Pulse Reading Mobile Application: Dr. Chi

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Abstract

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Developing applications on smartphone platform to perform medical and diagnostic functions has challenges of measurement precision, user interface design and the validity of diagnostic basis. The Dr. Chi capstone project team created the mobile application Dr. Chi. This application contains a program on the iOS platform and a sensor gadget which implements pulse reading as in Chinese medicine. Through measuring, storing and analyzing the heart pulse data, this application can give users instructive suggestions on stress management. We selected and optimized the sensor component for the sensor gadget by studying numbers of different kinds of sensors to improve the sensor precision. We designed the monitoring and diagnostic application by interviewing Chinese medicine experts and potential users to deliver an easy-to-use and instructive interface. The cost of this Dr. Chi application is under 30 dollars, which is much cheaper than the medical devices with similar functions on the market which cost thousands of dollars. The measurement accuracy is 50% better than the embedded sensors on the iPhone. Through measuring, storing and analyzing the heart pulse data, this application can give users information based suggestions on stress management.

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Introduction

Dr. Chi is a mobile application which implements heart pulse reading as in Chinese Medicine. This application runs on iOS platform and is working with a sensor gadget. The goal of this project is making the application fully functional in providing people with precise and useful wellness information based on their heart pulse. The design of the sensor gadget, the processing of the pulse signal and the user interface design are the main topics of this thesis.

Based on a survey of the existing devices that perform heart pulse analysis, we discovered that these devices falls into two categories. The first category is professional medical devices. These devices often come with a price of thousands of dollars, which is not suitable for personal use. The second category is applications on smart phones that take people's pulse through the embedded sensors on the smart phone itself, such as the built-in camera. However, these embedded sensors largely limit the accuracy of the measurement because they were not designed for pulse reading originally. Therefore, the wellness information provided by these applications has no significant value.

The capstone project designed a sensor gadget specifically for the purpose of pulse reading as in Chinese Medicine. The sensor gadget uses three piezoelectric membrane sensors to perform the measuring. A hijack module which utilizes the microphone jack of the iPhone will send the heart pulse data sampled by the piezoelectric sensors to the iPhone. For the analysis of the pulse signal retrieved by the phone, it can be done both on the smart phone or the cloud. The process on the iPhone mainly calculates some instant indices of the heart pulse, which indicates the current heart pulse quality of the user. The history pulse data of the user can be stored on the cloud server, and long-term analysis of the data can be achieved by machine-learning techniques.

This paper will explore the design process of the sensor gadget, the connection issues between the sensor gadget and the iPhone, the local signal processing process, user interface design and the application of cloud computing in this project.

Literature Review

The capstone project team did a survey on pulse reading mobile applications and professional medical devices with heart pulse measuring. The team explored the existing products and interviewed experts in pulse reading as in Chinese Medicine.

1. Existing Pulse Reading Mobile Application

By searching in the Apple App Store, we found a group of pulse reading mobile applications. The common element of these applications is that they utilize the embedded sensors of the iPhone. These sensors include the built-in camera, the accelerator and gyroscope and the microphone.

In this section, I will take a review of a typical example of them – the Instant Heart Rate application developed by Azumio [1]. This application utilizes the built in camera of the iPhone. The function of this application is that the user places his/her finger over the camera, and the measured heart rate will appear on display after about 10 seconds. The features of the application include the heart rate measurement, the real-time EKG like graph [1], interacting with social networks and a timeline.

According to [1], the application detects the pulse on the fingertip by measuring color variation caused by the light passing through the fingertip and the capillaries inside the finger. The light changes as they expand and contract with each heartbeat [1]. Figure 1 shows the screen shot of this application.

This Instant Heart Rate application has a free version and a pro version in the Apple App Store. The price of the pro version is 99 cents in the Apple App Store. [2] The difference between these two versions is that the pro version will allow the user to store more than 5 measurements in their timeline [1], contain no advertisements and shows a progress chart in the user interface.

Figure 1: Screenshot of Instant Heart Rate Application

2. Professional Pulse Reading Medical Apparatus Survey

Common pulse reading apparatus can only measure the heart rate without plotting the exact waveform of the heart pulse signal while Electrocardiograph (ECG) devices detect and amplify the tiny electrical changes on the skin that are caused when the heart muscle depolarizes during each heart pulse [3]. Besides these two kinds of medical devices, another apparatus called Electro-Pulse-Graphics is newly developed as shown in Figure 2. This device can display the rates of the heart pulse as well as plot the waveform and do analysis. In most cases, a personal computer connects to this device to provide the required computing power for the pulse analysis. The waveform plot of the pulse on each acupuncture point, the classification result of the pulse type and the diagnosis of the body condition appears on the display of the computer.

A fraction of the Electro-Pulse-Graphics devices with cutting-edge sensor technology have significant precision and extensive diagnostic values. As shown in Figure 3, High Energy Physics Center of the Chinese Academy of Sciences designed this device. This Electro-

Pulse-Graphics device can detect pulse on every single acupuncture point on the wrist to provide a rather comprehensive and accurate analysis of pulse. It is worth mentioning here that the average retail price of an Electro-Pulse-Graphics device is over 2000 U.S. dollars.

Figure 2: Typical Electro-Pulse-Graphics device

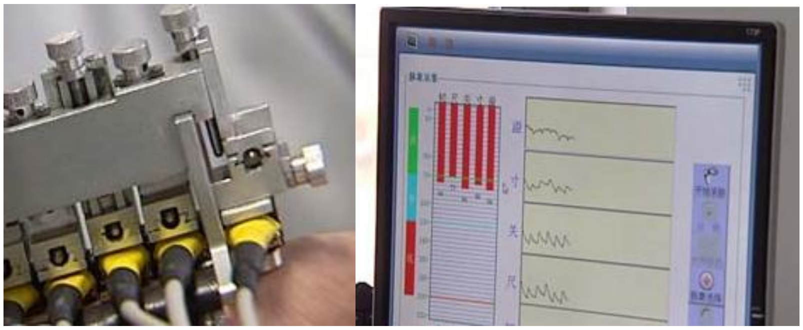


Figure 3: High-end Electro-Pulse-Graphics device

Methodology

1. Chinese Pulse Reading Methodology

TCPD (Traditional Chinese Pulse Diagnose) has been proven to be clinically convincing and valid over 5000 years of the history of Chinese medicine. However, many people still consider it to be mysterious because of the difficulty in mastering it and analyzing it in a scientific method. Therefore, it is necessary to articulate TCPD in a mathematical way.

Heart pulse can be recognized quantitatively by four metrics, the wavelength, the relative phase difference, the rate, and the peak ratio. This metric can reduce physician's personal bias when doing pulse diagnose. Based on these four metrics, Chinese pulse waveform patterns can be interpreted objectively.

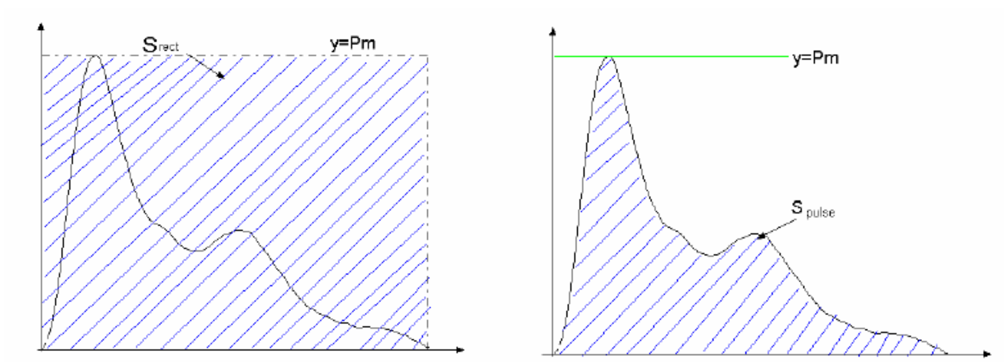


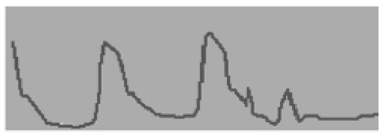
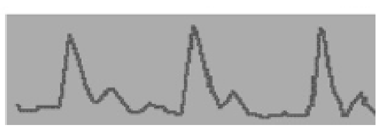
Figure 4: The scheme of areas computing, (a) S_{rect}, (b) S_{pulse}

As Figure 4 shows, the pulse area of every period (S_{pulse}) and its rectangle area (S_{rect}) can be calculated. The Ratio of Pulse Area (RPA) [4] is defined by

$$RPA = S_{pulse} / S_{rect}.$$

In general, the Chinese medicine theory outlined and interpreted 26 basic pulse types [5]. Table 1 presents these pulse categories (6 out of 26) and corresponding waveform. In the signal processing part of the application, we aim to classify the pulse by these patterns to give an informal diagnose of the user's health condition.

Table 1: Examples of the basic pulse types

Pulse Type	Waveform	Interpretation
Normal pulse [sanmai]		A normal pulse with smooth, even and forceful condition.(60-90 beats per min)
Knotted pulse [jiemai]		"A slow pulse pausing at irregular intervals, often occurring in stagnation of qi or blood" [5].
Intermittent pulse [daimai]		"A slow pulse pausing at regular intervals, often occurring in exhaustion of viscera organs, severe trauma, or being seized by terror" [5].
Hurried pulse [cumai]		"A rapid pulse with irregular intermittence, often due to excessive heat with stagnation of qi and blood, or retention of phlegm or undigested food" [5].
Fine pulse [ximai]		"A pulse felt like a fine thread, but always distinctly perceptible, indicating deficiency of qi and blood or other deficiency states" [5].
Slippery pulse [huamai]		"A pulse like beads rolling on a plate, found in patients with phlegm-damp or food stagnation, and also in normal persons. A slippery and rapid pulse may indicate pregnancy" [5].

2. Hardware Design (Sensor Survey)

The capstone project team studied optical sensors, piezoelectric sensors and MEMS sensors as candidates for the sensor of the application. Yuan Yang did a survey and research on Optical Sensors. Xi Peng did a survey and research on MEMS sensors. This thesis will introduce my survey and research on piezoelectric sensors and its advantages over optical sensor in this application.

A piezoelectric sensor uses the piezoelectric effect to convert measured pressure to an electrical signal [6]. Figure 5 shows the photo of piezoelectric sensor and its schematic diagram. The voltage *V* at the source is directly proportional to the pressure [6].

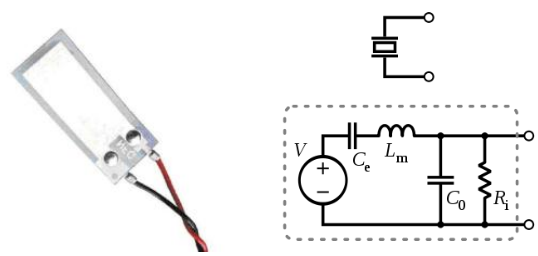


Figure 5: Piezoelectric Sensor and its Schematic Diagram

After searching different kinds of piezoelectric sensors and contacting suppliers, we decide to use a DT series and LDT series membrane piezoelectric sensor.

Besides piezoelectric sensors, we also did a survey on the optical sensors. Optical pulse sensors typically measure the optical power variation that is due to absorption or scattering when the amount of blood in the measurement volume varies [7]. There are two classes of optical sensors. One class is based on transmission, and the other one is based on reflection. The transmission optical sensor is not applicable to thick fingers or wrists. In such cases, reflection optical sensors are more effective. In order to do experiments, we bought a set of optical sensors from [8]. Then we plotted the heart pulse on the oscilloscope using optical sensor and piezoelectric sensor respectively.

After doing experiments on the different sensors and comparing the output, we chose to use the piezoelectric sensor in the sensor gadget. The result of the comparison will be found in the Discussion section. After the survey, Yuan Yang did most of the hardware design of the sensor gadget.

3. Interface

After some initial attempts, we settled on using the hijack module [9] to implement the data connection between the sensor gadget and the smart phone.

Hijack is a hardware/software platform for creating sensor peripherals for the iPhone. Hijack module harvests power and use bandwidth from the mobile phone headset interface [9].

The Hijack Development Kit provides a bi-directional interface between the mobile phone and the external peripherals [9], in this case, the sensor gadget. Given the bandwidth and frequency range of the interfacing channel, there are three ways to do the data transfer: (1) direct encoding in analog voltages, (2) encoding using modulated waveforms, (3) digitally transmitting serial data as a (Manchester-encoded) UART stream.

4. Signal Processing

The signal processing is an essential component in this application. Since the application consists of hardware and software parts, the signal processing is both done in the hardware part and the software. Yuan Yang did the major part of the hardware design. She designed a filter to damper the noise of the raw signal from the piezoelectric sensor.

Before the connection between the sensor gadget and the smart phone worked properly and stably, we used an Arduino module [10] to connect the sensor gadget to a personal computer or a Mac. We then experimented with the signal processing program. The Arduino module receives input from the senor gadget and transmits the signal to the computer via USB port. The connection issues between the sensor gadget and the smart phone will be discussed in the discussion section.

We used MATLAB to do the prototyping of the signal processing part. The capstone project team routinely interviewed with a Chinese Medicine expert and managed to translate her methodology of pulse reading and diagnosing to a signal processing program. Based on information from the interview, the team summarized the different aspects of signal processing in Table 2.

Table 2: Methodology of the different aspects of signal processing

Metrics of a heart pulse	Signal Processing Methodology	The implication of stress level in TCPD
Intensity of the pressure placed on the wrist	Detect the sudden jump in the waveform	The result produced by 3 different pressures indicates the wellness of different organs
Variation of frequency	Calculate the standard deviation of the time interval between peaks of the pulse waveform	The property of user's mental stress(long-term/short-term)
Variation of amplitude	Calculate the standard deviation of the peak values of the pulse waveform after normalization	The level of mental stress

Discussion

1. Implications of Sensor Selection

We found the advantage of piezoelectric pulse sensor is its similarity to the real pulse reading technique as in Chinese medicine. Optical sensors cannot detect the subtle details in the pulse waveform. However, these subtle details of the heart pulse are crucial for classifying the pulse using the method discussed in the previous section.

2. Implications of Interface Selection

There are two main interfaces that will be interacting with the end users. The first one is the connection between the sensor gadget and the smart phone, and the second one is the user interface on the smart phone. For the connection interface, the team has tried the Bluetooth, wireless sensor network and the wired hijack module.

The project team has come up with three different solutions for the connection issue in the designing stage of the project. The connection solutions have to consider the connection stability, the performance of the connection, the licensing issues and the cost. This section will then introduce three connection solutions we have tried on this project.

Bluetooth was the first option we have tried to utilize in the application because of its merit of mobility and a sufficient data transfer rate for this application. However, we are taking Apple's iOS platform as the starting point of the prototyping and Apple has not opened up the Bluetooth API for universal devices via the iOS development kit.

Then we also tried to make the smart phone receiving data from the sensor gadget using wireless sensor network. However, the sensor gadget will need a gateway to send the data, and this will largely affect the mobility of the sensor gadget.

After the previous two attempts, we have come up with the wired communication implementation and found the hijack module [10] a potentially viable choice for the sensor gadget.

3. Results

Figure 6 shows the final prototype of the sensor gadget.

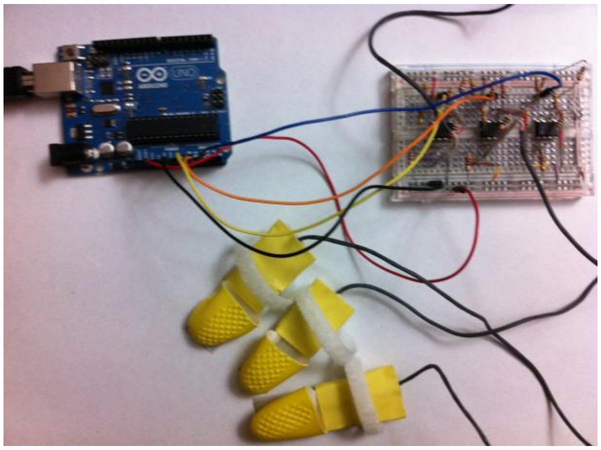


Figure 6: The hardware prototype of the sensor gadget

Figure 7 shows the connection between the sensor gadget and the smart phone.

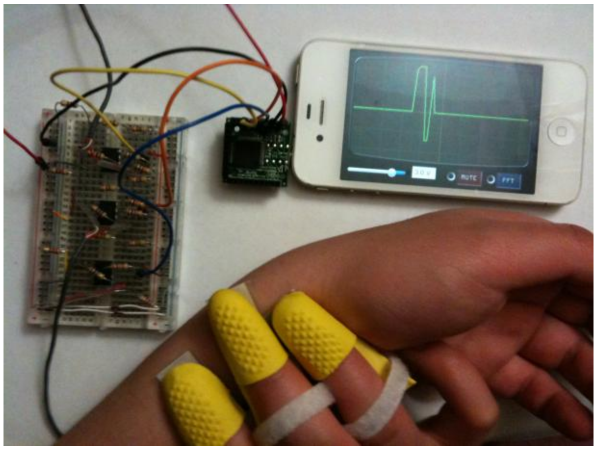


Figure 7: The connection between the sensor gadget and the smart phone using the hijack module

The capstone project team has collected each member's pulse data at different time points on a daily basis. What we are able to diagnose is the class of the pulse we have. However, we did not find a strong difference or relationship between the measurements on different days. Figure 8 shows a typical waveform we plot from the sensor data. The upper part is the original pulse signal waveform, and the lower part is the resulting plot after extraction of the peak. We have observed that the real world situation is identical to the hypothesis and methodology we applied in the signal processing part.

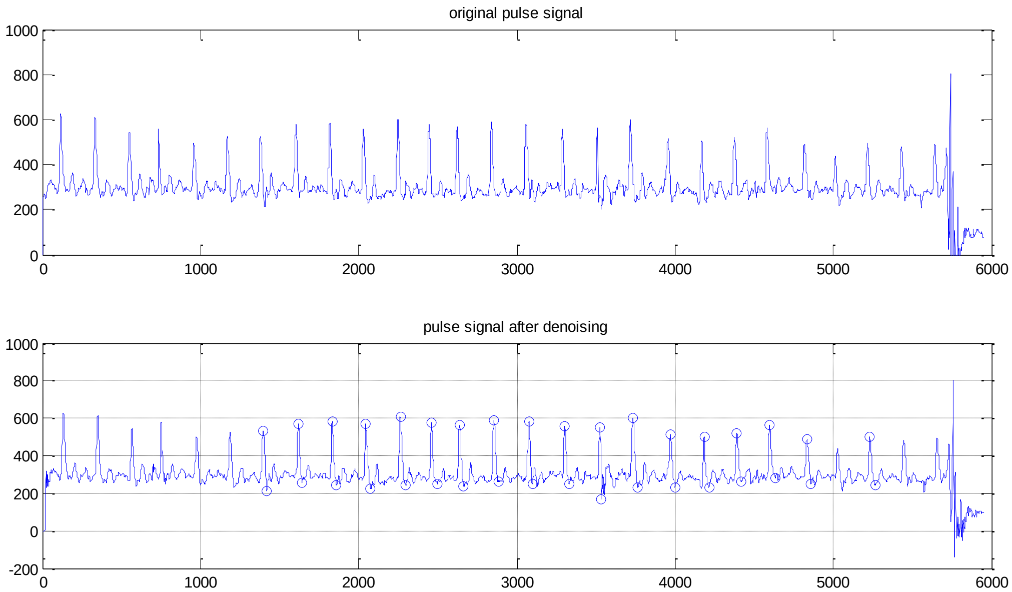


Figure 8: Typical waveform plotting

Conclusion

This paper elaborated and discussed the design and analysis of the prototype of the pulse reading mobile application. Sensor selection, sensor gadget design, interfacing, and signal processing are mainly discussed in this paper. Although the data connection solution between the sensor gadget and the iPhone is still under development, this paper has articulated the simulation of the pulse signal processing procedure in MATLAB. The pulse data collected from the sensor gadget provides sufficient data to the signal processing part. The signal processing mechanism can classify the heart pulse into different classes reflecting the mental stress level of the user.

The future work of this project can be designing the backend server of the application. The server will store the user's long-term pulse data and run a machine-learning mechanism which provides the users a long-term diagnosis.

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