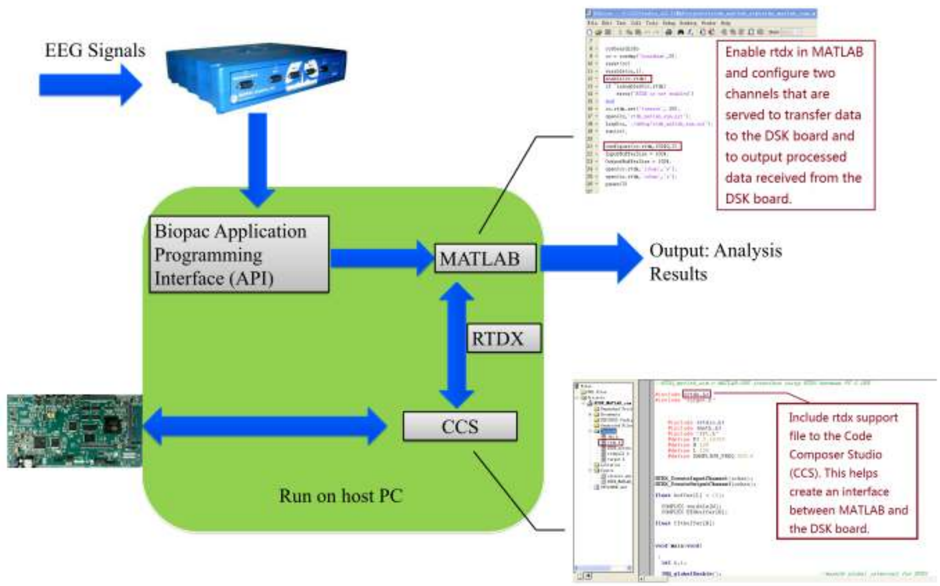

Figure 6 Interfacing between hardware

The first method was adopted in the project. That is, using the embedded *Link for CCS* of MATLAB, program with MATLAB to control the CCS to open, load and run the processing programs on DSP. MATLAB was also used for filter design and displaying the processed data. The RTDX (real time data exchange) function of the CCS enables the DSP chip to communicate and exchange information with the PC via a USB interface, so that DSP chip could directly exchange information with PC without discontinuing the execution of current job.

V. Conclusion

In this paper, a real time EEG processing system based on TMS320C6713 DSK was proposed and the implementation details were stated. This project is initially designed as a course project for BMET students. From this project, the student will get familiar with using of the TI's DSP, gain the experience of processing real world signals, and learn how to acquire and analyze EEG signals as well as how to program with DSP and other third party programming software. In the future, this project will be advanced for developing more sophisticated algorithms to process the EEG signals in real-time for the applications such as BCI, anesthesia depth monitoring, sleep testing etc.

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