# Design of 'Floating, Medium and Sinking' Pressure Simulation System for Remote Reduction of Pulse Condition in TCM

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**Abstract.** In order to solve the problem of simulating 'floating, medium and sinking' in remote diagnosis of TCM (Traditional Chinese Medicine), we designed a set of 'floating, medium and sinking' pressure simulation system which can feedback the remote pulse condition, including automatic pressurization device and pressure detection feedback device. The system uses a piezoresistive sensor to collect the compression force at the bionic prosthetic hand of the pulse recovery terminal and sends it back to the pulse collection terminal. The automatic pressure device at the collection end simulates the TCM doctor to automatically find the appropriate pressure intensity. In this paper, the pulse collection algorithm and pulse reduction algorithm are designed to make the pulse recovery more accurate. Through the collection of a large number of experimental data, and the experience of some professional doctors of TCM, it is believed that the system can well simulate the actual pulse process of 'floating, medium and sinking' pressure.

**Keywords:** TCM pulse acquisition · Remote reduction of pulse · 'floating, Medium and sinking' pressure feedback

## 1 Introduction

At present, remote diagnosis of TCM mainly relies on computer and network, sensor and communication to realize the diagnosis of looking, listening and asking, but there are still some difficulties in the study and application of remote pulse diagnosis. Since pulse diagnosis is a contact diagnosis method, the key technology to realize remote pulse diagnosis is to accurately reproduce the pulse signal collected by the pulse reproduction system, to generate the pulse consistent with the human body at the bionic hand of the pulse reproduction system[1,2]. The existing pulse complex system collects the frequency and amplitude of the typical pulse waveform, and then drives the linear motor to move up and down to produce a similar pulse. For example, Zhang Peng's pulse simulator based on voice coil motor designed by Shanghai Jiao Tong University [3]. This complex


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system can only be used for teaching TCM, but cannot be used for real-time pulse complex. There is another way based on hydraulic and mechanical design by Lv Hao of Tianjin University to use simulated pulsation. This way is to make full use of the advantages of hydraulic and mechanical vibration, to use the hydraulic system to generate blood vessel saturation, and to use the machine to generate simulated pulse pulsation. However, such a system is too limited to transmit pulse signals in real time, and can only extract pulse signals for a period of time for restoration [4].

The innovation of this system design lies in using a hydraulic system and waveform synthesis algorithm to establish pulse information reproduction system [3]. Besides, we designed a set of feedback remote pulse pressure device based on the TCM 'floating, medium and sinking' pressure pulse diagnosis method to make the pulse recovery more accurate. After testing, the system can simulate the radial artery and arterial blood flow of the human body more perfectly, to restore the pulse of the human body more realistically.

## 2 Pulse Condition Collection

The collection end of the remote pulse system is mainly responsible for collecting pulse information and extracting necessary pulse characteristic values. This system mainly uses the piezoresistive pulse sensor to collect data, displays real-time waveform on the PC display screen at the acquisition end, and then sends pulse characteristic data to the pulse restore terminal through the cloud server. And the pressure data obtained from the restore end is used to drive the automatic pressurization module for real-time automatic pressurization. The overall structure of the acquisition end is shown in Fig. 1.

### 2.1 Automatic Pressurization Module

The automatic pressure module is the core module to realize the pressure simulation system of 'floating, medium and sinking pressure' [4,5]. It can automatically pressurize to the feedback pressure to realize the simulated pressure of 'floating, medium and sinking pressure'. This module is based on the STM32F103 microcontroller as the core [6], using the drive motor mechanical rotation to control pulse sensor for automatic compression. The process of automatic compression module realization as follow, according to the real-time pulse pressure feedback from the restore end, the automatic compression module drives the motor to drive the pulse sensor to move up and down to realize compression. The piezoresistive pulse sensor can feedback the current static pressure and realize automatic compression through self-pressure correction of the automatic compression module.

Automatic pressure can eliminate many external interference factors, such as human interference factors. For example, in the collection process, the human arm inadvertently shaking. Since there is no professional person at the collection end to locate the pulse collection position, the pulse sensor may be placed in

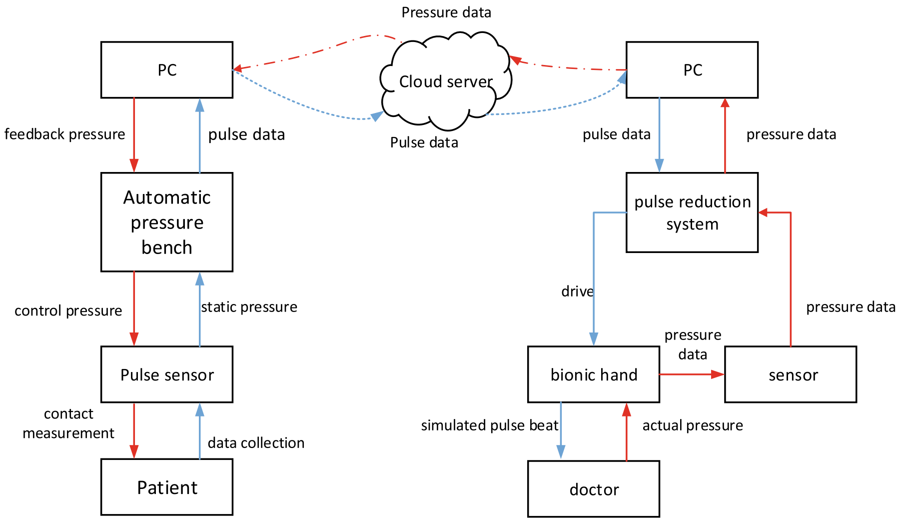



**Fig. 1.** System structure diagram.

the wrong position, leading to the collection of all wrong pulse signals, which is also a factor of human interference. Automatic compression can make the pulse sensor stable and correct collection. And the pulse sensor can be a stable acquisition. The most important thing is to realize the pulse collection synchronization between the collection end and the reduction end. Since this module is used for measurement in accordance with the pulse reduction module, the pulse pressure collected from the TCM doctor at the pulse reduction end will be feedback to the automatic pressure module through the network, so that the module will apply the same pressure to realize the synchronization of pulse real-time collection. The structure diagram of the automatic pressure module is shown in Fig. 2.

### 2.2 Pulse Characteristic Value Extraction

**Introduction of Pulse.** The pulse wave is formed because the vibration of the heart spreads outward along the arteries and blood flow [7]. Previous studies have found that pulse wave is mainly composed of an ascending branch and a descending branch, and the typical waveform is a three-peak wave, including the main-wave B, tidal-wave D and repulse F [8,9]. The ascending ramus and descending ramus constitute the main-wave B, and there is a notch on the descending ramus called isthmus E, which is immediately followed by the recurrent stroke F of isthmus E. Tidal-wave D often occurs between the main-wave B and the descending middle isthmus E, and the fore-wave is also weighed-wave. The schematic diagram is shown in Fig. 3.

**Pulse Characteristic Value Extraction Algorithm.** The pulse wave shape which has peak and valley is periodic, so we use the eigenvalue extraction method

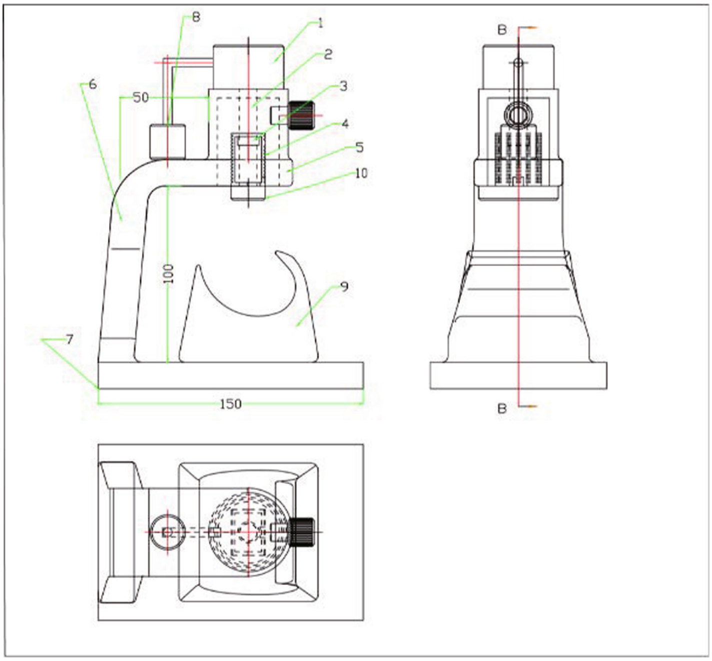



**Fig. 2.** Structure diagram of the automatic pressure module. (1-stepping motor, 2-motor lead screw, 3-nut, 4-connecting rod, 5-support sleeve, 6-support arm, 7-baseplate, 8-motor drive, 9-hand pillow, 10-pulse sensor)

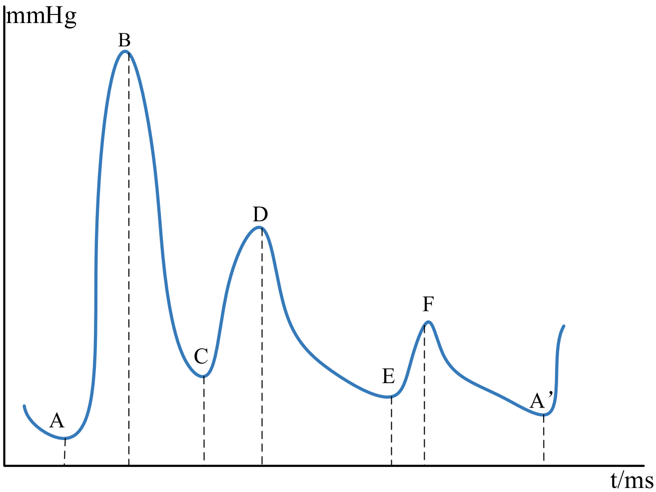



**Fig. 3.** Pulse waveform.

to process the data. We selects the time point (ms) of point B, C, D, E, F and a pulse period from point A to Point A'as eigenvalue [3]. The algorithm flow of data processing is as follows.

1) Filter the data. The differential method is used to remove some irregular abrupt values in the pulse sensor, which are generated by the data transmission circuit and reflected as the peak points in the waveform.
2) Data smoothing processing. In the process of pulse measurement, noise may be generated due to breathing, arm jitter, which requires data smoothing. In this paper, the method of sliding window filtering is used for data smoothing. Since the data collection frequency 200 Hz, and the pulse frequency of the human body is 1–2 Hz. In order to avoid big error of data, it is verified by experiment that it is better to select the sliding window with width of 5, including 5 data, to calculate the average and smooth the filtering effect.
3) Extract the pulse characteristic value. In a pulse period, after the second part, the curve becomes smooth, and the inflection point (extremum point) of the data can be obtained by using the method of difference between the front and the back of the data so that the complete period of the pulse wave and all the peaks and valleys within the period can be obtained. Then the timer of the main controller is used to get the corresponding time of the characteristic value, and finally, the data frame is packaged and sent to the pulse repeater.

## 3 Pulse Condition of Reduction

The pulse recovery end includes the simulation feedback module of 'floating, medium and sinking' pressure, which is mainly used to collect real-time pulse pressure data of TCM doctors. The data of 'floating, medium and sinking' pressure can be obtained by stabilizing the pressure data through the simulation algorithm of 'floating, medium and sinking' pressure, and the automatic compression module of cloud server feedback to the collection end can be used to realize remote pulse 'floating, medium and sinking' pressure simulation.

The pulse recovery terminal can receive the pulse data from the transit terminal (cloud server), and the embedded system drives the simulation arm and the hydraulic system uses the pulse recovery algorithm for pulse recovery.

### 3.1 Hydraulic Bionic System

The hydraulic system [10,11] designed according to the physiological rules of human arteries is mainly composed of motors, hydraulic pumps, solenoid valves, liquid storage tanks, silicone oil, oil pipelines and hoses. The motor and hydraulic pump are combined to drive the silicone oil flow, and there are two sets of motor and hydraulic pump combinations in the reduction equipment for static and dynamic pressure control at the pulsation. The hydraulic pump drives the silicone oil to circulate in the pipeline and hose to simulate the blood flow in the radial artery of the human body.

### 3.2 Pressure Simulation Feedback Module

The module consists of three piezoresistive sensors, which respectively detect the pressure of TCM doctors on the Cun, Guan, Chi. The module is placed on the position of the reducing end to simulate the Guan, because the Guan has the strongest pulse signal. After the doctor fixed the position, he began to apply pressure. After the pressure was stable, the piezoresistive sensors sent the data, that is, the network feedback was sent to the collection end, and then the automatic compression module was controlled to measure the pulse. The structure diagram of the pressure feedback module is shown in Fig. 4.

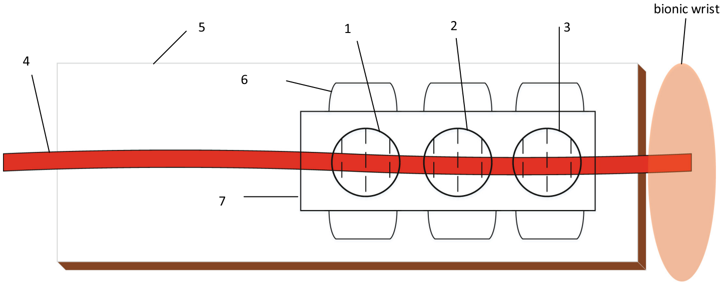



**Fig. 4.** Structure diagram of pressure feedback module (1,2,3-pulse sensor, 4-simulation of blood vessels, 5-simulation of the arm, 6,7-pulse sensor fixer).

### 3.3 'Floating, Medium and Sinking' Pressure Simulation Algorithm

In TCM diagnosis, 'floating' pulse lightly on the skin can be felt, the 'medium' is obtained by pressing between the muscles under the skin, the 'sinking' is under the muscles [12]. The above methods are used by TCM for pulse of 'floating, medium and sinking'. However, in the process of remote restoration, machines cannot directly feel pulse like humans, so how to stabilize the pressure and determine the numerical range of pulse of 'floating, medium and sinking' have become a research difficulty.

This paper adopts a pressure simulation algorithm to solve this difficulty. The entry point is to find the best pulse pressure, the best pulse pressure refers to the doctor when the finger feeling is the strongest, the most obvious pulse fluctuations on the pulse channel pressure, it is the doctor to determine the pulse in the main basis [13]. In this paper, the collection end was used to collect pulse data from normal people under nine pressures of 0.25N, 0.5N, 0.75N, 1N, 1.25N, 1.5N, 1.7N, 2.02N and 2.3N. The best pulse pressure ($F_g$) was the one with the strongest pulse signal.

By analyzing the data of optimal pulse-taking pressure and previous research experience, it can be concluded that the optimal pulse-taking pressure at the is between 0.7N and 1.7N, the floating pulse is less than 0.7N, and the sinking pulse is greater than 1.7N. After the range of 'floating, medium and sinking' pressure is obtained, the system determines that if the error of the collected pressure data does not exceed 0.1N, the data will be stable and sent to the collection end through the network for automatic compression.

The pressure data on the Guan can be obtained as shown in Table 1.

**Table 1.** Pressure data range.

| location | Floating pulse data | Medium pulse data | Sinking pulse data |
|---|---|---|---|
| Guan | <0.7N | 0.7N-1.7N | >1.7N |

### 3.4 Pulse Condition Reduction Algorithm

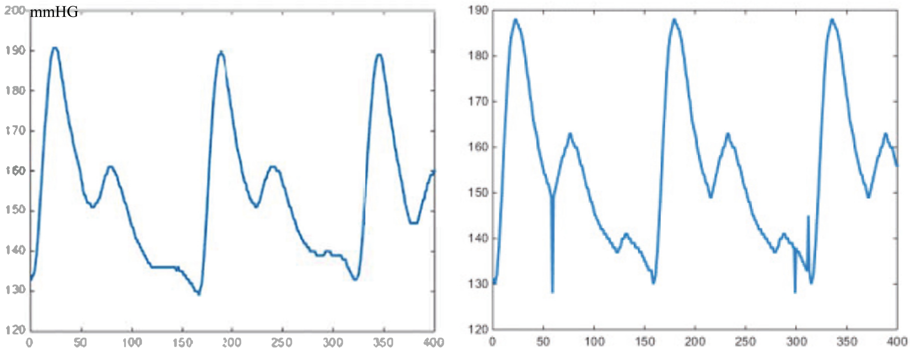
The waveform of the pulse of the human body has a dual wave and three wave. The waveforms are synthesized by using the amplitude of each pulse wave peak and the interval between peaks. According to the data frames received from the acquisition system, the characteristic values of the pulse waveform were obtained by solving the frames. Then, based on the amplitude of the characteristic values, the flow of silicone oil needed to form each wave peak and volley was calculated, denoted as peak flow (V) and volley flow (N), respectively. The total flow in the main wave rising time ($T_{AB}$) is denoted as the main wave total flow ($L_f$), and the main wave total flow divided by the main wave peak flow ($V_f$) can be denoted as the time when the solenoid valve needs to open to form the main wave, denoted as the main wave forming time ($T_f$). In the above description, the subscript f represents the main wave. The calculation method is as follows.

$$T_f = \frac{L_f}{V_f} = \frac{V_f \times T_{AB}/2}{V_f} = \frac{T_{AB}}{2} \tag{1}$$

Similarly, the waveform synthesis of tide-wave and repulse-wave is consistent with the principle of main-wave synthesis.

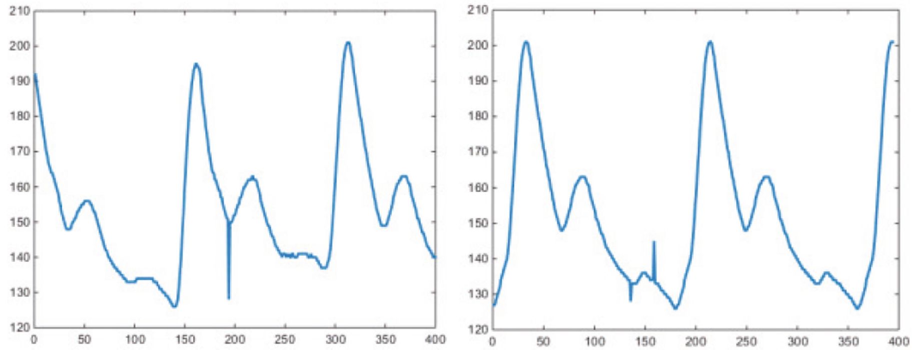
## 4 Experimental Results and Analysis

The pressure simulation system was used to collect the pulse at the 'floating, medium and sinking' pressure at an interval of 5 ms. We collect the actual waveform of the human body and compare it with the pulse reduction waveform under the 'floating, medium and sinking' pressure. Figure 5,6,7 shows the comparison between the actual waveform and the reduction waveform. Among them, the left figure is the actual waveform, and the right figure is the reduction waveform by the reduction system. The horizontal axis represents the data length and the vertical axis represents the pressure in mmHg.



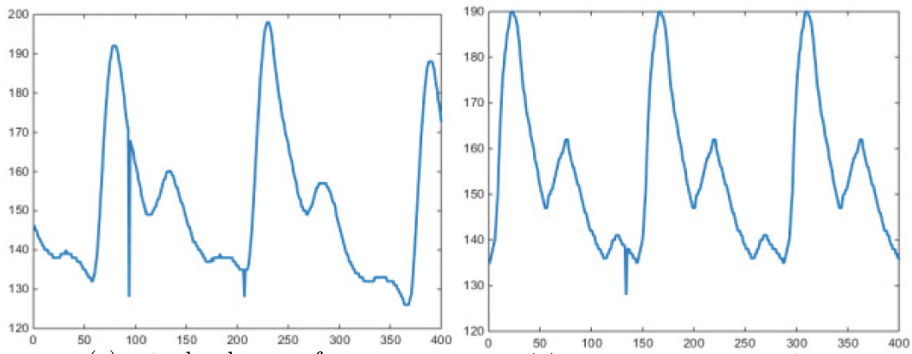

(a) actual pulse waveform (b) reduction pulse waveform

**Fig. 5.** Actual pulse wave is compared with the reduction wave under the 'floating'




(a) actual pulse waveform (b) reduction pulse waveform

**Fig. 6.** Actual pulse wave is compared with the reduction wave under the 'medium'




(a) actual pulse waveform (b) reduction pulse waveform

**Fig. 7.** Actual pulse wave is compared with the reduction wave under the 'sinking'

By comparing the eigenvalues of the actual waveform and the restored waveform, it is found that the Pearson correlation coefficient of the two groups of data is 0.8678, which proves that this algorithm can restore the pulse with a reduction degree of at least 85%, and it can be seen that the noise of the restored waveform is small and the data is relatively stable.

The pulse measurement photos of the prototype are shown in Fig. 8.


**Fig. 8.** Pulse collection photograph.

The eigenvalues of the actual waveform and the restored waveform are compared, as shown in Tables 2, 3, 4. It includes three pulse patterns of 'floating, medium and sinking' respectively.

**Table 2.** 'Floating' comparison of characteristic values of actual pulse and pulse reduction waveform.

| Eigenvalue | Actual value | Reduced value | Error value |
|---|---|---|---|
| $H_B$(mmHg) | 195 | 190 | 5 mmHg |
| $H_D$(mmHg) | 140 | 142 | 2 mmHg |
| $H_F$(mmHg) | 111 | 110 | 1 mmHg |
| $H_C$(mmHg) | 128 | 126 | 2 mmHg |
| $H_E$(mmHg) | 109 | 109 | 0 mmHg |
| $T_A B$(ms) | 118 | 113 | 5 ms |
| $T_A C$(ms) | 295 | 315 | 25 ms |
| $T_A E$(ms) | 580 | 585 | 5 ms |
| $T_C D$(ms) | 100 | 110 | 10 ms |
| $T_E F$(ms) | 50 | 55 | 5 ms |
| $T$(ms) | 750 | 810 | 60 ms |

**Table 3.** 'Medium' comparison of characteristic values of actual pulse and pulse reduction waveform.

| Eigenvalue | Actual value | Reduced value | Error value |
|---|---|---|---|
| $H_B$(mmHg) | 210 | 209 | 1 mmHg |
| $H_D$(mmHg) | 160 | 162 | 2 mmHg |
| $H_F$(mmHg) | 130 | 131 | 1 mmHg |
| $H_C$(mmHg) | 149 | 147 | 2 mmHg |
| $H_E$(mmHg) | 129 | 129 | 0 mmHg |
| $T_AB$(ms) | 120 | 115 | 5 ms |
| $T_AC$(ms) | 300 | 315 | 15 ms |
| $T_AE$(ms) | 585 | 580 | 5 ms |
| $T_CD$(ms) | 100 | 110 | 10 ms |
| $T_EF$(ms) | 50 | 55 | 5 ms |
| $T$(ms) | 750 | 800 | 50ms |

**Table 4.** 'Sinking' comparison of characteristic values of actual pulse and pulse reduction waveform.

| Eigenvalue | Actual value | Reduced value | Error value |
|---|---|---|---|
| $H_B$(mmHg) | 230 | 229 | 1 mmHg |
| $H_D$(mmHg) | 169 | 172 | 3 mmHg |
| $H_F$(mmHg) | 142 | 138 | 4 mmHg |
| $H_C$(mmHg) | 150 | 147 | 3 mmHg |
| $H_E$(mmHg) | 129 | 129 | 0 mmHg |
| $T_AB$(ms) | 120 | 115 | 5 ms |
| $T_AC$(ms) | 315 | 310 | 5 ms |
| $T_AE$(ms) | 585 | 600 | 15 ms |
| $T_CD$(ms) | 90 | 100 | 10 ms |
| $T_EF$(ms) | 50 | 55 | 5 ms |
| $T$(ms) | 715 | 765 | 50 ms |

## 5 Conclusion

The TCM remote pulse pressure simulation system is designed. The pressure simulation algorithm can accurately feedback on the real-time pulse pressure measurement of TCM doctors at the restoration end of the pulse. The TCM 'floating, medium and sinking' pulse sensing method is combined with modern technology to realize the wisdom of TCM. And the pulse reduction algorithm with the hydraulic system as the core makes the pulse image reduction accuracy further improved. Through the experience of many TCM doctors, the effectiveness of the system's restoring effect is verified, and then the remote wisdom of TCM diagnosis can be realized with the help of the platform.

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