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A Low-Cost Portable Real-Time EEG Signal Acquisition System Based on DSP

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Abstract

EEG apparatus are expensive and bulky. Their real-time performance is weak, and EEG signals are easy to be distorted. In this paper, a low-cost portable EEG signal acquisition system based on DSP is developed. By a noninvasive method with bipolar leads, weak EEG signals are induced to the pre-processing circuits, where they will undergo multi-level amplifying and filtering. Then, the analog signals are converted into digital signals using ADS8320. These digitized signals are filtered in DSP (TMS320VC5509) so that the power interference and physiological artifacts are removed with LMS (Last Mean Square) algorithm and ICA (Independent Component Analysis) algorithm. Experimental results demonstrate that the system can acquire weak EEG signals in real time, display and save the processing results. The acquisition system has the advantages of usableness and portability, and helpful to the popularity of community-based and family-based EEG diagnostic equipments.

Keywords: *digital signal processing; electroencephalogram; portable system; weak signal acquisition*

1. Introduction

EEG is a kind of significant bioelectricity signal with abundant physiological and psychological information [1]. By recording EEG, cerebral activities can be monitored for position, diagnosis, and treatment of a wide range of cerebral diseases [2]. At present, most of Chinese EEG equipments are imported from foreign countries [3, 4]. These equipments are expensive and bulky[5][6]. These disadvantages limit the further development of the EEG diagnostic equipment in China [7]. EEG is very weak, whose amplitude is under 100uV and frequency is less than 100Hz [8]. Besides, it is easily interfered from human body and ambient environment [9][10]. So, a variety of factors should be considered in EEG signal acquisition system. For the traditional EEG signal acquisition system, signals sampled by acquisition circuits are converted into digital signals generally [11]. Then the digital signals are transferred to the PC by the way of a wired or wireless transmission [12]. Data can be performed filtering in PC. Their real-time performance is weak inevitably, and they are not convenient for moving [13]. With the development of mobile health, it is demand to develop community-based and family-based EEG diagnostic equipments [14]. Therefore, a low-cost portable real-time EEG signal acquisition system based on DSP is designed and implemented in this paper.

2. System Design

The EEG signal acquisition system includes signal amplifying and conditioning model, analog to digital conversion model, data processing model, displaying and saving model and others modules. Structure diagram is shown in Figure 1. EEG signals are very

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weak, and it is vulnerable to external interference. Besides, the body's impedance is high, and the body condition is always in change. So the amplification factor of EEG signal acquisition systems is usually in the range of 5000 to 30000. Firstly, multi-level amplifying and filtering, shield guard and Right Leg Drive are used in the system to improve the input impedance and CMRR (Common Mode Rejection Ratio) for avoiding waveform distortion. Then, the analog signals are converted into digital signals using ADS8320. And the digitized signals transfer to the DSP to filter the power interference and physiological artifacts (EOG artifacts). Finally, the EEG signals are displayed on LCD and saved in SD card. Compared with current EEG signal acquisition apparatus, between \$3000 to \$30000, the cost of our system can be less than \$160, and it will contribute to universalize the EEG diagnostic equipments.

Figure 1. The Overall Structure Diagram

3. Hardware Design

The hardware of system is consisted of the analog circuits (the preprocessing circuits) and the digital circuits (DSP and its periphery circuits). EEG signals are induced when biological electrodes have good contact with skin, then they can be amplified and filtered in the preprocessing circuits. The functions of DSP and its periphery circuits involve acquiring digital signals, performing digital filtering and achieving human-computer interaction. The hardware structure chart is shown in Figure 2.

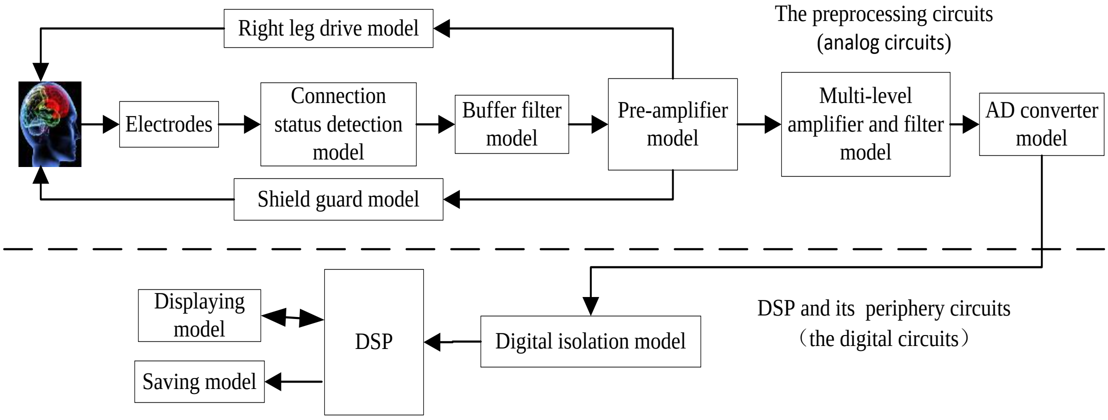

Figure 2. The Hardware Structure Diagram

3.1. Buffer Filtering and Amplifier

The buffer filtering circuit protects circuit away from overshoot current and overshoot voltage. It utilizes the property that current passing through capacity cannot change suddenly to restrain current rate of change, and the property that inductance voltage cannot change dramatically to restrain voltage rate of change. The passive high-pass filter is used to eliminate interference from the mV level polarization potential of electrodes. Otherwise, the polarization voltage will make pre-amplifier saturating. It also improves the post-stage amplifier gain, and provides the opportunity to enhance the CMRR of circuits. The circuits coupling resistances and capacities are comprised of C110, R147 and C111, R148 which constitute the passive high-pass filter.

Two aspects need to be considered for selecting pre-amplifier: 1. Signals as a differential mode signal input obtained from the scalp contain a large number of common-mode component .It requires pre-amplifier with high common-mode rejection ratio. 2. EEG signal is a weak source of high internal resistance, and it requires amplifier with a high input impedance. INA121 is selected as the pre-amplifier in the system. It's common-mode rejection ratio up to 120dB and the input impedance up to 10^{10}.The pre-level amplification factor G may be described as formula (1), $R_G = 100\Omega$

$$G = 1 + \frac{50k}{R_G} = 1 + \frac{50k}{100} = 501 \quad (1)$$

OPA130 is selected as the post-amplifier, and the post-amplification factor G_1 may be described as formula (2). Buffer filter circuit, the passive high-pass filter circuit and pre-amplification electric circuit is shown in Figure 3.

$$G_1 = 1 + \frac{100k}{10k} = 11 \quad (2)$$

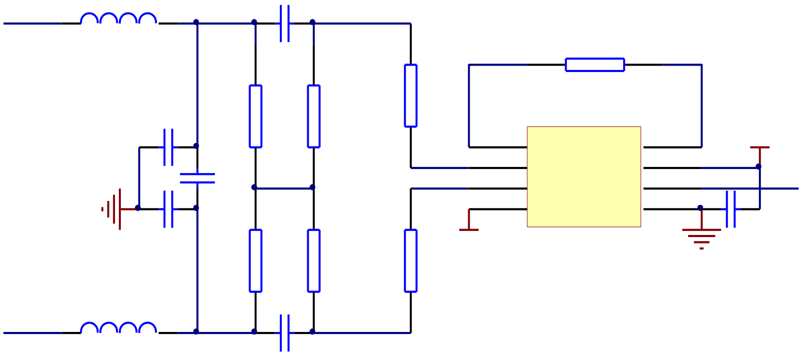

Figure 3. The Buffer Filter, the Passive High-Pass Filter and the Pre-Amplifier Circuit

3.2. Electrode Connection Status Detecting and the Design of Filters

The input signals inducted by electrode are amplified and compared to result a high low level. The low level represents bad connection, and the high level represents good connection. Because EEG concentrated in the low frequency band, it is necessary to design a low-pass filter to filter out high frequency noise. Filters usually have the transition bandwidth. For reducing transition bandwidth, many filters can be cascaded to increase the filter orders. The second-order voltage controlled active filter is used in the system, and it is cascaded to make a fourth-order low pass filter. The low pass filter is shown in Figure 4.The different parameters are adopted in the two second-order low pass filter to acquire good dampening characteristics. The standard form of transfer function of the second-order low pass filter is described as formula (3):

$$H(s) = \frac{w_n^2}{s^2 + \varepsilon w_n s + w_n^2} \quad (3)$$

Where, w_n is the angular frequency of free vibration, ε is damping coefficient, and the cutoff angular frequency w_c is expressed as:

$$w_c = \sqrt{\frac{(2-\varepsilon^2) + \sqrt{(\varepsilon^2 - 2)^2 + 4}}{2}} w_n \quad (4)$$

Including,

$$w_n^2 = \frac{1}{R_1 R_2 C_1 C_2} \tag{5}$$

The parameters of the first level low pass filter: R_1 =6kΩ, R_2 =18kΩ, C_1 =200nF, C_2 =100nF. The cutoff frequency: $f_c = w_c / 2\pi = 92\text{Hz}$ .The parameters of the second-level low pass filter: R_3 =27kΩ, R_4 =243kΩ, C_4 =100nF, C_5 =3.3nF, The cutoff frequency: $f_c = w_c / 2\pi = 157\text{Hz}$.

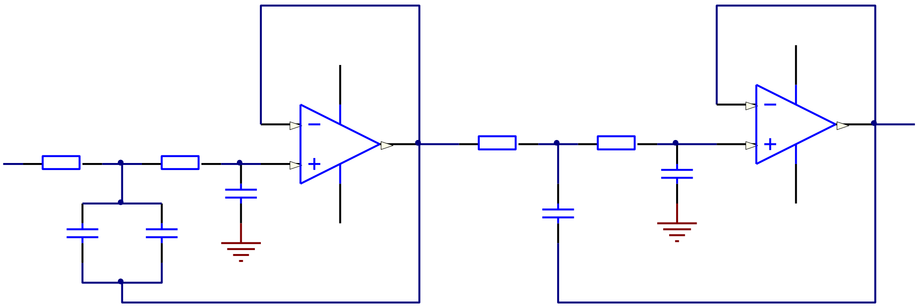

Figure 4. The Fourth-Order Low Pass Filter

3.3. The Design of Digit Circuits

The digital signal processing is implemented in TMS320VC5509A which is produced by TI. It is C55X series of a high performance, lowest-power DSP. The DSP applies to process algorithms and data. Signals must be converted into digital signals before the digital signal processor. So, ADS8320 is used in the system. The ADS8320 is a high-speed, 14bit resolution option, serial ports. The high speed magnetic isolation chips ADUM2400 and ADUM2401 is used to implement 5000V voltage isolation. The connection of ADS8320 and TMS320VC5509 is shown in Figure 5.

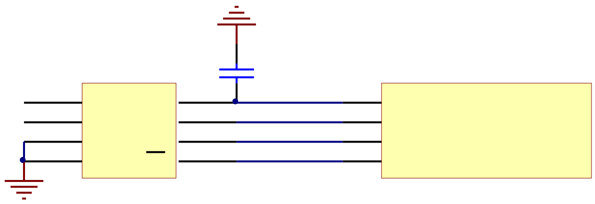

Figure. 5 The Connection of ADS8320 and TMS320VC5509

4. Data Processing Algorithms

4.1. Removing Power Reference

The power interference often fluctuates with changes in the power supply system. The fixed bandwidth notch filter cannot completely filter the power interference, and the EEG near the band may be filtered out. The adaptive filter is employed for tracking and processing the power interference. The adaptive filter can automatically adjust parameters according to the fluctuations in the power system. Assume that the power interference's reference input is $x(n)$, the original signals is $d(n)$, the weight vector is $w(n)$, then the output of filter can be represented:

$$e(n) = d(n) - w^T(n)x(n) \tag{6}$$

The standard EEG signal downloaded from MIT database is used to verify the effectiveness of the method. Firstly, the power interference is combined with standard

EEG signal. And then the EEG signal with power interference is filtered using the LMS algorithm. The frequency spectrums of original signal, the EEG signal with power interference, and filtered signal are demonstrated in Figure 6. As you can see, the power interference component is removed. And there is little impact on the EEG.

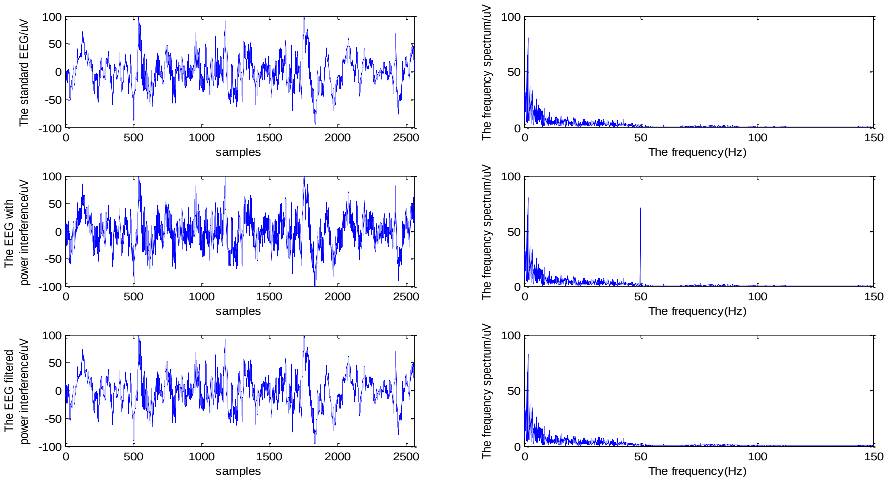

Figure 6. Comparison between Before and After Filtering

4.2. EOG Artifacts Removing

EEG has the strong time-varying sensitivity, so it is vulnerable to the interference from human body.EOG is low- frequency signal, and its frequency range is contained in the EEG signals' frequency range. Therefore, EOG artifacts seriously influence EEG signals. Independent component analysis method can effectively extract ingredient statistical independence from mixed signals. EOG and EEG can be considered a different signal source generates, *i.e.*, they are independent of each other. Therefore, ICA is used to decompose the acquired EEG signals in the system. The fixed-point FastICA algorithm using negentropy has higher computation efficiency. Therefore, it is used to decompose EEG signal in order to increase computational efficiency. The separate matrices W can be obtained by multiple iterations using independence measurement and optimization algorithm.

$$U(t) = WX(t) = [u_1(t), u_2(t), \dots u_n(t)]^T \tag{7}$$

The observed signals $X(t)$ are separated into many independent components $u_i(t)$ using above formula, and U(t) is the set of $u_i(t)$. The correlation between EOG as a reference signal come from EOG-lead and each individual component is analyzed. The major relevance component is as EOG artifacts and set to 0, others invariability. Then the new individual component $U^{'}(t)$ can be acquired: $U^{'}(t)=[u_1^{'}(t), u_2^{'}(t), \dots u_n^{'}(t)]^T$ After that, the EEG signals without EOG artifacts are reconstituted by W's inverse matrix W^{-1}:

$$X' = W^{-1}[u_1^{'}(t), u_2^{'}(t), \dots u_n^{'}(t)]^T \tag{8}$$

Firstly, the above algorithm simulation using MATLAB is shown in Figure 7 and Figure 8. The EEG signals with EOG artifacts are shown in Figure 7, where the red circle marks indicate EOG artifacts. The EEG signals filtered EOG artifacts is shown in Figure 8. Comparing the two figures is easy to see EOG artifacts have obviously been removed and good filtering effect. And then the algorithm is implemented in DSP by CCSLink in order to ensure the system's real-time performance and portability.

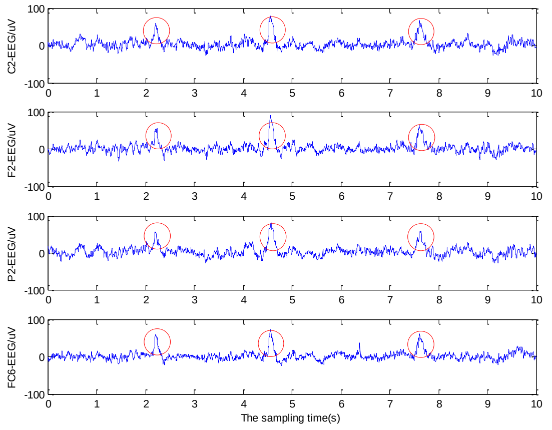

Figure 7. The EEG Signals with EOG Artifacts

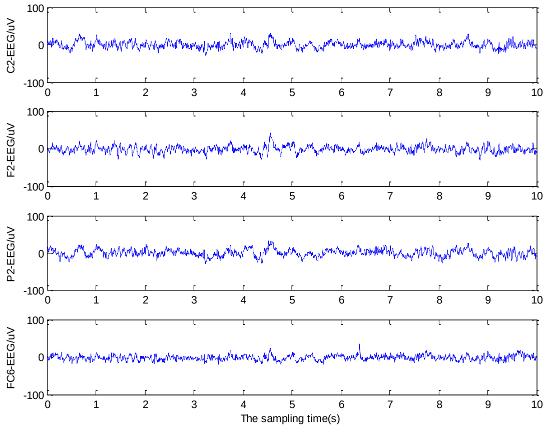

Figure 8. The EEG Signals Filtered EOG Artifacts

5. Experimental Result

The electrode cap is more expensive and not portable, so dots mounted on the head is used to test the system. Three dots are placed on the less muscle place to reduce physiological artifacts interference. Red dot and green dot make up of measuring circuits, and the yellow one is reference dot. As shown in Figure 9, the yellow dot is placed on the ramp above of brow, the green dot is placed on the cheekbone and the red dot is placed on the middle of forehead. EEG acquired using the system is shown in Figure 10. Experimental results show that the system can smoothly and accurately acquire and display EEG. The system meets the design requirements.

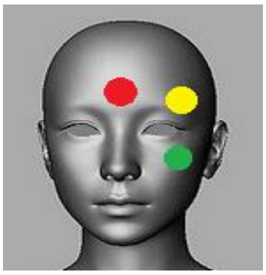

Figure 9, Position of Dots

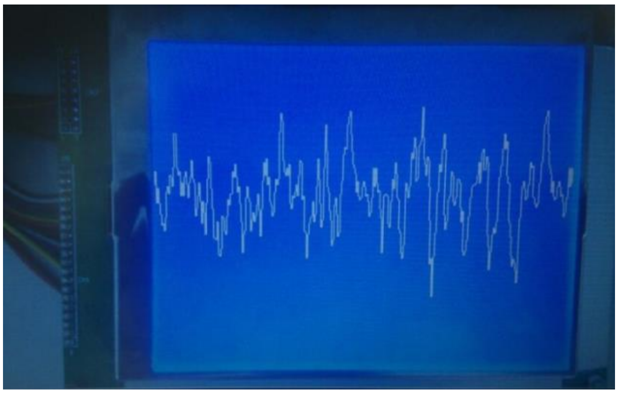

Figure. 10 Acquired EEG using the System

6. Conclusions

Aiming at the situation that the acquisition technology of EEG is required to improve continually, a DSP-based low-cost portable real-time EEG signal acquisition system is designed and implemented using technologies of analogue signal processing and digital signal processing. The system can stably acquire EEG, and it may provide a technical support for portable brain health and real-time mobile monitoring.

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