Research Paper ■

Objectifying Researches on Traditional Chinese Pulse Diagnosis

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Abstract. This paper describes our recent researches on objectifying of Traditional Chinese Pulse Diagnosis (TCPD) by means of some modern signal processing methods. In order to demystify TCPD and prove its efficiency, its significance, theory and features are briefed firstly. Secondly, a survey of recent developments in the researches of TCPD is provided. Thirdly, our researches on baseline removal, monitoring of the pulse and the feature extraction of the pulse are introduced. Furthermore, our pulse acquisition diagnosis system is presented. Finally, the prosperities and future works are also pointed out.

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Introduction

TCPD has been proven to be worthwhile and clinically valid over 5000 years of the Chinese medicine history recorded. However, due to the difficulty to master it, many people still take it as a mystery. Thus, it is extremely necessary to introduce TCPD and let more and more people understand it. Many kinds of apparatus and systems that can automatically detect pulse from patients demonstrate that the researches of TCPD are significant and successful, but the modern research of TCPD has slowed down for a long time due to pulse's complexity and variation. [1] Nevertheless, the development in medical, sensor, pattern recognition, signal processing, database and other relative fields accelerate the research of TCPD forward recently.

This paper aims to employ some modern feature extraction and signal processing technologies to the objectifying researches on TCPD and point out its brighter future. First, the background, significance and the features of TCPD is stated. Then, an overview of recent achievements of TCPD is presented and our research on TCPD is introduced. Finally, we point out future tasks, emphases and restrictions of modern research on TCPD. For the clarity of understanding, some Chinese explanations corresponding to the English terms of TCPD are given in the round brackets together.

Traditional Chinese Pulse Diagnosis

TCPD, one of the four diagnostic methods of TCM, is to judge disease by means of fingertips palpating patient' pulse image shown in the superficial arteries. Many western people may consider that pulse waveform is just the same as electrocardiogram (ECG) and the patient's ECG analysis is enough. The signal of ECG acquired through several electrodes only reflects the bioelectrical information of body. Having analyzed the pressure fluctuation signal of pulse, doctors can detect and predict some symptoms that ECG cannot. TCPD can not only deduce the positions and degree of pathological changes, but also is a convenient, inexpensive, painless, bloodless, noninvasive and non-side effect method promoteded by U.N. [2]

The substance of pulse is the blood and the power of pulse is the heart. The heart pumps and blood into all parts of the body through vessels and then the blood enter viscera inward and reach limbs & skin outwards incessantly. Besides, the blood circulation also depends on other viscera, which coordinates the heart. The lung meets all vessels and the blood circulation all over the body should converge into the lung; the liver stores blood and is in charge of its conducting; the kidney stores essence. Thus through the vessels, all visceral state and disease condition can be understood by means of pulse diagnosis. [3,4] Pulse diagnosis is to palpate pulses with fingertips and then to understand and judge the disease condition through the process of diagnostician's comprehension. It also named pulse-palpating, pulse-feeling, pulse-touching, pulse-reading, pulse examination or pulse taking. Pulse taking is the common word. To sum up the ancient Chinese Medicine, the significances of TCPD research today are as follows:

1. The physical examinations for the people of special careers such as students, pilots, athletes and some others, especially for the workers in chemical plants;

2. The researches of drug' s functions and effects on blood vessels & heart;

3. The monitoring of patients, pregnant women, fetus and so on;

4. The important reference for the doctors to recognize the exterior and interior of disease, to judge the deficiency and excess, to ascertain nature of disease, to identify the cause of disease, to predict the prognosis and to inspect the disease mechanism;

5. The medical education and training for medicos;

6. The researches on the circulation system, nerve system, body fluid regulation, the emotions and so on; [5]

7. The researches on fitness and exercise (checking the effects and revising the exercise plan);

8. The surveying of psychology and the detecting of liar; [6-9]

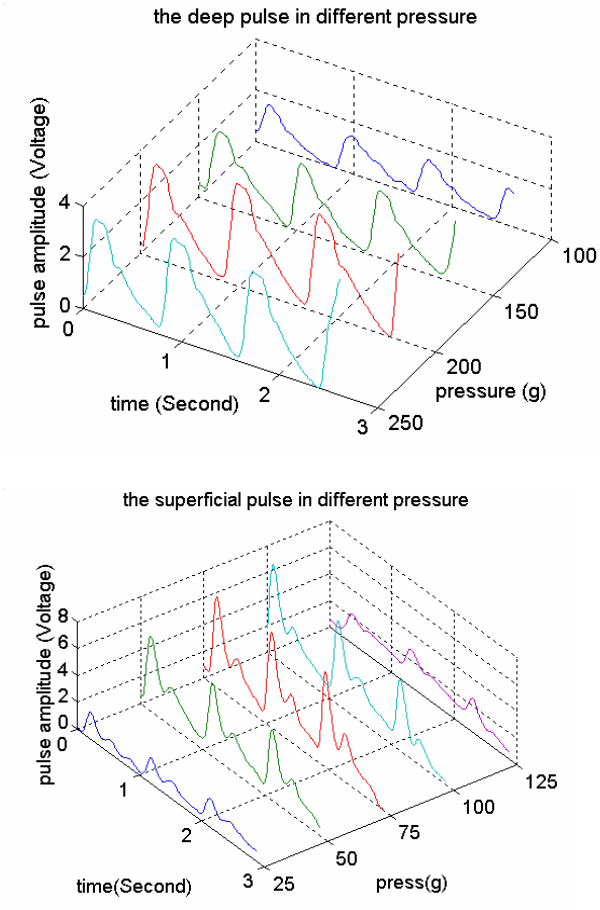

Figure 1 (a) Deep pulse (Cheng Mai) images, (b) Superficial pulse images

Since ancient times, doctors have been paying great attention to pulse taking and have accumulated rich experiences. Taking pulse in TCPD, involving counting the number of beats and identifying its form & pattern, does not just mean the identifying of pulse waveform as the researcher of modern medicine did. [10] It should be borne in mind that each of the types doesn't represent just one aspect of a given pulse. For example, floating and sinking describe the depth; slow and rapid describe the rate, whereas surging and fine describe the size of the pulse. Actually, these parameters occur in combinations. In most cases, a patient's pulse is described with a composite term such as floating, slippery, and rapid, or sinking, wiry, and thin.

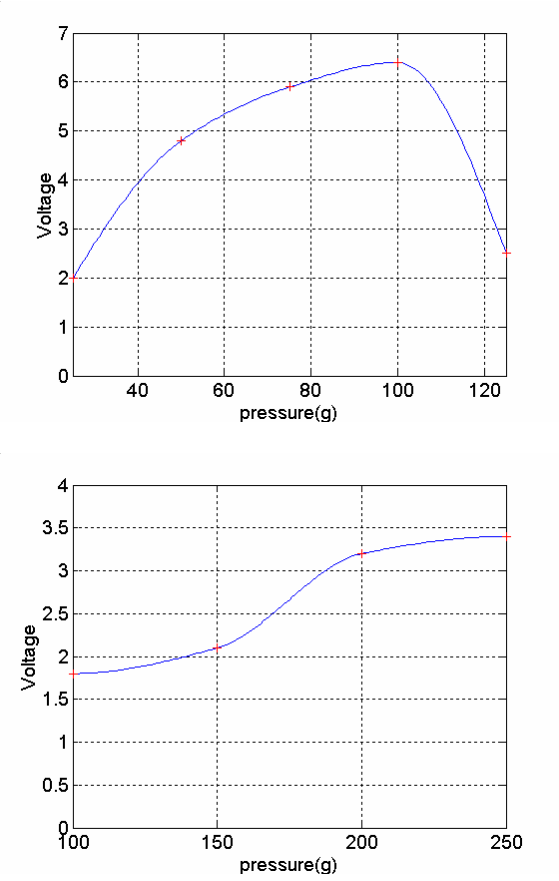

Figure 2 (a) Trend of superficial pulse images, (b) Trend of deep pulse images

According to the theory of TCPD, we use different pressure to acquire the pulse image and then judge the pulse whether floating or sinking, whether excess or deficiency and so on. Pulse shape varies with pressures. When the pulse waveform amplitude is the highest among those pulse

waveforms, it is named optimal pulse waveform. If the pressure acquired the optimal pulse waveform is smaller than 100g, this kind of pulse must be superficial pulse. When the pressure acquired the optimal pulse waveform is more than 200g, this kind of pulse must be deep pulse. Normal pulse's pressure acquired the optimal pulse waveform is smaller than 200g and more than 100g. Figure 1(a) and (b) are the superficial pulse and deep pulse we acquired. Their trends are illustrated in Figure 2. The deep pulse, defined only by its deep position, is often described as deficient on light pressure and excess by heavy pressure. Only when the pressure is more than 100g, the deep pulse can be felt. The best shape of the pulse is at the pressure of 200g or so. When the pressure is bigger than 250g, the pulse shape is still clear. The superficial pulse, defined only by its superficial position, is often described as excess on light pressure and deficient by heavy pressure. When the pressure is 25 g or so, the superficial pulse can be felt with ease, but when the pressure is bigger than 125g the pulse is not so clear. The best shape of the superficial pulse is at the pressure of 75g or so.

Thus, the researches on TCPD are more than the studies on pulse waveform. It just means the multi-dimension information. According to TCPD, we name those pulse waveforms as Pulse Image. What's more, new disease and new problems associated with our modern civilization have begun to show consistencies in TCPD. For example, the "ceiling dripping" scattered pulse of AIDS and a kind of knotted pulse related to cancer are among the few recently identified syndromes which seem to have characteristic pulse images. [11]

Developments of Researches on TCPD

To reveal the scientific essence of pulse diagnosis, a lot of researches have been made in the fields of TCM, western medicine, medical engineering and their related fields from 1950's. But some of them did not base on the theory of TCPD. Beside the researchers in China, some researchers in Japan,[12] Korean,[13,14] German, [15] Canada and US got interested in this research of TCPD. [16] In order to objectify pulse, engineers have designed many kinds of pulse sensors to acquire pulse. Of all these kinds of pulse sensors, the pressure sensors can reflect the information just as pulse feeling based on TCPD better. The HMX pulse sensor made by Shanghai Medical Instrument Company has better reproducibility in operation. [17] According to the theory of elastic cavity, McDonald, [18] Liu Zhaorong studied the circulation system. [19] But the cardiovascular system is so complicated that it cannot be modeled accurately. It is meaningful but it still needs the further systematic research.

Our Researches on TCPD

At present, the parameters' extraction is mainly carried out by time-domain signal processing method such as computing the amplitude, slope, area and so on. Among these parameters, the ratio between some of them also can be used to justify vascular elasticity and peripheral resistance. Due to some limits of related fields, the researches in TCPD make less progress. With the application of modern signal processing methods and technologies, some biometrics technologies such as speech recognition and signature recognition have made rapid progress. Thus, the research of TCPD should combine with the modern signal processing too.

In this section, all the pulse data are acquired by our pulse diagnosis system, which comprises a set of pulse sensor, adapter, amplifier, and computer. The sensor, named HMX-4, was made by Shanghai Medical Instrument Company. It is a hyperbolic contact-terminal type of the strain cantilever beam transducer, which is not the same as the previous sensors for studying the western medicine. Our sensor's probe is a trapezoid whose area is 29.4 mm^2, that makes the probe's little deviation do not influence its repeatability. Thus the impersonal, stable, high-precision pulse waveform is ensured. The following is our works

on baseline drift removal, monitoring and features extraction of pulse.

Baseline Drift Removal of Pulse Waveform

Pulse waveform can easily be influenced by many factors such as respiration, body temperature, muscle's dithering, body's movement and so on. The whole pulse goes down when exhaling and goes up when inhaling. Holding the breath may make pulse more stable. But these restricts not only make the patient uncomfortable and inconvenient, but also prevent us from acquiring the long period of stable pulse. Thus, we developed an algorithm for baseline removal.[20] The pulse, with its baseline being adjusted, is ***signal3*** in Figure 3, and its original pulse curve is ***signal1***. ***Signal2*** is the baseline drift.

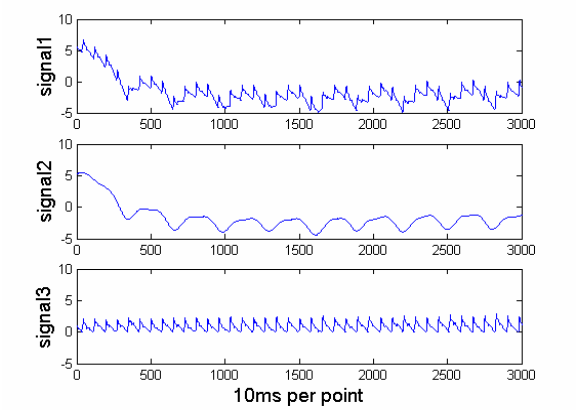

Figure 3 Actual pulse and its results filtered by wavelet

Monitoring of Pulse

TCPD has been researched worldwide. Some success has achieved. The means of acquiring the pulse information and the performance of pulse sensor are satisfied. But the research of pulse's monitor is reported seldom because of baseline drift and noise interferences. Having combined some modern signal processing technology, we extracted the baseline drift and noise interference. Thus, the monitoring of pulse can be realized. This does have the pathological and physiology meaning. Figure4 illustrates a period of the monitored pulse data. The signal in the upper is the contaminated pulse; the signal in the lower panel is the baseline being extracted; the signal in the middle is the real pulse.

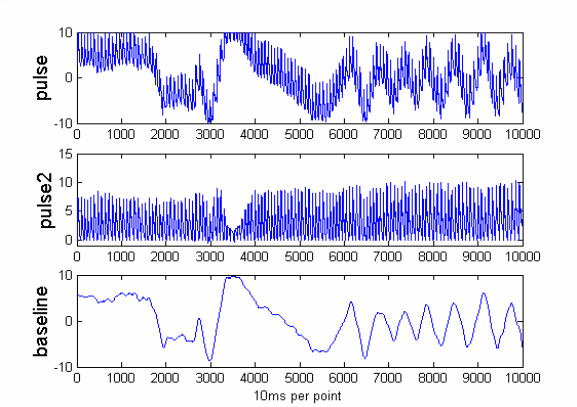

Figure 4 The monitoring of pulse

During the process of monitoring, we can study the pulse rate's variation too. As far as pulse' rhythm concerned, it often changes even to a healthy person. Figure5 shows us this phenomenon. The period's mean value is 0.8 second and its standard deviation is 0.0667. The knotted pulse **(Jie Mai)**, scattered pulse **(San Mai)** and intermittent pulse **(Dai Mai)**, all have their distinctive characters of the rhythm respectively.

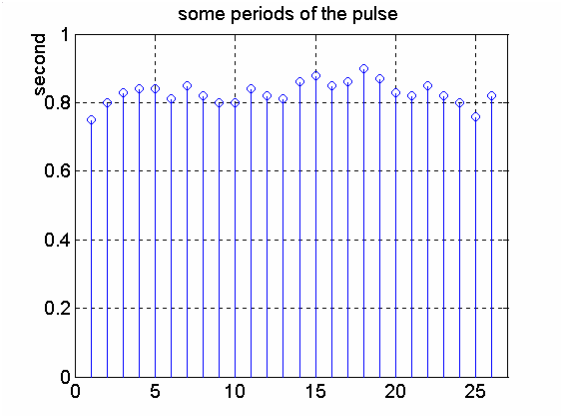

Figure 5 The pulse's period fluctuation

Table 1 Comparison of three different pulse's RPA

RPA \ pulse name	Taut pulse	Normal pulse	Smooth pulse
RPA (Ratio of pulse area) Maximum	0.65	0.40	0.35
RPA (Ratio of pulse area) Minimum	0.40	0.35	0.25

Feature Extraction

During the time domain analysis of the pulse, we find that the ratio of pulse area is a feature for differentiating the typical pulses. As Figure6 shown, the pulse area of every period (S_{pulse}) and its rectangle area (S_{rect}) can be calculated. The rectangle area (S_{rect}) equals to the value of pulse's main peak multiple its period. The ratio of pulse area (RPA) to the rectangle area is defined as follows.

$$RPA = S_{pulse} / S_{rect} \qquad (1)$$

Illustrated in Table1, the RPA of taut pulse ***(Xian Mai)*** is bigger than 0.4, while the RPA of normal pulse ***(Ping Mai)*** is bigger than 0.35 and less than 0.4, the RPA of smooth pulse ***(Hua Mai)*** is more than 0.25 and less than 0.35.

About the extraction of pulse features, this article promotes two kinds of area grade analysis methods, namely X-axis area analysis and Y-axis area analysis. Applying the X-axis area analysis method, the systolic area and diastolic area and some related parameters are calculated. What's more, by means of the Y-axis area analysis method, the main peak's width and the variation of pulse waveform shape characters can be got. As Figure7 illustrated, we gets the main peak's value P_m at first, then draw a line y=Pm. Then draw the equispaced lines parallel with the X-axis such as y=0.99* P_m, y=0.98* P_m,…, y=0.02* P_m and y=0.01* P_m. Next, the pulse waveform intersects with these lines and the areas of these intersects can be calculated. According to these areas trend, we can classify the various pulse images. If we combine these two kinds of area analysis method, the classification will be more satisfied.

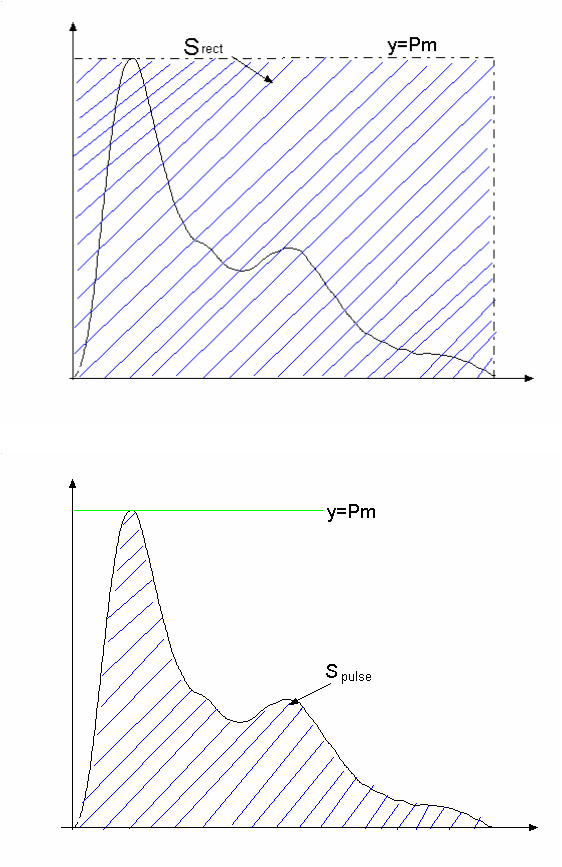

Figure 6 The scheme of areas computing, (a) The calculation of Srect, (b) The calculation of Spulse

Ling Y Wei found that the energy rate of pulse power spectrum did have some relation with the disease. This illustrates that the frequency analysis of pulse image is significant. From the power spectrum analysis, we can find that the ratio of the spectral peaks is very important in analyzing people's physical condition. Table 2 lists some of the comparisons. A_0, A_1, A_2, A_3, A_4,

A_5, ……, stands for the direct current component, first harmonic, second harmonic, third harmonic, fourth harmonic, fifth harmonic of the pulse and so on respectively. Applying method of power spectrum analysis, we can also analyze slow pulse ***(Man Mai)***, rapid pulse ***(Kuai Mai)***, moderate pulse ***(Huan Mai)***, scatter pulse ***(San Mai)***, knotted pulse ***(Jie Mai)***, running pulse ***(Cu Mai)***, intermittent pulse ***(Dai Mai)*** and so on.[21-25]

The choice on the method of the pulse's analysis is significant. Due to the variability of pulse mentioned above, some statistical approaches need to be used. Statistics alone do not help all the time, however. There is also a need for some signal processing algorithms, which are robust to this variability. Although several modern signal-processing algorithms have been developed for the research of pulse-taking, some technologies such as wavelet, STFT (Short Time Fourier Transform), Higher order spectrum, AR-spectrum array, neural network and so on were successfully applied in the research of heart's sound can be applied to study the TCPD too.[26,27] The methods of speech processing also can be used for reference. Based on our ever-growing database of pulse, our lab is on the way to improve the pulse image's efficiency of signal processing and recognition.

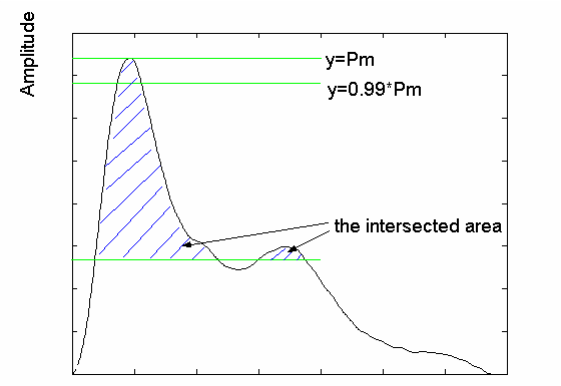

Figure 7 Schematic figure of Y-area analysis method

Table 2 Comparison of three different pulse's harmonics

Harmonic Amplitude	A0	A1	A2	A3	A 4	A5	A6
Taut pulse	0.47±0.05	0.30±0.05	0.12±0.02	0.04±0.01	0.02±0.01	0.02±0.01	0.02±0.01
Normal pulse	0.34±0.05	0.29±0.05	0.15±0.02	0.09±0.02	0.06±0.01	0.04±0.01	0.03±0.01
Smooth pulse	0.46±0.05	0.28±0.05	0.18±0.02	0.05±0.01	0.02±0.01	0.01±0.01	0.0

Conclusion

For the purpose of probing the mechanism of manifestations of the pulse of Traditional Chinese Medicine (TCM), this article has made lots of researches on pulse image by using signal processing methods. What's more, the monitoring of pulse is researched for the first time. In time domain, a brand-new area analysis method is proposed. In frequency domain, harmonic features are also extracted. With these comments, we end our discussion of TCPD by stating some of its developing directions.

1. Unifying the instrument for acquiring pulse pressure, the analysis methods and the normalization of TCPD;
2. Combining the integral and dynamic researches on TCPD with clinic;
3. Applying some modern signal processing & technology and looking for the new breakthrough of TCPD;
4. Combining with some other diagnosis methods such as tongue diagnosis, ECG, EEG and heart sound.

Acknowledgements

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