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Assistive technology implementation with brain-machine interface

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Abstract. As the development of the Brain Computer Interface, it can be a possible way for human to control the external devices by the mind. This can be good news for the handicapped people whose life qualities are greatly decreased. In this paper, designed an assistive robot arm for those disabled. The assistive robot arm mainly contains a filter, a microcontroller and a motor drive system. The filter can filter out the noises while the microcontroller judging the brain signals and turn it into an actual control signal. The actual control signal will finally drive the motor and for the sake of safety and stability, a PID circuit was add in the motor drive system. The mechanic arm designed can turn what people think to the actual robot behaviour and this will obviously increase the life quality of the disabled people. It's also a light weight system with a wide range of versatility and will bring benefits to all the handicapped.

Keywords: brain-machine interface, circuit design, mechanic arm.

1. Introduction

With the development of the Brain Computer Interface (BCI), it will be possible for human to control the external devices. It's good news for those who are handicapped. Especially there are more than 4.4 million handicapped people in Australia [1]. In order to increase the life quality of these handicapped people, this paper designed a mechanical arm to help the handicapped people to realize what they want to do but they cannot do. The mechanical arm designed mainly contains 3 parts, the filter the microcontroller and the motor drive system. The filter designed is to filter out the noises and amplify the brain signals. The filter contains two parts the low-pass filter and the band-stop filter. The low-pass filter is to filter out the noises and keep the brain signals because most of the brain signals are less than 100HZ, while the band-stop filter is to filter out the power noise for the power is only 50HZ. Then the microcontroller will process these signals from the brain and output the control signals to the motor drive system. In order to make our microcontroller more versatile program the microcontroller. The program mainly did such things that calibrate the clock frequency, judging the brain signals and according to the brain signals to output the control signals. Finally, is the motor drive system, it will help the handicapped to grab the things. In this system, using a PID circuit which will greatly improve our system's stability and provide the motor from getting burnt. The mechanic arm obviously provides a good prospect for the disabled people. It is obvious that the mechanic arm designed will improve the development of all the Brain Computer Interface industry and it can bring benefit to all the disabled people.

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2. The processing and analysis of the EEG

2.1. The introduction of the EEG

The Electroencephalograph (EEG) is a bioelectric phenomenon which is caused by the ion charge to transmit information in the nerve cells. The EEG signals can be collected by the electrodes set on the surface of the scalp [2]. There are two types of signals among the EEG signals one is called the spontaneous brain wave while the other is called induced brain wave.

2.1.1. The Spontaneous Brain Waves. The spontaneous brain wave mainly contains five kinds of brain waves. δ wave: It is related to the state when humans sleeping deeply. There won't be a δ wave when a human is awakened and it will only appear when human is sleeping. It may also appear at the situation of deep anesthesia, lack of Oxygen or there is a lesion in human's brain. θ wave: It is related to the state when human is in meditation. It will appear when human is tired and strengthened during the sleeping. The appearance of it means that the central nervous system is in suppression. α wave: It means that human is get relaxed, it's also the basic frequency of normal human brain wave. When human is in a clear mind and relaxing situation there are mainly α waves appear in human's mind. β wave: It means that the brain is exciting, it will appear when the human's brain is active. γ wave: It is relevant to some pathological site such as the finger tics and the tongue tics [3]. The Spontaneous Brain Waves frequency and amplitude are shown in table 1.

Table 1. The Spontaneous Brain Waves.

The name of brain waves	Frequency Range (HZ)	Amplitude (μV)
δ wave	0.5~3	0~200
θ wave	4~7	100~150
α wave	8~13	20~100
β wave	14~30	5~20
γ wave	30~45	

2.1.2. The Induced Brain Wave. The induced brain wave is a kind of nervous system reaction that caused by the stimulation of the environment. The stimulations mainly include the auditory stimulation, visual stimulation, tactile stimulation etc [4]. This kind of brain wave can also be related to some kinds of mental activity. The visual evoked potential and the event-relevant potential are widely used among the induced brain waves.

2.2. The Processing and Analysis of the EEG

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2.2.1. Wavelet Transform Wavelet Transform is developed among the Fourier Transform. The differences between the wavelet transform and the Fourier transform is that the wavelet transform can analyze the signals by shifting the basic wavelet. So, it can get information from the signals more effectively and is an ideal way to analyze and process the signals.

Suppose the $\Psi(t) \in L^2(R)$ (The $L^2(R)$ represents Square the space of integrable real numbers) it's Fourier Transform can be remarked as $\widehat{\Psi}(\omega)$. When $\widehat{\Psi}(\omega)$ meets the requirements that:

$$C_\Psi = \int_R \frac{|\widehat{\Psi}(\omega)|^2}{|\omega|} d\omega < \infty \quad (1)$$

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This paper called the $\hat{\Psi}(\omega)$ the Mother Wavelet. After scaling and shifting $\hat{\Psi}(\omega)$ signal, can get another wavelet transform. Supposing the scaling factor $a = 2^j,\ j \in Z$, the translating factor $b = ak,\ k \in Z$, so can get the binary orthogonal wavelet form.

$$\Psi_{j,k}(k) = 2^{-\frac{j}{2}}\Psi\left(2^{-j}t - k\right) \quad k \in Z \tag{2}$$

For arbitrary signals $f(t) \in L^2(R)$ it's binary orthogonal transform is

$$WT_f(j,k) \leq f,\ \Psi_{j,k} \geq \int f(t)\overline{\Psi_{j,k}(t)dt} \tag{3}$$

The $\Psi_{j,kt}(t)$ can be seen as a characteristic of filter and using wavelet transform means that divided the filter into two parts the high frequency detail part and the low frequency approximation part [5].

According to the discussion above, by using the wavelet transform, the design could divide a mother signal into some sub signals. This provides a possible way for us to extract the rhythm signals from the complex EEG signals and what need to do is to choose a proper wavelet to do the wavelet transform.

After the simulation by the Matlab, finally found that the Daubechies Wavelet with db4 is the best wavelet for EEG analysis. If use the Daubechies with lower db to the describe the EEG signals, it will be too rough. While using Daubechies with higher db to describe the EEG signals will have too much fluctuations, which will cover up the origin signals.

2.2.2. Identification Methods by neural networks. The BP neural network is a widely used network that are practiced by back propagation algorithm. BP neural networks includes 3 parts the input layer, the output layer and the hidden layer. Each layer is completely connected with the others. Also, the state of the neural layer can only affect the next state of the neural state.

The network mainly has two parts during it's specific application. The first part is the training. It will let the network has the ability to memorize and predict. It mainly includes the following steps [6]:

(1) The initialization of the network.Due to the output sequence (X, Y), could certain the input layer nodes n, the hidden layer nodes l, the output layer nodes m. Also, could certain the connection weight ω_{ij}, ω_{jk} between the input layer, hidden layer and the output layer, certain the threshold a of the hidden layer, certain the threshold b of the output layer and finally certain the learning speed and the neural activation function.

(2) The calculation of the hidden layer. Due to the input vector X, the weight between input layer and hidden layer ω_{ij}, the threshold a of the hidden layer the network will calculate the output H of the hidden layer.

$$H_j = f(\sum_{i=1}^{n}\omega_{ij}x_i - a_j) \quad \text{j=1,2,…,l} \tag{4}$$

(3) The calculation of the output layer. Due to the output H of the hidden layer, the linking weight ω_{jk} and the threshold b, calculate the prediction output O of the BP neural network.

$$O_k = \sum_{i=1}^{n}\omega_{ij}x_i - b_k \quad \text{k=1,2,…,m} \tag{5}$$

(4) The calculation of error. According to prediction output O and the desired output Y, calculate the errors e of the network prediction.

$$e_k = Y_k - O_k \quad \text{k=1,2,…,m} \tag{6}$$

(5) The renewal of the weight. According to the errors e of the network prediction, renew the linking weight ω_{ij}, ω_{jk} of the network.

$$\omega_{ij} = \omega_{ij} + \eta H_j(1 - H_j)x(i)\sum_{k=1}^{m}\omega_{jk}e_k \quad \text{i=1,2,...,n; j=1,2...,l} \tag{7}$$

$$\omega_{jk} = \omega_{jk} + \eta H_j e_k \quad \text{j=1,2...,l; k=1,2...,m} \tag{8}$$

Among the formula the η represents for the learning speed, $0<\eta<1$, usually the η gets the number between 0.25~0.75. Also, the size of η will influence the learning speed.

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(6) The renewal of the threshold. According to the network prediction errors e renew the threshold a,b of the network nodes.

$$a_j = a_j + \eta H_j(1 - H_j) \sum_{k=1}^{m} \omega_{jk} e_k \quad \text{j=1,2…,l} \tag{9}$$

$$b_k = b_k + e_k \qquad \text{k=1,2…,m} \tag{10}$$

Noticing that the chosen of hidden layer nodes are very important to the construction of the BP neural networks. If the nodes are not enough the BP neural networks cannot establish a complex mapping relation which will cause a big error. If the nodes are too many, then the BP neural network may overfitting that is the neural network may fit to the specific sample but not others.

BP neural is the most widely used artificial network in all research fields. It has the abilities to learn, associate and fault tolerance. However, its speed of convergence is slow.

3. Detailed design

In this chapter, some detailed circuit design to transfer the raw signals into the motor control signals. There are four main parts in our circuit design. The filter, the AD converter, the microcontroller and the Motor Drive system.

3.1. Filter

The filter is an equipment that can filter out the useless noises and keep the useful signals. In our circuit design, using the filter to filter out the 50HZ alternating circuit. Also, using the filter to amplify the EEG signals. It is important for us to choose a proper filter in our circuit design.

3.1.1. The theoretical foundations of filter. The filter is a circuit that has the ability to select the frequency. The working theory of filters are using the characteristic that filters can decay different signals with different frequencies and finally reach the goal to separate different signals. However during the actual measuring system, the frequencies between noises and signals often overlap with each other. If there isn't too much overlapping, still can use filters to suppress the noises.

The basic forms of the filters are linear four terminal networks. Its characteristic can be described by the transfer functions [7]. This paper define the ratio of output voltage and the input voltage as the transfer function.

$$H(s) = \frac{U_o(s)}{U_i(s)} = \frac{\sum_{k=0}^{m} b_k s^k}{\sum_{l=0}^{n} a_l s^l} \tag{11}$$

In this equation, the $s = \sigma + j\omega$ represents the Laplace variable. The factors a_l, b_k in the numerator and the denominator is decided by the network structure and the device parameter in circuit. Meanwhile the n is called the order number of filters, that is to show how complex the circuit is.

$$f_c = \omega_c/(2\pi) \tag{12}$$

In this equation the f_c means the frequency that signals are damped to the 1/2 (about 3dB). This paper called it corner frequency that is also the boundary point between the pass band and the rejection band.

$$S_x^y = \frac{dy/y}{dx/x} \tag{13}$$

Because of the changing of each device in the filter can influence the filters' ability. It's important for us to define the performance index y related to the variation of the component parameter x. So, that is the sensibility of filters.

$$\tau(\omega) = \frac{d\varphi(\omega)}{d\omega} \tag{14}$$

This paper often use the group delay functions to describe the output signals' phrase distortions degree after the filter. When $\tau(\omega)$ is closer to the constants, it means that the phrase distortions is lower.

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3.1.2. The filter design. As have mentioned above most of the EEG signals in humans' brain are less than 100HZ. So, this paper decided to design a low-pass filter that can filter out the signals above 150HZ because most of the noises are above 150HZ. Also it is important for us to design another band-stop filter to filter out the 50HZ noises that caused by the power. Any complex filter networks are consisted of several basic first-order filters and second-order filters. As shown in figure 1 and 2.

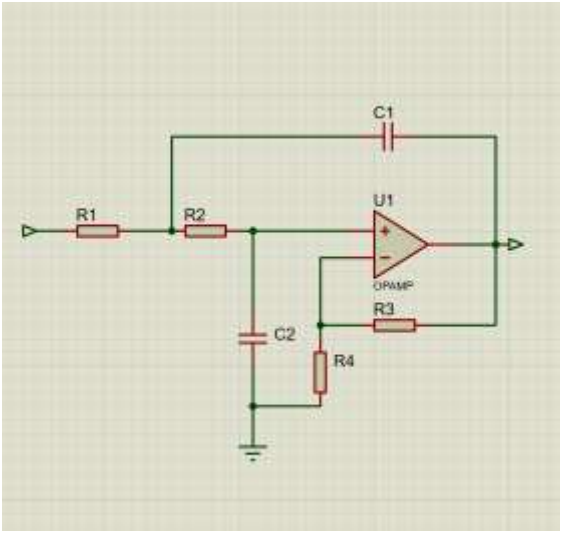

Figure 1. The low-pass filter.

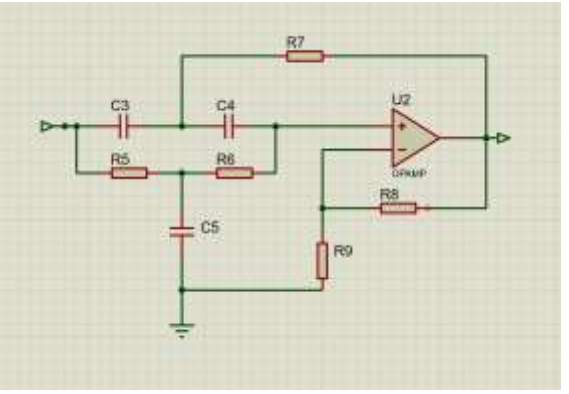

Figure 2. The band-stop filter.

These are filters designed that can filter out the noises and keep the useful brain signals.

3.2. Microcontroller

3.2.1. The brief introduction of the Microcontroller. The microcontrollers are the central processing unit that made by the integrated circuit. So the microcontrollers have a powerful logic calculation ability. Compared with the traditional central processing unit, the microcontrollers are small, light and easy to modularize. The basic parts of the microcontrollers contain registers, arithmetic, timing control circuit, data bus and address bus. The microcontroller is the key of the micro control system.

The C51 series microcontroller is the most widely used microcontroller in the industry. The early microcontroller made by the Intel Company like 8031/8051/8751 are still widely used. The PIC series microcontroller is the products produced by American MICROCHIP company. They are also widely used in the home appliances [8]. DSP is another kind of microcontroller that can process a lot of digital signals. The theory of DSP is to receive the analog signals and change them into the digital signals with 1 and 0. Finally, it will do some complex transform and processing to the digital signals. During the late 20th century, the ATMEL company also developed a kind of microcontroller called AVR [9]. This kind of microcontroller has a more simplified instructions which provide a faster processing speed. It is also the kernel of Arduino.

3.2.2. The chosen of Microcontroller and coding. In project, this paper finally choose the ATMEGA328P as our microcontroller. It's a powerful microcontroller. The Atmega328P has a pinout diagram. It has digital input output pin, AD converter channels, I2C communication module, timing modules, PWM Channels [10]. As shown in figure 3.

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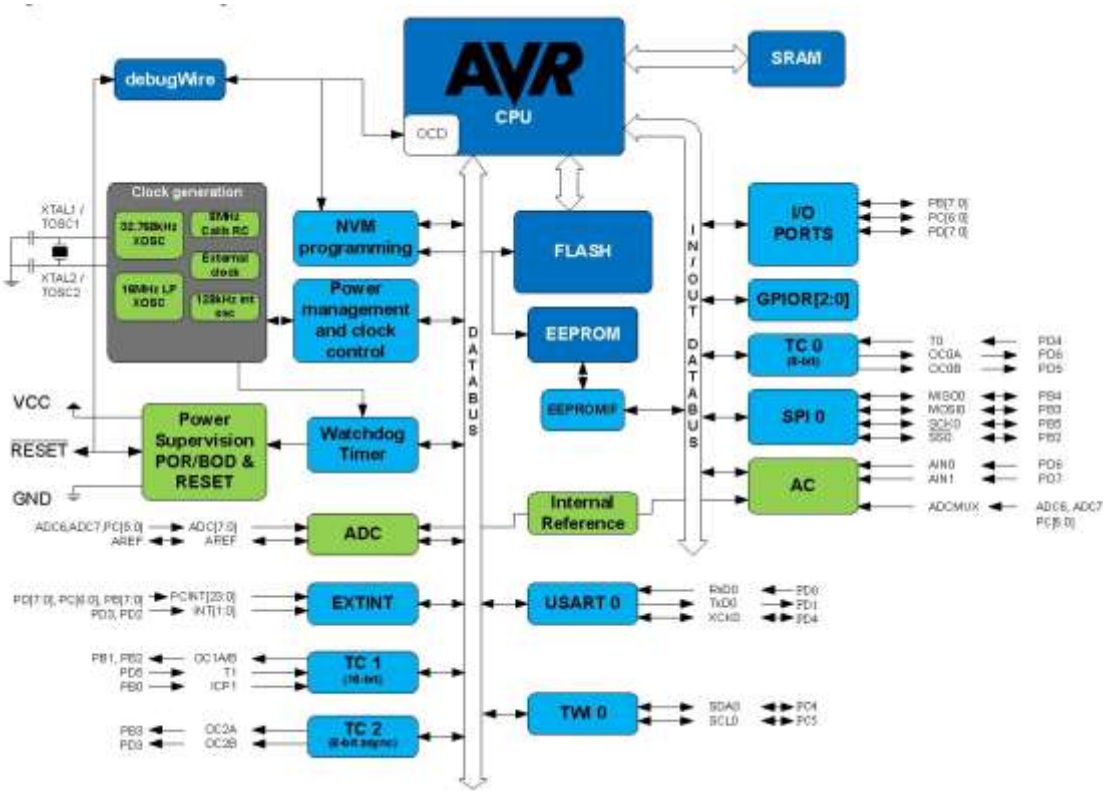

Figure 3. ATMEGA328P Block Diagram.

After chose this microcontroller, this paper program it and to realize some functions in figure 4.

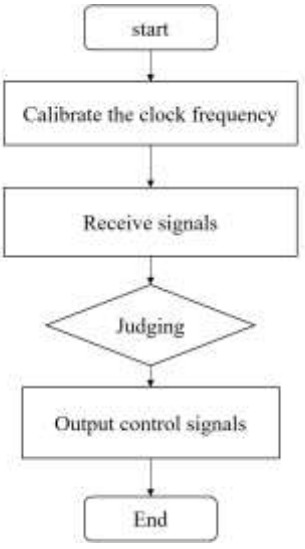

Figure 4. The microcontroller designing diagram.

4. Motor Drive system

The PID circuit is a useful circuit that can adjust the motor working speed. So, decided to design a PID circuit in our Motor drive system. There are three parts in the PID circuit the proportion circuit, the integration circuit and the differential circuit. First, is the proportion circuit. The proportion circuit can

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quicken the sensibility of the adjustment. The integration circuit can eliminate the Static Error or Offset in the circuit. The integration circuit can also suppress the interference. The differential circuit can reduce the delay in the motor circuit and quicken the adjust speed of the circuit. It's obvious that using a PID circuit in our motor drive system can greatly improve the stability of our motor drive system. As shown in figure 5 and 6.

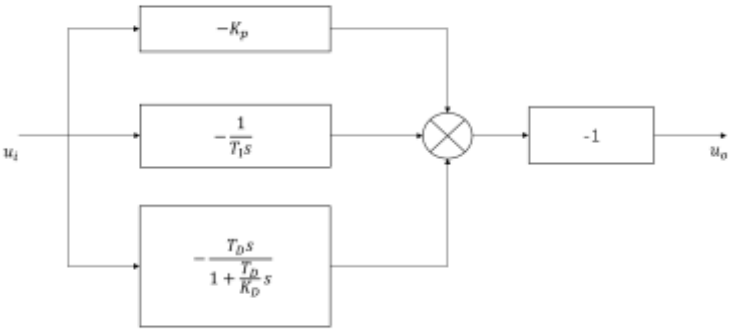

Figure 5. The PID circuit block diagram.

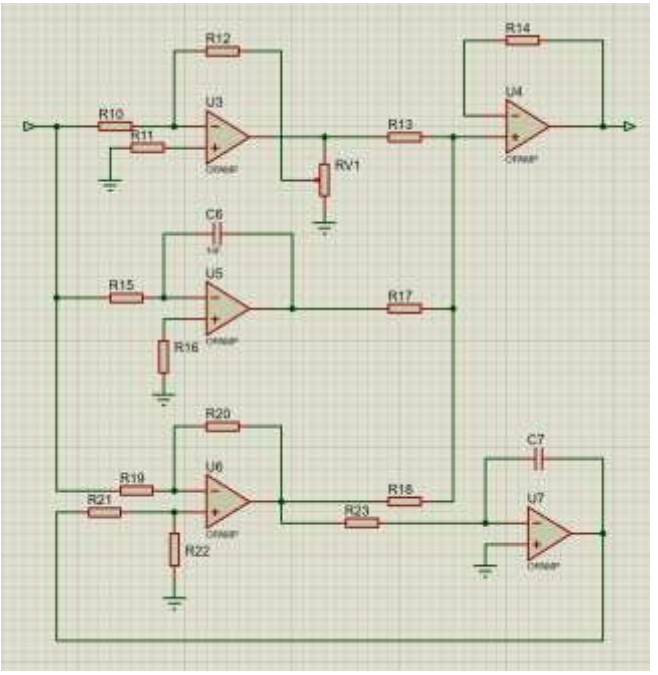

Figure 6. PID circuit.

In this block diagram, the K_p means the actual proportion factor, the T_I means the actual integration time while the T_D means the actual integration time. Obviously, it use the parallel PID circuit that can avoid the cumulative amplification of the integrated errors also it can improve the overall accuracy in the motor drive system. Finally, using the parallel PID circuit can eliminate the overall alteration caused by the changing of T_I T_D. The Figure 6 is the actual circuit designed.

The PID circuit is actually used in the motor of the mechanic arm. As you can see in the figure 7, the mechanic arm used a PID circuit for the sake of stability.

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Figure 7. Mechanic Arm.

5. Conclusion

In the mechanic arm this paper designed, it uses a filter, a microcontroller and a PID circuit to realize our functions. The filter used is to filter out the noise and amplify the brain signals. Also, using a microcontroller to judging the brain signals and to process these signals. After the judgment the brain signals turned into the controlled signals and these signals finally transmit to the motor drive system. In order to improve the system's stability and to prolong the using time of the motor drive system, it use a PID circuit to adjust the signals to the motor. However, there are still some disadvantages need to improve. For examples, in our design the reaction time is too long and when there are some other useless actions like nodding heads, it will greatly influence the data it collected which will finally cause the output signals have a lot of noises. So, need to find a proper way to filter out the noises like these. Also, in our mechanic arm design don't use an isolating circuit which means the sudden burst current in the motor drives system may influence the microcontroller and may break down it. However, if put isolating circuit, the cost will greatly increase, this design still needs to find a way to improve the stability of our mechanic arm. Generally speaking, although there are still some disadvantages in our mechanic arm design, it still finds a possible way for those disabled people to help increase their life quality.

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