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Detection of multipoint pulse waves and dynamic 3D pulse shape of the radial artery based on binocular vision theory

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ABSTRACT

Background and objective: Pulse signals contain a wealth of human physiological and pathological information. How to get full pulse information is especially challenging, and most of the traditional pulse sensors can only get the pulse wave of a single point. This study is aimed at developing a binocular pulse detection system and method to obtain multipoint pulse waves and dynamic three-dimensional pulse shape of the radial artery.
Methods: The proposed pulse detection approach is image-based and implemented by two steps. First, a new binocular pulse detection system is developed based on the principle of pulse feeling used in traditional Chinese medicine. Second, pulse detection is achieved based on theories and methods of binocular vision and digital image processing. In detail, the sequences of pulse images collected by the designed system as experimental data are sequentially processed by median filtering, block binarization and inversion, area filtering, centroids extraction of connected regions, to extract the pattern centroids as feature points. Then stereo matching is realized by a proposed algorithm based on *Gong*-shape scan detection. After multipoint spatial coordinate calculation, dynamic three-dimensional reconstruction of the thin film shape is completed by linear interpolation. And then the three-dimensional pulse shape is achieved by finding an appropriate reference time. Meanwhile, extraction of multipoint pulse waves of the radial artery is accomplished by using a suitable reference origin. The proposed method is analyzed from three aspects, which are pulse amplitude, pulse rate and pulse shape, and compared with other detection methods.
Results: Analysis of the results shows that the values of pulse amplitude and pulse rate are consistent with the characteristics of pulse wave of the radial artery, and pulse shape can correctly present the shape of pulse in space and its change trend in time. The comparison results with the other two previously proposed methods further verify the correctness of the presented method.
Conclusions: The designed binocular pulse detection system and proposed algorithm can effectively detect pulse information. This tactile visualization-based pulse detection method has important scientific significance and broad application prospects and will promote further development of objective pulse diagnosis.

1. Introduction

Pulse is one of the most important and reliable source of information to evaluate the physiological state of the human body. In traditional Chinese medicine (TCM), pulse diagnosis is an effective method of disease diagnosis. To achieve objective pulse diagnosis, many researchers are dedicated to the exploration and study

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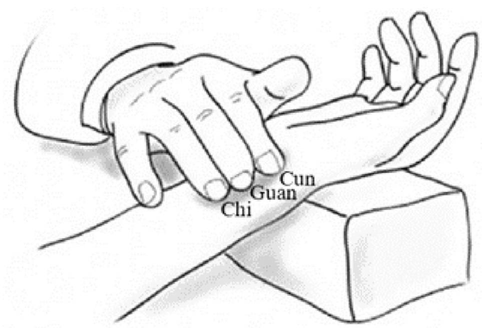

Fig. 1. Schematic diagram of pulse feeling in TCM.

of pulse sensor. The traditional pulse sensors are mainly piezoresistive, photoelectric and piezoelectric [1–4], which convert the spatial variation of pulse to a simple output of electrical signal that cannot reflect the detailed changes in the pulse of each point in the skin surface. Niu et al. used an ultrasonic probe to observe the movement of a vessel cross section [5,6]. Single-probe pulse sensor can only get limited information, which is quite different from pulse feeling used in TCM. As shown in Fig. 1, there are three important positions, Cun (寸), Guan (关) and Chi (尺), for pulse feeling in TCM, which are located at the wrist radial artery. Jin and coworkers studied the multipoint pulse sensor that can simultaneously measure pulses of Cun, Guan and Chi [7,8]. However, due to the sensor structure, size, performance, manufacturing processes and other factors, this method only measures a few points and cannot achieve simultaneous measurements in different parts of different vessel cross sections. In 2007, Jiang et al. applying laser triangulation measuring method detected skin surface vibration at the radial artery and achieved the pulse wave at a single point [9]. In 2013, Malinauskas et al. using laser triangulation method combined with projection moiré method measured the skin surface deformations of vascular graft under different input pressures [10]. The above optical measuring methods are constrained to be used only in laboratory and cannot be applied in practical situations, because of low signal-noise ratio, vulnerability to interference, and extreme harsh requirements for measurement environment. Zhang et al. designed and developed a bi-sensing pulse diagnosis instrument that could carry out simultaneous detection at Cun, Guan and Chi. This new method achieved good results [11–13]. Although the pulse sensor has been developed from the original single-position acquisition to three-position acquisition, from single-point acquisition to array-based multipoint acquisition, and greatly promoted the development of objective pulse diagnosis, there are some shortcomings, such as acquisition signal is limited, and the exact coincidence with actual pulse still needs to be further improved. Recently, Zhang et al. successfully developed a silk-molded flexible, ultrasensitive, and highly stable electronic skin for real-time monitoring of human physiological signals, such as pulse, heart rate and throat muscle group vibration, by attaching it to the human skin [14]. However, the pulse signal currently being measured using this electronic skin is single-channel.

To sum up, the existing usual rhythm detection methods and systems can only detect one dimensional electrical signals varying with time. Even the array pulse sensor can only detect a limited number of points on the same section. Moreover, the detected amplitude is not the longitudinal displacement caused by the pulse pulsation. Therefore, the three-dimensional (3D) shape of pulse cannot be reconstructed, and the concept of multi-dimensional pulse condition in TCM cannot be reflected. Furthermore, we cannot obtain accurate two-dimensional pulse information such as pulse width and pulse length, which are of great significance to reflect the physiological state of the human body.

If we can avoid or overcome the shortcomings in previous studies to a certain extent, and find a new method to fully detect the pulse information, to access dynamic 3D pulse shape, we could extract more pulse information and achieve a breakthrough in the field of objective pulse diagnosis. We have been devoted to the study of pulse tactile visualization method. A single-position dynamic pulse image acquisition system [15] was successfully developed, which could collect pulse images from one position of Cun, Guan and Chi. A three-position dynamic pulse image detection device [16] was also developed to synchronously collect pulse images of Cun, Guan and Chi. Consequently we achieved the image-based detection of pulse information. However, the 3D coordinates of spatial points are still defective based on monocular vision measurement principle, resulting in the accuracies of reconstructed 3D pulse shape and pulse wave not meeting the requirements of practical applications [17,18]. Binocular stereo vision imitates the way human and many animals catch spatial depth information using two eyes [19,20]. The use of binocular vision measurement technology for 3D detection is very suitable for our research. Therefore in this paper we describe a new binocular pulse detection system which was developed in order to access 3D pulse information, and which allows to analyze multipoint pulse waves over a rather big surface.

The remainder of this paper is organized as follows. In Section 2, binocular pulse detection system is introduced, and followed by the methods of pulse wave extraction and 3D reconstruction of pulse shape. Section 3 shows the experimental results and analysis, while Section 4 presents discussions of the method. The final conclusions are summarized in Section 5.

2. Methods

First, according to the principle of pulse feeling adopted in TCM and the pulse characteristics of human wrist radial artery, a binocular pulse detection system is developed. Second, multipoint pulse waves and dynamic 3D pulse shape are achieved by the proposed algorithm based on theories and methods of binocular vision and digital image processing.

2.1. Binocular pulse detection system

The system is introduced from four aspects, which are working principle, system hardware, system software and working process.

2.1.1. System working principle

The general working principle of the system is to visualize the pulsation of radial artery first, and then extract pulse information from visual information. The main part of the designed pulse detection system is shown in Fig. 2(a). A flexible thin film with mark patterns combined with an aluminum alloy cavity is used in the system to make an airbag probe which simulates the action of the finger pressing on radial artery. Pulse beating of the radial artery is reflected by the motion of the thin film. Two cameras above the probe synchronously collect dynamic images of thin film, i.e., the pulse images. Using the theories of imaging model and digital image processing, as well as binocular vision measurement principle, to process and analyze the pulse images, then the multipoint pulse amplitudes can be obtained. And multipoint pulse waves are acquired based on the collected pulse image sequences. 3D reconstruction of the thin film surface can be realized by the method of interpolation, then the 3D pulse shape is subsequently obtained by analyzing the motion and deformation of the thin film. Finally, dynamic 3D pulse shape is achieved. Fig. 2(b) shows a diagram of pulse detection.