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Design and Implementation of a Chinese Pulse Condition Acquisition System

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Design and Implementation of a Chinese Pulse Condition Acquisition System

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Abstract: Nowadays, with improvements in the quality of life, people are paying more attention to their health. Traditional Chinese medicine offers great advantages for daily care. In this paper, we present the development of a remote health care system, namely, Chinese Pulse Condition Acquisition System (CPCAS), based on the principle of Chinese pulse diagnosis in Chinese medicine and a wireless sensor network. We designed a remote health care terminal with a mini-pulse collection bench to overcome the challenge of differences in pulse characters of different people. An effective measured pressure control algorithm is proposed to achieve a balance between control accuracy and control time. The special signal conditioning circuit showed good performance in analog pulse signal processing. We also performed significant research to address the challenges of symptom recognition. Other distinctive features of this system include the following: intelligent sensing, a wireless health care network, effective energy management, small size, lightweight, and the ability to be networked for remote management. In this paper, we have introduced the design and implementation of CPCAS. We also demonstrate the use of the system and give evaluations on this system by several experiments. Our results indicate that CPCAS has significant practical feasibility.

Key words: Chinese Pulse Condition Acquisition System (CPCAS); traditional Chinese medicine; Chinese pulse diagnosis; symptoms recognition; wireless sensor network

1 Introduction

While people pay more and more attention to their health, medical technology improves. Nowadays, modern medicine can tackle most health problems and decrease pain. But the same cannot be said for chronic diseases as the basis of modern medicine is focused on the cure approach. Traditional Chinese Medicine (TCM) pays more attention to health conditions. It is more effective than modern medicine in the treatment of hypertension, cirrhosis, sub-health, chronic disease, and other physical discomforts. Furthermore, TCM can predict some illnesses early before symptoms appear, while the modern medicine cannot do this. It offers many advantages for daily health care and for human longevity. Chinese Pulse Diagnosis (CPD) is a very important part of the TCM diagnostic method. According to TCM theory, the pulse can reveal a lot about health and it is convenient for disease diagnosis and prediction. In practice, the Chinese doctor makes a health evaluation from three basic pulse positions on each wrist, known as “cun”, “gun”, and “chi”. CPD is a powerful tool for gathering comprehensive information about users’ health.

Simultaneously, the contradiction between the need for medical care and the available resources can
aggrevate social problems, such as the aging population, guardianship of infants, and rehabilitation of cogenic diseases. Remote health care is a possible optimistic way to solve these problems\cite{3–7}. It could be very useful to particular patients, e.g., those with congestive heart failure or hypertension, and thus plays a more and more important role in preventing hospitalization\cite{8}. So a remote health care system which is based on the theory of TCM, particularly CPD, can offer much better daily care. It is a very novel and useful solution in the field of medical care.

A Wireless Sensor Network (WSN) provides a wireless approach to enable data to be shared in the network, anytime, anywhere\cite{9}. The features of the WSN can aid the easy implementation of remote health care, for example, it can gather the data from several terminals at the same time without any cables, so the user can wear it and move around easily as they wish.

There are some research groups working on a telemedicine system for use in remote medical care. Motecare is a system for health monitoring designed by the Sydney University of Technology\cite{10}. It consists of a wireless network, based on WSN, that collects data from ECG monitors which users access via a PDA. Yamagata University in Japan proposed a remote medical care-supporting system\cite{11}. This system uses the Internet for data transmission and detects health parameters such as temperature and blood pressure.

Kang et al.\cite{12} described a Wrist-Worn Integrated Health Monitoring Device (WIHMD) with tele-reporting functions for emergency telemedicine and home telecare. It uploads vital biosignals and location information to experts through the commercial cellular phone network. Zhang\cite{13} proposed an individual device to detect the pulse wave. This device is dedicated to pulse detection data under different measured pressures. But there are still some deficiencies, such as great complexity during use and inconvenience for the user, as it does not have a data transmission network and the users have to be confined at a fixed position during measurements.

Moreover, most existing research on remote health applications pays more attention to establishing a remote health system or presenting a more complete solution by integrating multiple-technologies\cite{14,15}. However, the contradiction between the medical care needed and the available resources becomes obvious. In other words, most existing remote health care systems can only transmit, display, and process simple disease data to remote centers or have merits such as low cost or remote access via many kinds of connection\cite{14,15}. At present, there are few reports on WSN-based mobile remote medical care systems incorporating TCM.

Compared with existing research, our work attaches more importance to wearability, mobility, and ability to identify symptoms. In our previous work\cite{16}, a remote telemedical care system, namely a Wireless Networked Chinese Telemedicine System\cite{17}, was developed and is the solid foundation for the present work.

In this paper, we propose an improved Chinese Pulse Condition Acquisition System (CPCS) for evaluating human health conditions. This system is based on a combination of sensing technology, signal processing, pattern recognition, CPD principles, and WSN technology. It is much closer to reality than the previous version as we have carried out further research into pressure control, analog signal processing, and health evaluation. The primary goal of the proposed system is to help doctors estimate the users’ condition and give some advices on keeping fit. Furthermore, it provides a platform for quantitative research into TCM. The distinctive features of the proposed remote health care system include: small size, light weight, easy to use for multiple pulse detection, and networked multi-user management.

2 CPCAS Design

Based on a WSN, CPCAS is a networked system divided into three levels: the community networks, the sub-servers, and the main server. The main server is the core node in the whole topology. A community Local Area Network (LAN) can be built using many Remote Health Care Terminals (RHCT). Some RHCTs are used for family health care, others are used for common health care. The RHCT senses the pulse wave signal from special bio-sensors and picks up some eigenvectors for data post-processing. Afterward the user can get their health report and some health advice from the network via the sub-servers. The main server will usually be set up in a hospital or medical research institute where doctors can manage the user information and researchers can upgrade the software. Not just one, but many communities can be linked with the main server, building a large health care network through the Wide Area Network (WAN). At the same time, it provides basic services to users such as information.
3 RHCT Design

The RHCT, as a sensor node, is a basic unit of CPCAS within the whole WSN structure. It is the transmitter from the human pulse waveform to the digital data flow and can pick up many key points and eigenvectors from the raw data, and link into the health care network for information transmission. The RHCT consists of a set of function modules as shown in Fig. 1.

The core module, MCU, is the control and processing module. It realizes the control policy and processing algorithms via the specifically-designed firmware. The mini-pulse collection bench is a micro-device, fitted to the user’s wrist, that gathers pulse data and includes several sensors and a micro-motor mechanical device. The sensors convert the biological signals to electronic signals under steady pressure.

The micro-motor mechanical device is a pressure generator, controlled by the MCU, that maintains a steady measured pressure according to the user settings. Because the original analog signal is made up of a big DC component and a small pulse wave signal, it is not suitable for analog-digital conversion and further processing. A signal conditioning module is necessary to deal with this problem and it plays a key role in improving signal quality. The DC and AC components from the signal conditioning module are used to control the pressure generation and eigenvector extraction, respectively.

The wireless transmission module is designed to build a network with other devices and servers. The processed data or key information is transmitted to the server by this module. Moreover, we provide a friendly user interface for easier operability. Typically, this includes a matrix-keyboard input module and an LCD output module. User can get real-time information and easily set the measurement parameters using this Input/Output interface. For the other functions and expansibility of system, an auxiliary function module is designed into this structure. The power supply module, linked with each module, is the basic power management and consumption controller unit.

3.1 Mini-pulse collection bench

During Chinese pulse diagnosis, Chinese doctors always put their fingers on the wrist pulse positions and feel the pulse trace attributes under different measured pressures, such as “locations”, “frequency”, “rhythm”, “shape”, and “force”. This traditional approach is based on the doctors’ experience but has low repeatability. It is a challenge for medicine to identify a similar approach for quantitative research with high repeatability. In order to be consistent with the traditional CPD approach and provide a similar implemented platform for TCM research, we provide a pulse collection device with a mini-bench structure, shown in Fig. 2. It is small and easy to use, and can provide the different measured pressure on each of the three pulse points.

This bench consists of a main frame, micro-motor catheters, adjustment bolts, wristband, and sensors. The main frame concatenates the other parts and can be fixed to the users’ wrist with a wristband. The micro-motor and other transmission units are fixed in the catheters which are fixed to the main frame by adjustment bolts. The sensor is attached to the bottom of the transmission unit in the catheter. The relative position of the sensors...
can be finely adjusted by tuning the adjustment bolts.

Accurate health information, picked up from the pulse tracing attributes, is related to the measured pressure, so a steady pressure is necessary throughout the whole measurements. In practice it is a challenge to realize a measured pressure steadily and quickly. The micro-mechanical controller is the core control unit designed for pressure building. The real-time pressure situation can act as feedback from the signal conditioning module, the details of which we will discuss later.

The different pressures on the sensors are similar to the Chinese doctor pressing patients’ vein in the wrist, namely “Fu”, “Zhong”, and “Chen”. To maintain a steady pressure and prevent the pressure controller shifting its working status too frequently, a pressure control algorithm is essential. We implement an effective control algorithm for setting up steady pressure as a user setting and get a balance between control accuracy and control time. The flow chat is shown in Fig. 3.

The first step is initializing the system parameters and user interface, especially the non-volatile parameters, for power-down protection. Because of the differences in the sensors, we used the natural pressure parameter to eliminate the bias under no external pressure. For reducing the pressure change frequency, we set two thresholds to trigger the working state of the mechanical device. When the pressure is below the bottom threshold or above the top threshold, the mechanical device starts pressurization or decompression, respectively. Once the pressure is within the steady working range, the controller should keep still for measurement stability.

The sensors are sensitive to slight pressure, so we need to slow down the speed of the pressure adjustment to ensure stable measurements. Unfortunately, low speed greatly increases the adjustment time. In our pressure control algorithm, we check the gap between the current pressure and the setting value during the adjustment process. If it is a considerable distance away from the setting value, the mechanical device makes a quick adjustment to save time. When closer to the setting value, the controller slows the speed and enters the slow adjustment mode to give much more accurate control.

3.2 Signal conditioning module

This module is a bridge between the sensors and the Analog-Digital Converter (ADC) to make the signal suitable for the post process. A higher quality signal
is better for analog-digital conversion and post process. But, the problems of how to adjust the signal to meet the design requirements and weaken the effect of the differences of sensor are unavoidable challenges to be faced.

For better signal quality, we designed three independent signal conditioning circuits for three sensors’ signals. This structure of the conditioning module can effectively decrease the crosstalk between signals and reduce the impact of the circuit. But, this improved performance is at the cost of increasing the number and cost of microchips. The structure of one circuit unit of the signal conditioning module is shown in Fig. 4.

The prime purpose of this circuit is to separate the AC component from the DC in the raw signal, then amplify the pulse signal (AC component) appropriately and adjust the signal bias. Meanwhile, the DC component indicates the pressure put on the sensor and can be used by the pressure controller.

Because the raw sensor signal is too small to be processed and the large DC component easily leads to signal saturation, we have to run amplification after removing the DC component. Therefore, we adopt a two-stage amplification process in this module. When the raw signal from the first stage amplification is large enough, two types of integrators are used for extraction of the DC component. A slow integrator is used to generate the DC component that will be removed from the raw signal. Because of the insensitivity of the slow integrator to time, it will get an almost ideal result of the DC component to the blocking process. But it is too slow to be used for real-time pressure control. Considering the signal processing result and pressure accuracy, a quick integrator is used for individual real-time pressure control. The second-stage circuit uses a typical instrumentation amplifier for further amplification and removal of the signal DC component.

In addition, considering the differences of sensor and characteristics of the amplifiers, a bias voltage is sometimes necessary. We introduce an adjustable bias voltage to several parts of the circuits with some resistances and adders.

### 3.3 Control and processing module

This module is the core controller in the RHCT. It works from instructions programmed by the designer. Our application software is implemented based on an embedded system named TinyOS which was developed for WSN. The MCU provides a series of hardware units for system building such as the ADC, user interface, general interfaces, and timers. The main structure is shown in Fig. 5.

As a controller and processor, this module ensures that the terminal is working correctly as the developers designed. Firstly, it manages system timers for all kinds of timing processes, such as watch dog and timeout handling. Based on an energy-saving strategy, it manages the power supply of each module and provides several low-power modes. Cooperating with the user I/O module, it implements a friendly user interface for better operability. Through a multi-level option menu, users can easily set the options and select the working mode. For the wireless transmission module, it provides basic interfaces to access the hardware module and some networking protocols to help build a robust network.

Moreover, this module realizes the pressure control algorithm with the software. At the same time, it carries out signal conversion from the ADC, and pre-processes the data before wireless transmission. The data flow from the analog-digital conversion may contain some incorrect data because of the complex environment and device error. In the WSN, the wireless bandwidth is limited and the link quality is unstable. Therefore, a large amount of raw data is unsuitable for transmission.

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**Fig. 4** Structure of signal conditioning circuit.

**Fig. 5** Structure of control and processing module.
How to filter error data to decrease the amount of data transmitted is important research work in the WSN field. Focusing on our system, the pre-process is necessary for the accuracy of the data and the limited wireless transmission bandwidth. Mostly, it includes digital filtering and data compression among other functions. The design is shown in Fig. 6.

A digital filter is a good choice for picking up incorrect data. Specifically, we used a Sliding Mean Filter to process the data flow. The human pulse wave signal is a kind of continuous signal, so we set a window to define the interval between two consecutive data occurrence in the flow and discard any deviant data outside of the preset window.

Next, we ran data compression on the limited wireless bandwidth to save energy. After the analog-digital conversion, we read the result from a two-byte register (16 bits). But the ADC we used had a 10-bit accuracy, so there were 4 unused redundant bits. The core idea of compression is to cut off the redundant bits and splice the effective bits together in each data string. This is a lossless compression method to ensure accuracy of the system. For example, we read the register 4 times to get 4 raw data (16 bits/raw data), and make them into one group. Obviously each group takes 8 bytes without compression. Based on this compression process, by picking up the 10 effective bits from each raw data and splicing them together, we get 40 bits stored in 5 bytes. These 5 bytes contain all the information on this group for transmission. In this way, we can cut off 3 bytes from each raw data group. In other words, it saves the amount of data flowing by up to 37.5%.

3.4 Wireless transmission module

The wireless communication is based on the wireless transmission module which supports working frequency bands at 315 MHz, 433 MHz, 868 MHz, and 915 MHz. Specifically, the RHCT works at 433 MHz considering the transmission distance and power consumption. In our system, RHCTs can communicate with each other at a distance of over 100 m. Based on the TinyOS, it can realize a typical kind of WSN with BMAC and other networking protocols.

3.5 User I/O module

The user I/O module provides a Graphical User Interface (GUI) via the LCD output module and a matrix-keyboard. Users can get real-time information and set the measurement parameters easily by using this I/O interface. The display can be disabled during the active state to save energy.

3.6 Power supply module

There are many modules in RTHC all powered by different voltages. We designed multiple power supplies to meet the needs of each module. For modules using the same voltage, we separated their power supplies from each other to decrease the crosstalk between them. Meanwhile, because the energy is limited in the WSN and the portability is an important character of the apparatus, the RHCT should be powered by the battery. The power supply module controls the power supply of each part of the RHCT as shown in Fig. 7. It delivers appropriate power to each part, based on a particular working status, using a multi-channel analog switch. The under-controlled parts include the LCD, micro-mechanism driver, wireless module, amplifiers, and sensors. The power supply delivered to the amplifiers is converted by a DC-DC converter and that to the sensors is regulated by a voltage regulator after the DC-DC conversion.

4 Design of Server

The server is the host server in the CPCAS which gathers, analyzes, and stores data from the RHCT. In practice, the server can be realized as two-level (sub-server and main server), or adopted as an independent super-server. In this paper, the server is regarded as one whole. The server provides a number of modules including the network interface (serial port interface), protocol decoder, display module, analyzing and processing module, database, display module, and GUI. The structure of server is shown in Fig. 8, and its
First, real-time pulse data information detected by the RHCT is transmitted via the wireless network to the sink node. The sink node is a wireless networking device connected to the server by a USB cable. Next, the data flow is uploaded to the server by the sink node. The network interface provides the necessary drive for connection with the sink node. For data transmission in the wireless network, the data is encapsulated by the net protocol. The protocol decoder is necessary to get the original data from the transmission package. The original data is used to obtain information regarding the health condition in the analysis and processing module. Mostly there are three important sub-processes: pre-processing, feature extraction, and training and classifying. Pre-processing procedure includes some functions such as data filtering, data standardization, and data normalization. The feature extraction procedure obtains several key feature points from all the pulse waveform data. After generating a feature vector corresponding to every original pulse waveform data, we trained the system with a sample set and obtained training parameters to identify whether or not one sample showed a symptom. The analyzing and processing details are discussed in Section 3.2. Finally, the original data, feature vectors, and classification results were stored in the database. Physicians or family members can use the remote accessing service to gather useful information on the user’s health condition via the Internet. In addition, the display module and GUI are designed to provide an input/output interface to the users.

In addition, through the GUI in the server software, some useful relevant information is shown during pulse data collection, e.g., apparatus and serial port status. The position of these feature points in the pulse waveform can also be examined. The quality of the collected pulse waveforms may be checked by zooming out from the waveform display region in the GUI.

5 System Evaluations

In order to test the effectiveness and usability of our system, we conducted real experiments by collecting human pulse waveform data. Our experiments involved many human symptoms such as sub-health, hypertension, and coronary. These were conducted in the Experimental Research Center of the China Academy of Chinese Medical Sciences and the Institute of Computing Technology of the Chinese Academy of Science. To verify of the accuracy of our experimental results, we compared them with diagnosis feedback from clinical doctors.

Pulse waveform data flow, sensed by our RHCT, consisted of the sequence number of continuous detection and the corresponding pulse pressure value for every instance. In CPD theory, some particular points in the pulse waveform are considered as very important physiological parameters. These are called the trough pulse point, peak pulse point, peak point before the dicrotic pulse, trough point of the dicrotic pulse, and peak point of the dicrotic pulse. In this paper, we name them as key feature points and show them in Fig. 9.

For identifying symptoms and classifying experiments, we created one feature vector corresponding to every original pulse waveform, as shown in Fig. 10. The feature vector with 22
dimensions, as shown in Fig. 10, is made up of time-domain and frequency-domain feature variables, both from the original pulse waveform data. By analyzing and processing the pulse waveform data, the former are created according to the feature points (as shown in Fig. 9). The latter, as shown in Fig. 11, are generated by transforming and analyzing the frequency.

In Fig. 10, variables from No. 1 to No. 15 can be computed in the time domain and those from No. 16 to No. 21 in the frequency domain. Some details are shown in Figs. 9 and 11, respectively. The 22nd variable is processed as the measured pressure. According to Fig. 11, $H_1$ is the amplitude value and $f_1$ the frequency value of the greatest energy point in the frequency domain. Similarly, $H_2$ and $f_2$ are the second greatest energy points in frequency domain and $H_3$ and $f_3$ correspond to the third greatest energy point.

On the basis of previous research, we conducted an experiment to evaluate the proposed system. In this evaluation experiment, there were 230 samples with various symptoms, such as hypertension, sub-health, pregnancy, and cirrhosis. The objects were the pulse waveforms collected from 3 positions on each wrist, namely “Cun”, “Guan”, and “Chi”. So each sample included 6 group pulse waveforms considering both the right and left hands. A high-dimensional feature vector, corresponding to one owner’s sample, was generated according to the 6 group pulse waveforms. First, by using a linear kernel function, we trained and classified the two groups with the Support Vector Machine (SVM). Next, we verified the validity of the pulse waveform data collected by RHCT is valid for the evaluation human health conditions and that CPCAS can meet the needs of remote human health care. Furthermore, it provides some proof of the basic theory of TCM diagnosis.

In addition, according to the aforementioned experiments, we improved our related process algorithms, then conducted a further experiment to evaluate the proposed system. In this experiment, we only recognized pregnancy symptoms by 3 kinds of core functions, such as the K-fold, Holdout, and Jackknife functions. Among the 43 samples used in our experiment, one group had 28 pregnant women and the rest had none. A recognition accuracy of over 85% is shown in Table 2 and confirms that our system is usable and effective. Furthermore, we can get higher accuracy by improving the statistical method used.

### 6 Conclusion

Research on the CPCAS which based on WSN is significant. It promotes traditional Chinese medical treatment and meets increasing health care requirements, especially remote health care. The proposed system provides a powerful method for the detection of pulse information and evaluation of human health conditions with good recognition accuracy. At the same time, it implements a platform for quantitative research into the CPD theory in TCM. The Individual Remote Health Care Terminal is wearable and can be connected to build a wireless network for information distribution. Experimental results indicate the significant practical feasibility of this system. By extending the sample base and improving the statistical

| Symptom name          | Recognition accuracy (%) |
|-----------------------|--------------------------|
| Hypertension recognition | 75.00                     |
| Sub-health recognition   | 52.30                     |
| Pregnancy recognition    | 93.02                     |
| Cirrhosis recognition    | 97.02                     |

| Statistical method | Recognition accuracy (%) |
|--------------------|--------------------------|
| Hold out            | 86.90                    |
| K-fold              | 90.28                    |
| Jackknife           | 93.02                    |
methods, we could achieve better accuracy and apply them to more and more practical purposes.

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