New Pulse Recognition System for Coronary Heart Disease Patients Based on Pressure Sensors

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***Abstract*—The Coronary Heart Disease (CHD) is the most common cardiovascular disease due to the risk of heart-related complications. Currently, pulse diagnosis in Chinese medicine is an important method to recognition tool recognition of CHD. Here we designed pulse signal acquisition and recognition system based on the pressure sensors. The sensing units of the pulse signal utilized the ionic gel-based pressure sensors. Combined with the acquisition circuit board and convolution neural networks, the pulse signal acquisition and recognition system was established to identify CHD. This developed system provides an idea for the diagnosis of CHD in the homes of middle-aged and elderly people, and accelerated the development of the modernization of Chinese medicine.**

***Index Terms*—Chinese medicine, ion gels, neural network, pressure sensor, pulse recognition**

I. INTRODUCTION

According to the World Health Organization (WHO), cardiovascular diseases are the number one worldwide cause of death, enumerating around 17.9 million victims on a yearly basis [1], and continue to be the foremost cause of death among both males and females [2]. Coronary Heart Disease (CHD) represents a major cardiovascular disease. There are about 11 million patients with CHD in China, which has become a major social problem. Therefore, the prevention and diagnosis of coronary heart disease is a matter of urgency [3].

At present, the diagnosis of coronary heart disease is mostly the way of Western medicine [4]. And the Chinese traditional medicine to take the pulse to diagnose the health condition of a person has gradually withdrawn from the stage of history with the development of social modernization. However, Chinese medicine, the essence of Chinese culture [5], is not useless in the modernization process. Since the pulse beat reflects the blood ejection of the heart, Traditional Chinese Medicine (TCM) doctors can directly understand the health of the heart by taking the pulse [6], which is a very efficient and non-invasive way to determine cardiovascular diseases [7].

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A variety of sensors have been investigated to capture the pulse, including piezoelectric [8, 9], piezoresistive [10, 11], and capacitive [12, 13] sensors. Pulse sensors can be divided into the single sensor and array sensors [14]. Their work focused on flexible sensors, thanks to their ability to fit well to the human skin. Among these sensors, the gel pressure sensor stands out [15]. Ionic gels have attracted the attention of researchers because of their unique combination of high stretchability, transparency, biocompatibility, and low cost. Many high-performance sensors have been fabricated on the basis of ionic gels [16]. This ionic gel sensors had excellent mechanical properties, high electrical conductivity and good sensing characteristics. At the same time, the ionic gel sensors had good flexibility to fit the skin, and the pulse signal acquisition with this material was well suited.

In order to further investigate the relationship between pulse and disease, many works used machine learning methods to analyze the pulse, with convolutional neural networks being the most mainstream used to identify the pulse. Convolutional Neural Networks (CNN) [17], which perform both feature extraction and classification, are widely applied in studies that implement deep learning (DL) techniques [18, 19]. However, current studies of the pulse are limited to the identification of individual channels and do not combine the identification of the three parts (Cun, Guan, Chi) of the body in Chinese medicine [20].

In this work, we proposed a system that combined a flexible pressure sensor with a neural network to achieve multi-dimensional acquisition and discrimination of the pulse. This work provided a novel solution for modernizing TCM for the prediction of CHD by combining TCM, flexible electronics and artificial intelligence.

II. WORKING MECHANISM OF THE SYSTEM

The whole system consisted of three parts as shown in Fig. 1: the flexible sensing module, the signal processing and acquisition module and the intelligent recognition module. First, the tester placed the hand on the acquisition device and the inflatable airbag was inflated to apply pressure so that the sensor fit tightly against the radial artery. The sensors transmitted the collected voltage signal to an amplifier circuit. The signal was amplified and then converted into a digital signal by the digital-to-analogue converter module. The FPGA board transmitted the digital signal to the computer via RS485. Eventually, the computer compared the acquired signals with the neural network, realizing the judgement and recognition of the signal, presenting the three-dimensional information of the pulse. The wrist was placed on the acquisition device and the pulse can be judged and identified in about 10 seconds in a stable state, while the pulse at the three positions (Cun, Guan, Chi) can be displayed.

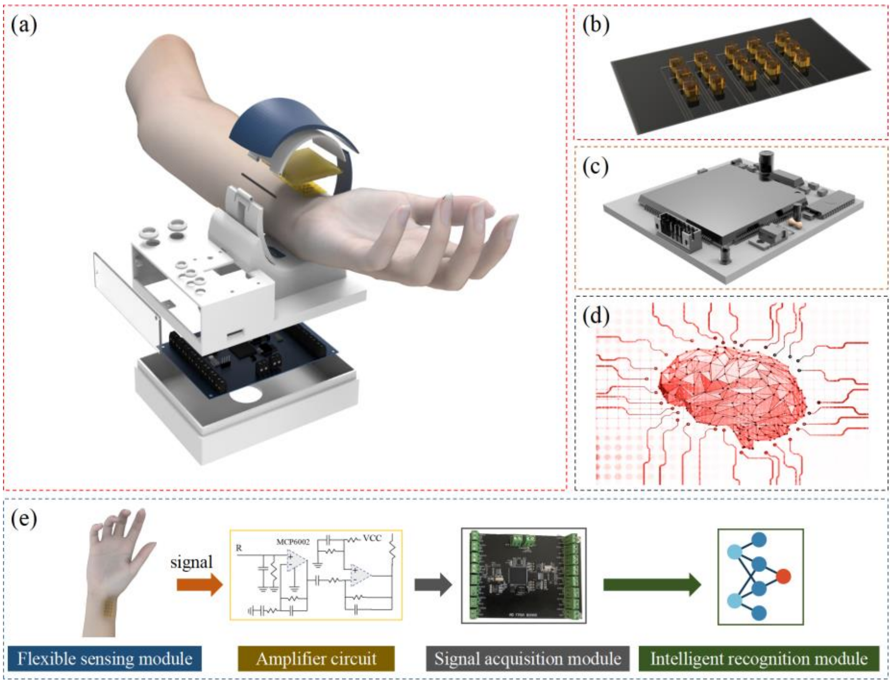

Fig. 1. Composition of the system: (a) exploded view of the system, (b) flexible sensing module: 3×5 ionic gel sensing array, (c) signal processing and acquisition module, (d) intelligent recognition module: it simply consists of a neural network trained model, and (e) relationship diagram of each module.

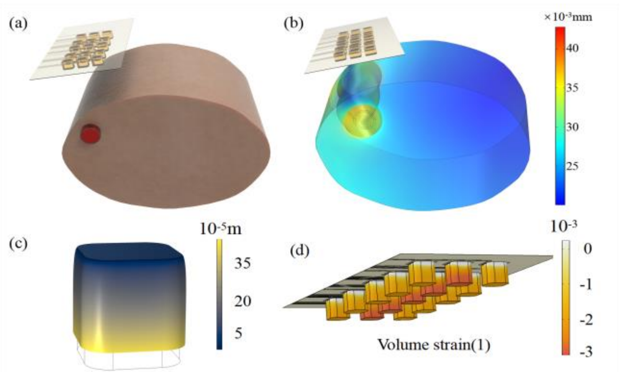

Fig. 2. Simulation results of the sensing modules: (a) schematic diagram of the radial artery and sensor position, (b) expansion of the blood vessels during the pulse beat, (c) deformation of the sensing unit under a 5kpa force, and (d) deformation of the entire sensing array under normal conditions of pulse force.

III. Simulation and Experiments

A. Design and Performance of the Sensing Module

This work took a model of the radial artery and vessel with an outer wall diameter of 3 mm and an inner wall diameter of 2.5 mm. The width of the wrist was 6 cm. A flow-solid coupling simulation of the wrist and vessel model was carried out using COMSOL simulation software to calculate the expansion of the vessel during one cardiac ejection cycle to design the width of the vessel expansion (Fig. 2). The 3×5 array of sensors was applied to the skin surface of the radial artery of the wrist and the pressure on the sensors was calculated for one pulse beat cycle.

The results showed that the force on a single ionic gel was approximately 1 kPa. Including the pressure of the inflatable airbag, the maximum pressure on a single ionic gel during the detection process was approximately 5 kPa. The mechanical simulation of the single ionic gel sensor showed that its mechanical properties met the requirements. The deformation of the whole array was simulated and the results showed that the deformation met the design requirements. The results of the design showed that the sensing array can meet the basic requirements for collecting multidimensional pulse images.

The preparation of sensors was fabricated similar to the reported literature [14]. The sensor had mainly sandwiched structure. The ion gel is used as pressure sensing layer prepared by polymerizing method of an ionic liquid. The obtained sensor had very good stability and fast response time (Fig. 3). The response time was 55 ms when pressure was applied and 110 ms when force was removed. The results of the tests showed that the flexible sensor had good stability and fast response. Moreover, the sensor could apply in the wearable system to detect the human activities. The facile fabrication and the excellent performance opened a novel way to fabricate the wearable sensor.

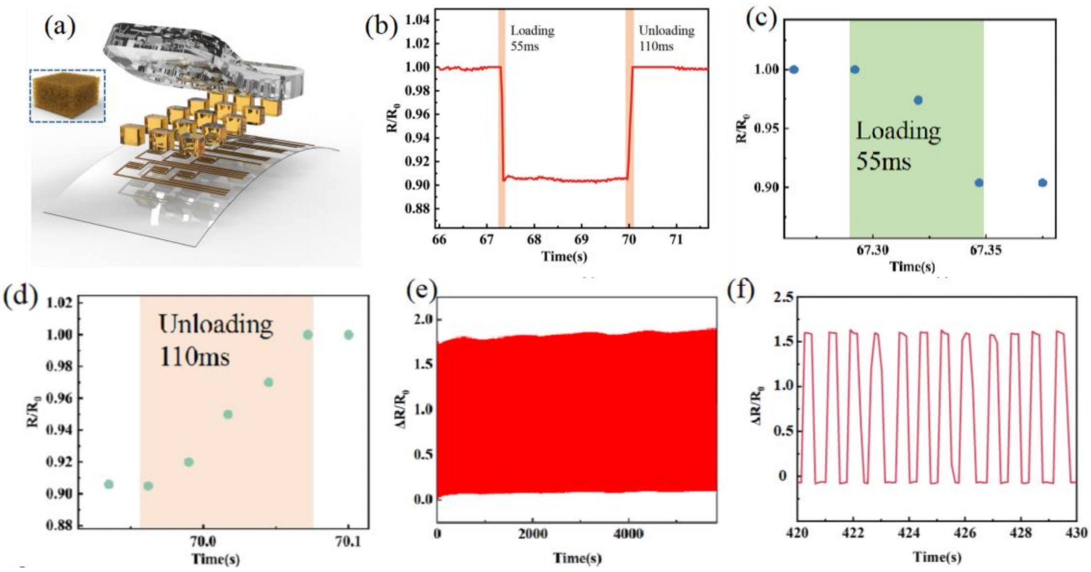

Fig. 3. Sensors and performance characterization: (a) schematic diagram of the sensor, which includes PDMS, ionic gel flexible sensing array, and flexible electrodes, (b) response time graph of the sensor, (c) response time of the sensor when force was applied to the sensor, (d) response time of the sensor when force was removed from the sensor, (e) pressure cycle test, and (f) a time period in the stress cycle test.

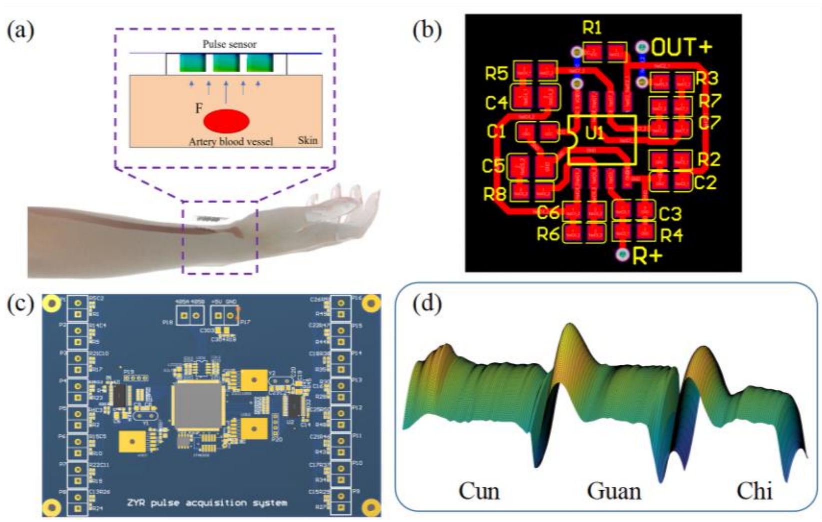

Fig. 4. (a) Sensor signal generation principle, (b) schematic diagram of the op amp circuit, (c) FPGA circuit diagram, and (d) 3D map of the collected pulse.

B. Design of the Signal Acquisition Module

The signal acquisition principle was shown in Fig. 4(a). The resistance of the sensor, which fit tightly on the skin surface, varied with the beating of the pulse. The length of the sensor was able to cover the position of the Cun, Guan, Chi of the normal human pulse and the width was able to cover the pulse width. As the pulse beats weakly, resulting in a small change in sensor resistance, the signal needs to be amplified before it can be acquired. The signal is processed with a secondary amplifier circuit and processed with a digital-to-analogue converter module, while the FPGA high-speed acquisition chip captured the digital signal and sent it to the computer via RS485.The frequency of the acquisition is 50 Hz.

The layout of the board was shown in Fig. 4(c). The entire board was powered by a 5 V supply only and measures 10 cm × 14 cm. The multidimensional pulse signal acquired by the FPGA was shown in Fig. 4(d). The Cun-Guan-Chi means the three locations of the pulse. Fitting a three-dimensional spatial pulse with a multi-channel array sensor can well imitate the three-finger pulse-taking sensation in Chinese medicine (Fig. 4(d)).

C. Design and Construction of the Intelligent Recognition Module

To enable comfortable pulse acquisition, a 3D-printed base for stable acquisition of the patient's radial artery pulses was designed. The physical diagram of the whole system was shown in Fig. 5(a). An FPGA-based high-speed circuit acquisition board was constructed. Due to the weakness of the signal, the amplifier circuit was designed to amplify the pulse signal before the high-precision ADS1256 digital-to-analog conversion. The sensor signal was transmitted to the neural network model through the digital-to-analogue converter module and the FPGA board. The collected data was compared with the neural network model to achieve discrimination, as shown in Fig. 5(b). Finally, a neural network model framework was used. The signal input was first transformed in the frequency domain, and then in turn entered a multilayer convolutional layer, a pooling layer and a dense layer. The CNN framework was shown in Fig. 5 (c). In this work, 185 pulse data from patients with CHD were collected and collaborated and 225 data from normal students were collected during school as a normal sample. CNN were used for training, mainly because they have several advantages: (1) CNN can share weights and reduce the number of parameters. (2) CNN are used to convolve and pool features at all levels. CNN have excellent performance in classification [21].

In this work, 80% of the pulse data collected from coronary and normal subjects were used for training and 20% for testing. The acquired data was converted in the time-frequency domain before entering. The time-domain signal was converted into a frequency-domain signal because the frequency-domain signal was better at extracting features of the coronary pulse in frequency, such as arrhythmias. After the fast Fourier transform (FFT) [22], the signals entered the convolution and pooling layers and finally passed through the flatten layer and dense layer. Experiments showed that the accuracy after processing with the fast Fourier transform was increased by about 5% to 91.46% (Fig. 5 (d)). In this work, the CNN trained model was saved to a computer for the purpose of real-time pulse recognition by the system. After assembling the flexible sensing module, the signal acquisition and processing module and the intelligent recognition module into a system to realize real-time judgement and reality of multidimensional pulse.

Eventually we integrated the three modules into a system where middle-aged and elderly people at risk of coronary heart disease can simply place their wrists on the device and recognize whether they have coronary heart disease characteristics in real time after collecting the pulse image. This device can realize the home health monitoring of middle-aged and elderly people, and also provided a new way of thinking for the modernization of Chinese medicine.

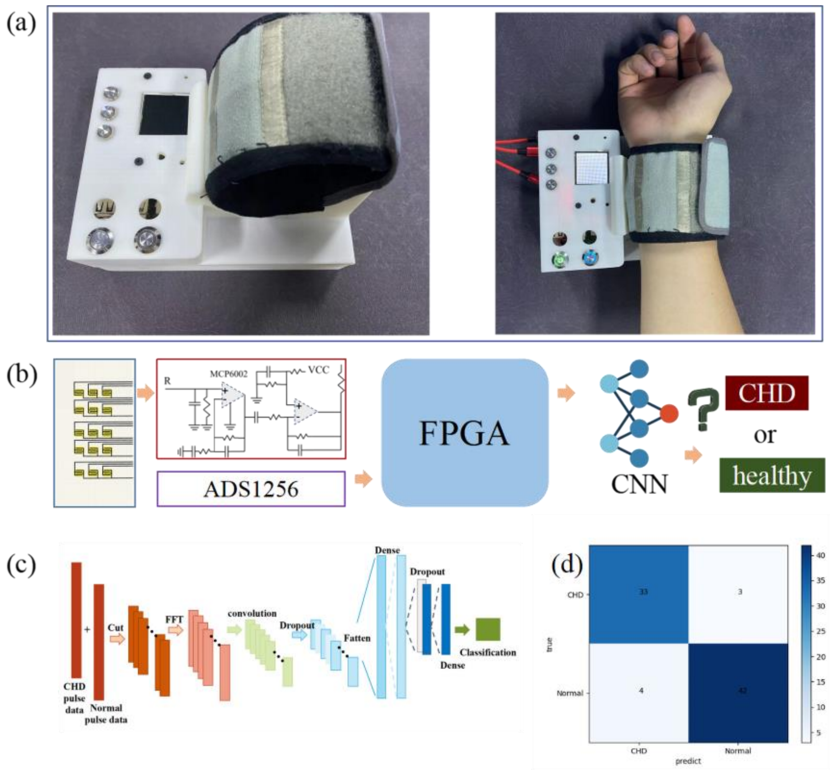

Fig. 5. Intelligent recognition module: (a) physical view of the system, (b) the flow chart of signal recognition, (c) CNN framework diagram, and (d) test result, recognition accuracy was 91.46%.

IV. Conclusion

In summary, we had researched and developed a pulse signal acquisition and recognition system to intelligently detect the pulse of CHD. The system mainly consisted of three modules: a flexible sensing module, a signal processing and acquisition module, and an intelligent recognition module. The device can realize the monitoring and recognition of CHD pulse in middle-aged and elderly people at home. The recognition rate of the system for CHD pulse was approximately 91.46%, and we were able to identify the people with CHD. It also presented a new idea for the modernization and development of Chinese medicine combined with artificial intelligence.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Yirun Zhu, Ze Ding and Fengning Zhang conducted the research; Yirun Zhu and Ze Ding analyzed the data; Yirun Zhu wrote the paper; Fengxia Wang and Lining

Sun provided technical guidance; all authors had approved the final version. These authors contributed equally: Yirun Zhu, Ze Ding.

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