Human Pulse Signal Acquisition System Based on PVDF Piezoelectric Film

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Abstract. Nowadays, traditional Chinese medicine (TCM) is attracting more attention. As the most complete methods of pulse diagnosis, the method named ‘three regions nine subdivisions’ has come to the fore. It is important to collect accurate pulse signals in this way. Hence a pulse signal acquisition system is developed, which includes a pulse sensor based on PVDF (Polyvinylidene fluoride) piezoelectric film, charge amplifier, low-pass filter, voltage amplifier, voltage follower, and a software system based on LabVIEW for controlling the acquisition process and storing data. And PVDF piezoelectric film has suitable performance for this system which as a new kind of polymer piezoelectric material. Finally, the experiment results demonstrate that the system can extract effective pulse signals without heavy pressure, laying a solid foundation for the subsequent analysis on pulse signals.

1. Introduction

More and more attention has been paid to human health, especially to the early prediction and prevention of disease [1], since the early 21st century. Traditional Chinese medicine (TCM) has been more and more popular and attracted many attention in more countries in recent years for its specific advantages [2]. As a very important diagnostic method in TCM, the pulse information has been applied in the early prediction and prevention of diseases which has a history of thousands of years [3][4]. As the most complete method of pulse diagnosis, ‘three regions nine subdivisions’ has been paid more attention. Although it is comprehensive, it also has disadvantages. One is that it has more parts to measure, which is more complex and time-consuming; Another, there are some parts which are inconvenient to obtain pulse information through heavy pressure. In order to determine the pulse type of patients accurately, doctors need to get pulse information by feeling the pulse, which requires several years of learning and experience, and which may be influenced by many subjective factors and external factors. Therefore, it is of great significance to obtain the patient's pulse signal accurately.

There are many ways to detect the pulse signal of human body, and the commonly methods include optics [5][6], image processing [7], acoustics [8] and piezoelectric effect [9][10]. Among these methods, the piezoelectric sensor based on the principle of piezoelectric effect is more intuitive, accurate and sensitive [1]. Among many piezoelectric materials, PVDF piezoelectric film, as a new polymer material, has obvious pressure effect, wide frequency response, large dynamic range, high sensitivity and high mechanical strength after processed. Hence, PVDF piezoelectric film material was used in this study to make up the pulse sensor, and this study design signal pre-processing circuit which be put after the pulse sensor to avoid interference signals and extract reliable signals for subsequent studies.
2. Signal source analysis
The circulatory system of the human body is composed of the heart, blood vessels and blood, which is responsible for the transport of oxygen, carbon dioxide, nutrients and wastes. When the heart's left ventricle contracts, large amounts of blood enter the arteries, which put pressure on the arteries and cause them to dilate. This dilation can be felt in the arteries at the shallower part of the body, which is known as pulse signal. Pulse signals can be measured in the arteries of many parts of the body, and we measure the pulse signals at the wrist. The frequency of the pulse signal is usually below 10Hz [7]. Because the pulse depends on the relaxation of the heart and the expansion and elasticity of the arterial wall, the pulse signal carries a lot of information about human health. Since the differences of individual will lead to differences in arterial pulse strength, the acquisition circuit is designed as a gain adjustable mode.

3. System scheme
As shown in figure 1, the human pulse acquisition system consists of detection circuit, acquisition card and software system. The first part of the system includes PVDF pulse sensor, charge amplifier, low pass filter, voltage amplifier, voltage follower and power module. The second part is an acquisition card containing ADC, FIFO and PCI. And the third is a software system with a sampling controller and a database.

![Figure 1. The structure of the pulse signal acquisition system](image)

PVDF piezoelectric film material is used to make pulse sensor. The sensor picks up the pulse and generates a weak charge, which is amplified by a charge amplifier and converted into a voltage signal. In order to suppress 50Hz power frequency interference and other high frequency interference of circuit and human body, let the signal pass through a low-pass filter with cut-off frequency of 30Hz with considering the frequency range of human pulse signal. In order to make full use of the ADC resolution, the gain of voltage amplifier is adjustable so that the voltage range output is consistent with the supply voltage. The voltage follower is designed to reduce output impedance of the circuit to match the impedance of ADC. Since the power supply mode of the circuit is single-supply, the power module provides a reference voltage to the circuit additionally. Figure 2 shows the pulse acquisition system circuit board. The acquisition card converts continuous analog voltage output by the detection circuit into discrete digital values. The software system is based on LabVIEW, a graphical programming
language. The sampling controller can set the sampling parameters of the acquisition card. And the database is established to store collected data in a specified format.

**Figure 2.** Pulse acquisition system circuit board

### 4. Detection circuit

#### 4.1. Charge amplifier

The resistance of piezoelectric film is very big which is generally more than $10^8 \, \Omega$, and the pulse signal from the piezoelectric film is very weak. Which requires that the input resistance of the subsequent circuit must be at least $10^8 \, \Omega$ to absorb more signal. The Figure 3 shows the schematic of the charge amplifier. The core component of charge amplifier is feedback capacitor $C_f$ which plays the role of current integrator [11]. The piezoelectric sensor senses vibration and a charge which is proportional to the stress appears on its surface. The charge is converted into a voltage which is proportional to the stress through the integration and amplification of the charge amplifier [12].

**Figure 3.** Schematic of charge amplifier

Figure 4 shows the equivalent circuit of the charge amplifier. Suppose that the piezoelectric film which under pressure generates charge $Q$, $C_a$ is the interelectrode capacitance of the sensor, $C_c$ is the capacitance of transmission cable of the sensor, $C_i$ is the input capacitance of charge amplifier, $C_f$ is the feedback capacitance of charge amplifier and $R_f$ is the feedback resistance. Suppose that the open-loop coefficient of the op-amp is $A$, $U_d$ is the differential voltage generated at the inverse phase input end of the op amp, and $U_o$ is the output voltage. They can be expressed as:

$$U_d = \frac{Q}{C_a + C_c + C_i + (1+A)C_f} \quad (1)$$

$$U_o = A \cdot \frac{Q}{C_a + C_c + C_i + (1+A)C_f} \quad (2)$$

Ignoring the part of small order of magnitude, can be expressed as:
So the output voltage of the charge amplifier is related to the input charge $Q$ and the feedback capacitance $C_f$. For the feedback resistance, a smaller feedback resistance can be selected if the change is fast and usually does not require a long duration, but a larger feedback resistance should be selected if the change is slow. The frequency of pulse signal is lower which should fall into the second category.

4.2. Low-pass filter

The pulse signal frequency of human body is about 0.2Hz~45Hz, and most useful signals have low frequency, which concentrated between 0.5Hz ~10Hz and generally around 1Hz [13]. Moreover, when weak signals are collected, the signals will be affected by 50Hz power frequency interference. And its energy is not only limited to 50Hz, but often appears in the form of multiple frequencies. Therefore, this system designs a low-pass filter with a cut-off frequency of 30Hz to filter out 50Hz power frequency interference and the form of a multiple of it. Using 30Hz low-pass filter can effectively remove the interference and retain most of the information of pulse signal, which is better than 50Hz notch filter.

An ideal low-pass filter cannot be realized, but a practical filter which is close to ideal characteristics can be made by using circuit elements. The most commonly used and feasible filters are Butterworth filter, Chebyshev filter and Bessel filter. The Butterworth low-pass filter has the characteristics of maximum flat amplitude-frequency response and good linear phase. Therefore, the type of low-pass filter designed in this study select a Butterworth low-pass filter. The higher the order of the Butterworth low-pass filter is, the faster the attenuation of amplitude-frequency characteristic is, but the more complex the hardware is. Considering both performance and complexity, this design adopts a 4-order Butterworth low-pass filter. The 4-order low-pass filter can be cascaded by two 2-order low-pass filters [14], as shown in figure 5.

![Figure 5. Low-pass filter](image)

However, we should take the value of the capacitance and resistance coefficient actually into account for the convenience of purchasing, so the value of the coefficient can be slightly different from the theoretical value. The fourth-order Butterworth low-pass filter of this system is shown in figure 6, and its amplitude-frequency response curve is shown in figure 7. The attenuation is about -3dB when near the frequency of 30Hz, which meets the design requirement which require the attenuation frequency is...
30Hz. At about 50Hz, the attenuation of the frequency is about -15dB, which converted to attenuation multiple is about 5~6 times. Therefore, the low-pass filter can effectively suppress the 50Hz power frequency interference and its form of multiples, which meets the design requirements.

![Figure 6. Low-pass filter of this system](image)

![Figure 7. Amplitude-frequency response curve of low-pass filter](image)

4.3. Voltage amplifier

The output signal of the piezoelectric film pulse sensor which amplified by the charge amplifier is generally at millivolt level. This system is powered by a single power supply and 2.5V reference voltage is set, so the range of maximum signal that can be output is ±2.5V. And since the amount of charge the sensor outputs is related to the individual's physical characteristics, which is also related to the intensity of the sensor being pressed on the acupoints. So this system design two stage amplifier circuit: the amplification of the first stage is 2 times, and the amplification of the second stage is 0~50 times which is variable. In this way, the amplification factor can be flexibly adjusted to make the output signal meet the requirements.
4.4. Voltage follower
In order to avoid the mismatch between the system circuit and the impedance of acquisition card, which may cause too much energy consumed at the input end of acquisition card. It is relatively safe to add a voltage follower among them, which is helpful to improve the performance of the system.

5. Acquisition card and software system
In order to discretize analog signal, acquisition card is used in this system. In order to timely adjust the acquisition parameters, the software system configures the acquisition card by control signals, as the hollow arrows shown in Figure 1. The acquisition card (PCI-1747U) designed by Advantech, offers 16-bit high resolution, 250kS/s sampling rate. The modules on the card mainly are a 16-bit A/D converter, a 1k-sample FIFO buffer, and a universal PCI bus.

Controlling the software system relies on LabVIEW. As a graphical programming language, LabVIEW can simplify the programming procedure and show the function of the system intuitively. The software system can control the value of the sampling frequency and the nodes where the sampling begins and ends flexibly. Data stored procedures and their storage formats can also be managed with software systems. Figure 8 shows the workflow chart of functions realized by the software, such as configuration parameters, tasks start and stop, data output, and storage.

6. Experiments and results
To verify the capability of the pulse acquisition system, volunteers have been recruited to perform experiments. The pulse sensor was attached to the wrist artery of the volunteers, and the signal was measured and recorded after the subject sat quietly. There will be some interference when the signal is collected by the circuit device, especially the power frequency interference is the most serious. Therefore, the original signal collected by the acquisition system is used to compare with the signal had been removed the power frequency interference by PyCharm software, as to verify whether our system was qualified in suppressing power frequency interference. Figure 9 is the actual experimental scene.
Figure 9. The experimental scene

Figure 10 is the pulse waveform output by the system. The A is the original waveform, and the B is the waveform after removing the 50Hz frequency by using PyCharm. The A and B figures in Figure 11 is the spectral figures which correspond to the A and B in Figure 10 respectively. As shown in the figure, the pulse waveform of the wrist from this system is similar to the wrist pulse waveform in the references [1]. It can be seen that the pulse data collected by this system is reliable. Moreover, it can be seen from Figure 10 that, compared with the part B, the signal in part A has little power frequency interference, but which basically has no influence on the overall signal. Further analysing Figure 11, it shows that the energy of the original signal collected by the system is mostly concentrated in 0~10Hz, and the interference of 50Hz power frequency takes up a small proportion compared with the main part, and this small part of energy can be easily filtered out by software. This indicates that the acquisition system can suppress most interference signals, laying a foundation for the subsequent data analysis, and it is suitable for pulse signal acquisition without great pressure.

Figure 10. Pulse signals from the volunteers
7. Conclusion
To sum up, this study developed a human pulse signal acquisition system, which makes a pulse sensor with PVDF piezoelectric film material. The pulse picked up by the sensor, which through charge amplifier, low-pass filter, voltage amplifier and voltage follower, is inputted to the acquisition card controlled by the software system. The actual test shows that the sensor can sense pulse beating effectively. The detection circuit can suppress 50Hz power frequency interference and its frequency multiplication interference, and amplify the signal into the desired interval. The acquisition card controlled by software can discretize the signal effectively. The acquisition system could collect effective pulse signal without heavy pressure, which more suitable for the method ‘three regions nine subdivisions’. In addition, the system adopts single power supply of 5V and reference voltage of 2.5V, which provides the possibility for the subsequent portable development of the system. However, considering more complex detection scenarios, portable and multi-channel pulse measuring system remains to be studied.

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