The Development of a New Three-channel Self-pressurized Wrist Pulse Acquisition System

Zhou Kan-Heng[1], Qian Peng[2], Xia Chun-Ming[1] and Wang Yi-Qin[2]
[1]*School of Mechanical and Power Engineering, East China University of Science and Technology, No.130 MeiLong Road., Shanghai, China*
[2]*School of Basic Medicine, Shanghai University of Traditional Chinese Medicine, Shanghai, China*

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Abstract: A new three-channel self-pressurized pulse acquisition system based on the principle of wrist pulse diagnosis in Traditional Chinese Medicine (TCM) was introduced in this paper, including the hardware and the software design of this acquisition system. This acquisition system can not only get three-channel wrist pulse waveforms under the best pulse taking force through the automatic pressure control module composed of stepper motors and ball screw pairs, but also simulate the process of the three regions and nine pulse-takings wrist pulse diagnosis in TCM. Besides, this acquisition system also can real-timely display and store three-channel wrist pulse waveforms. It can been seen that this wrist pulse acquisition system solved the problem that only the pulse waveforms in Guan region of the wrist can be detected, which does most of the existent pulse acquisition systems have. The system provided a user-friendly flexible sample collection platform, laid the foundation for analyzing the multi-channel wrist pulse waveforms and pushed forward the development of the standardization of wrist pulse waveforms and the objectification of wrist pulse diagnosis in TCM.

1 INTRODUCTION

In TCM theory, the diagnosis and the treatment of diseases are mainly based on wrist pulse diagnosis, which is pretty hard to learn. Therefore, modern people long for a kind of objective pulse detection and description method to systematically explain the principle of wrist pulse diagnosis in TCM (Li Jing-tang, 2001).

Recently, with the development of sensor technolygy, domestic and foreign researchers have already invented a series of pulse detectors to acquire and analyze wrist pulse waveforms, such as MX-811 pulse detector made by Nanchang Radio Instrument Factory, BSY-14 pulse detector made by Beijing Medical Factory, MX-3 pulse detector made by Shanghai Medical Research Institute, MTY-A pulse detector made by Tianjing Medical Research Institute, ZM-III pulse detector made by Shanghai University of Traditional Chinese Medicine and CMB-3000/2000 pulse detector made by Japan Colin company. Although these pulse detectors have described and analyzed wrist pulse waveforms from various aspects, most of these pulse detectors only have a single-probe sensor, which can only detect the pulse in one region of Cun, Guan and Chi of the wrist, as shown in the figure 1 below, and mainly detect the pulse of Guan region. These pulse detectors simplified the precisely multi-dimensional sensor of doctor's finger with a single-probe sensor. Therefore, the wrist pulse waveform sampled by these detectors does not carry complete information of wrist pulse (Fei Zhao-fu, 2003). In addition, the pulse sampling way of these pulse detectors differs form the pulse feeling of "three regions and nine pulse-takings" in TCM clinical science. The pulse feeling of "three regions and nine pulse-takings" is a triditional way of pulse feeling, in which the wrist pulses in the region of Cun, Guan, Chi are felt respectively and the wrist pulse in each region is felt under the floating, medium and sinking pulse taking pressures. Therefore, there are totally nine pulse-takings.

In order to conform to the pulse feeling of "three regions and nine pulse-takings" in TCM clinical science, our research group developed a new three-channel self-pressurized pulse acquisition system.

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1－Chi region 2－Cun region 3－Guan region

Figure 1: The region of Cun, Guan and Chi.

This acquisition system can not only acquire three-channel wrist pulse waveforms under the best pulse taking force through the automatic pressure control module composed of stepper motors and ball screw pairs, but also simulate the process of the three regions and nine pulse-takings wrist pulse diagnosis in TCM. Besides, this acquisition system can real-timely display and store three-channel wrist pulse waveforms.

2 DESIGN OF HARDWARE

The three-channel self-pressurized pulse acquisition system consists of three-probe pulse sensor, signal pre-processing circuit, automatic pressure controlling module and data acquisition and processing system. The diagram below shows the realization of the hardware.

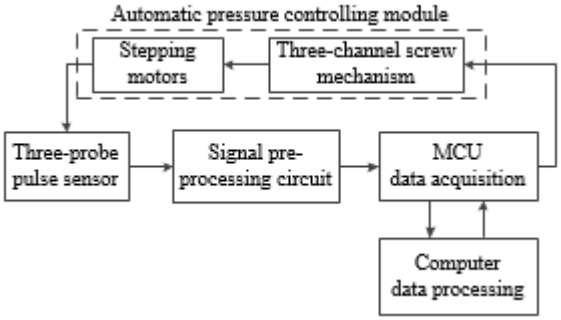


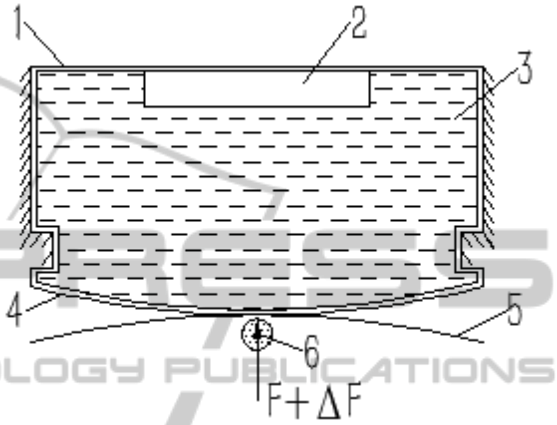
Figure 2: The block diagram of the hardware of three-channel self-pressurized pulse acquisition system.

2.1 Design of Three-Probe Pulse Sensor

The three-probe pulse sensor which is composed of three independent piezoresistive pressure sensors in the region of Cun, Guan and Chi, as shown in the figure 4 below, can not only realize automatic pressure increasing but also simulate the process of the three regions and nine pulse-takings wrist pulse diagnosis in TCM.

2.1.1 Principle of Pulse Detection

Among many kinds of pulse detection methods, ergography, which is more in line with the pulse feeling in TCM, is one of the most widely used method in the field of pulse detection. Therefore, three-probe pulse sensor applied the basic principle of ergography. The diagram below shows the physical model of each piezoresistive pressure sensor with the same design parameters.



1 － aluminium alloy case 2 － piezoresistive pressure sensor chip 3－liquid 4－aluminium alloy film 5－skin 6－blood vessel

Figure 3: Physical model of piezoresistive pressure sensor.

When aluminum alloy film 4 applies pressure onto “skin 5 and blood vessel 6” system round the radial artery (equal to the floating, medium and sinking pulse taking pressure with fingers), the aluminum alloy film 4 detects the reaction force of pulse taking force F and pulse force ΔF (Tang Wei-chang, 2005). Because of the incompressibility of liquid, the resultant force of these two forces is transferred to piezoresistive sensor chip 2 and makes the resistivity of the sensor chip 2 made by semiconductor material changes. The signal pre-processing circuit, attached by the sensor chip 2, outputs signals in different levels with the changes of resistivity caused by the changes of $F + \Delta F$, so different pulse taking forces and different pulses are able to be distinguished according to different signals, so as to realize qualified detection of pulse.

2.1.2 Parameters of the Pulse Sensor

All pulse sensors applied in three-probe pulse sensor are piezoresistive pressure sensors (NPI-12-101GH) manufactured by GE. Each sensor applies silicon elastic thin film as pressure sensitive element and measures pressure through the pressure electricity

conversion circuit, the Wheatstone bridge circuit, which is composed of 4 same resistance resistors fabricated by MEMS technology. Compared with the pressure sensor applied traditional metal strain foil, the sensitivity of this sensor is 50~80 timers higher. In addition, there is no mechanical linkage, therefore, the measurement accuracy of this sensor is relatively higher and the repeatability error and pressure hysteresis effect of this sensor are much lower. After testing, the main static capability indexes are as follows:

Sensitivity: 10mV/gram-force;

Linear range: 0~1000 gram-force;

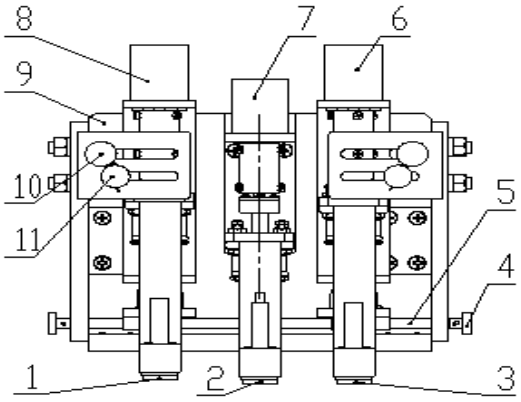
Accuracy: ±0.1%;

Working temperature: 10℃ ~ 40℃;

Composite error of linearity, pressure hysteresis effect, repeatability and temperature error: <4% FSO.

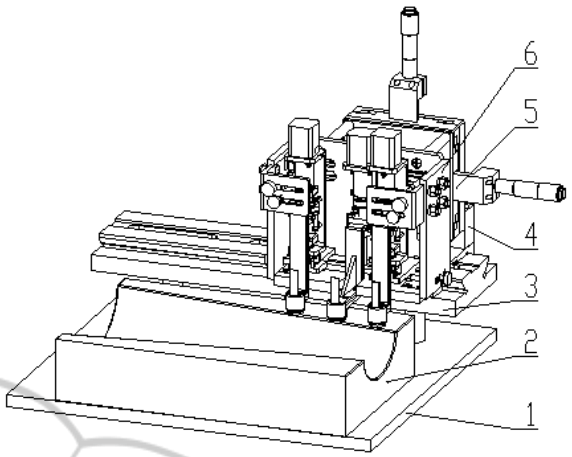
2.1.3 Structure of Three-Probe Pulse Sensor

In order to simulate the process of the three regions and nine pulse-takings wrist pulse diagnosis in TCM, the structure of three-probe pulse sensor can not only realize acquire wrist pulse waveforms simultaneously in the region of Cun, Guan and Chi under various pulse taking forces, but also realize the adjustment of the axial relative distance and the radial relative distance of these three separate pulse sensors. Figure 4 shows the structure of three-probe pulse sensor and figure 5 shows the structure of three-channel self-pressurized pulse acquisition system.



1－sensor of Chi region 2－sensor of Guan region 3－sensor of Cun region 4－x-axis position adjustment knob 5－x-axis threaded shaft 6－pressure controlling module of Cun 7－pressure controlling module of Guan region 8－pressure controlling module of Chi region 9－fixed bracket 10－y-axis fixed knob 11－y-axis position adjustment knob

Figure 4: The structure of three-probe pulse sensor.



1－base 2－wirst bracket 3－sliding guide table 4－connecting plate 5－x-y axes precise manual adjustment platform 6－three-probe pulse sensor

Figure 5: The structure of three-channel self-pressurized pulse acquisition system.

As can be seen form figure 4, three separate pulse sensors are attached to their own pressure controlling modules and these modules attached to the fixed bracket by various directions adjustment mechanisms which are all screw transmission mechanisms. The sensor of Guan used as location basis can only adjust the position along z-axis, while the sensor of Cun and Chi can not only adjust the position along z-axis via automatic pressure controlling module, but also adjust the distance relative to the sensor of Guan along x-axis via the knobs on both sides so as to adapt to the different patients with different relative distance among the region of Cun, Guan and Chi. In addition, the sensor of Cun and Chi can also adjust the distance relative to the sensor of Guan along y-axis via the knobs on the front panel so as to adapt to the inconsistency of the axial physiological curve of radial artery. The feature of the three-probe pulse sensor, which can adjust the position of three separate sensors flexibly along the axes of x, y and z, makes it can simulate the process of pulse feeling in TCM.

As can be seen from figure 5, compared with most pulse sensors that fixed with wristlet, three-probe pulse sensor is fixed on a precise manual adjustment platform. The wrist is laid on the wrist bracket under the three-probe pulse sensor when acquiring wrist pulse waveforms, which can not only avoid the measurement error caused by the excessive deformation of soft tissue because of fixed with wristlet, but also be more in line with the form of pulse feeling in TCM clinical science.

2.2 Signal Pre-Processing Circuit

The signal pre-processing circuit consists of mixed amplifier, pulse signal amplifier, pulse taking pressure signal amplifier and output circuit.

Each mixed amplifier amplifies the pulse taking pressure and the pulse signal that detected by the pulse sensor. In order to keep the amplified signal stable and low-noise, instrumentation operational amplifier, which has advantages of low noise, low drift, low power consumption, high consistency and strong anti-interference ability, is applied.

Each pulse signal amplifier consists of band-pass filter and general operational amplifier. Because there is DC component in the original signal amplified by the mixed amplifier, which will cause the output signal saturation and distortion if this signal is put into the main amplifier directly, so as to amplify the pulse signal (AC component of the original signal), band-pass filter is applied to remove this DC component in the signal. At the same time, appropriate time constant should be calculate according to the frequency characteristics of pulse signal.

Each pulse taking pressure signal amplifier consists of low-pass filter and general operational amplifier. Low-pass filter is used to get the low-frequency component of the original signal and general operational amplifier is used to amplify the low-frequency component of the original signal. The amplification factor should not be too large to cause the output signal saturation.

Each output circuit is an adder circuit that consists of general operational amplifier. And the function of the output circuit is to synthesize the complete wrist pulse waveform involving the pulse taking pressure and the pulse signal. Then, this wrist pulse waveform is transmitted to the data acquisition and processing system to real-timely display and store.

2.3 Automatic Pressure Controlling Module

The automatic pressure controlling module, which is applied to realize automatic compression in the region of Cun, Guan and Chi, but also can simulate the process of the three regions and nine pulse-takings wrist pulse diagnosis in TCM, is composed of three independent screw mechanisms and stepping motors. Data acquisition and processing system calculates the pulse taking pressure of each channel and analyzes the peak-to-peak value of wrist pulse waveforms to find the best pulse taking force. And at the same time, it sends commands to automatic pressure controlling module to adjust the position of each sensor along z-axis to ensure these sensors acquire wrist pulse waveforms under the best pulse taking force. Some researchers have studied on the range of the pulse taking pressure that human body can endure and find the upper limit is 261.19 gram-force (Wang Jing-jing, 2010). Therefore, the maximum setting of the pressure range of the automatic pressure controlling module limited by the software and hardware is 0 ~ 250 gram-force.

2.4 Data Acquisition and Processing System

After A/D conversion, three-channel pulse data, which acquired under the best pulse taking force, is uploaded to the host computer through serial communication. Data acquisition and processing system mainly realize real-timely display of the wrist pulse waveforms, real-timely calculation of the pulse taking pressure and dynamic pulse data storage, which lays the foundation for analysis of multichannel wrist pulse waveforms.

3 DESIGN OF SOFTWARE

The software of three-channel self-pressurized pulse acquisition system is composed of Micro Control Unit (MCU) data acquisition program and PC data processing software.

3.1 MCU Data Acquisition Program

The MCU, applied in three-channel self-pressurized pulse acquisition system to acquire three-channel pulse data, is a STM32 series chip, whose kernel architecture is ARM Cortex-M3. MCU data acquisition program, which simulates the process of the three regions and nine pulse-takings wrist pulse diagnosis in TCM, uploads the three-channel wrist pulse waveform samples acquired under various pulse taking pressures to the host computer. At the same time, the host computer calculates the pulse taking pressures and the peak-to-peak value of wrist pulse waveform samples to search for the best pulse taking force. After finding the best pulse taking force, the host computer sends it back to MCU to set the pulse taking pressure to the best one via automatic pressure controlling module. And then, MCU filters the signals with sliding filter, samples

the wrist pulse waveforms under the best pulse taking force and uploads the best wrist pulse waveforms to the host computer through serial port.

3.2 PC Data Processing Software

Three-channel self-pressurized pulse acquisition system applies personal computer as the host computer to receive the three-channel pulse data sent from MCU and do corresponding processing. This computer data processing software, which is written by C#, is based on the Microsoft .NET Framework 4. The interface of the software is shown in figure 8.

This data processing software can not only real-timely display three-channel wrist pulse waveforms and their corresponding spectrums, but also real-timely display current pulse taking pressure in the pressure display area on the left side. Besides, this data processing software can also search for the best pulse taking force through comparing the peak-to-peak value of two adjacent cycles of the wrist pulse waveforms and the specific process as shown in figure 6. Also, this data processing software can regulate the pulse taking pressure manually through pressure regulating button. All three-channel pulse data acquired can be stored into the database automatically according to the patient's name, sampling date and time and other information and can be loaded form the database for viewing and analysis at any time.

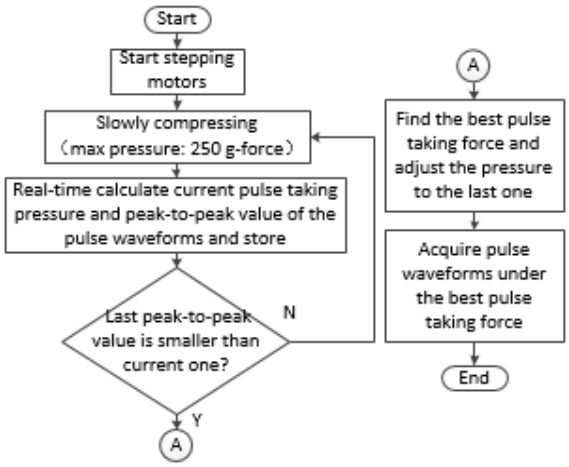


Figure 6: Searching process of the best pulse taking force.

4 RESULTS

4.1 Result of Pulse Sensor Test

Our research group has carried out the static test of the pulse sensor between 0 ~ 250 gram-force. Figure 7 shows the result of the linear regression, whose y-axis represents output voltage (mV) and x-axis represents input pressure (gram-force). The R-square of the linear regression is 0.9983, which indicates the linearity of the pulse sensor is excellent in the range of normal pulse taking pressure and can detect the pulse taking pressure accurately.

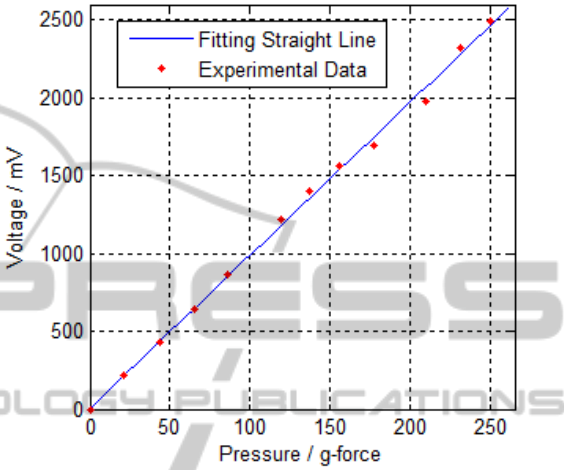


Figure 7: The result of the linear regression of the pulse sensor.

4.2 Result of Pulse Acquisition

Figure 8 shows the three-channel wrist pulse waveforms acquired by the three-channel self-pressurized pulse acquisition system, which indicates the acquisition system can get clear three-channel pulse data and accurate pulse taking pressure.

5 DISCUSSIONS AND CONCLUSIONS

All pulse sensors applied in three-probe pulse sensor are piezoresistive pressure sensors with silicon elastic thin film, which are fabricated by MEMS technology. Compared with the pressure sensor applied traditional metal strain foil, the sensitivity of this sensor is much higher. At the same time, because of no mechanical linkage conversion, the measurement accuracy of this sensor is relatively higher and the repeatability error and pressure hysteresis effect of this sensor are much lower.

The three-probe pulse sensor avoids being fixed with wristlet, while applies wrist bracket to fix the wrist, which can not only avoid the measurement

error caused by the excessive deformation of soft tissue because of fixed with wristlet, but also be more in line with the form of pulse feeling in TCM clinical science.

The PC data processing software of the three-channel self-pressurized pulse acquisition system acquires wrist pulse waveform samples under various pulse taking pressures through slowly continually compressing and then search for the pulse taking pressure of the largest peak-to-peak value of the wrist pulse waveforms as the best pulse taking force, which is more accurate than that searching for the best pulse taking force form several setting pressures and can acquire better wrist pulse waveforms.

The three-channel self-pressurized pulse acquisition system can not only simulate the process of the three regions and nine pulse-takings wrist pulse diagnosis in TCM and acquire the wrist pulse waveforms in the region of Cun, Guan and Chi under the best pulse taking force automatically, but also real-timely display the pulse taking pressure and the pulse waveforms of the wrist, which lays the foundation for analysis of multichannel wrist pulse waveforms and improving the development of the standardization of wrist pulse waveforms and the objectification of wrist pulse diagnosis in TCM.

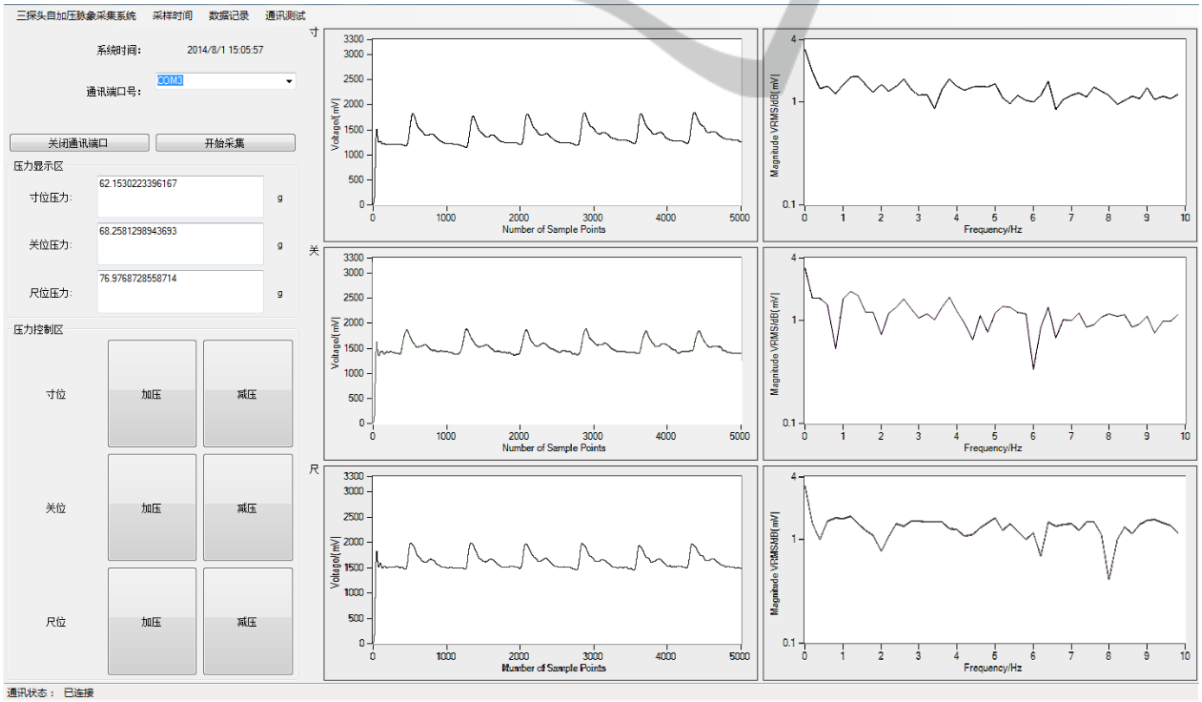


Figure 8: The interface of the software with three-channel wrist pulse waveforms.

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[Δ] Qian Peng contributed with Zhou Kan-heng, and they are both the first author. These authors contributed equally to this work.