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Capstone Project Report

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Abstract

Traditional Chinese Medicine treats pulse diagnosis as a very important diagnostic tool which can give very detailed information on the state of the state of internal organs. However, it is seldom used by people in monitoring their own daily health because it requires training and experience. We've designed a personal 'Pulse Reading' sensor gadget that can take the pulse information from three different wrist positions at the same time and detect the frequency, stress, rhythm and the change under three different pressures. It can also communicate with a personal computer and show readings that can be used for stress recognition based on Traditional Chinese Medicine. A wide market survey of this kind of product was done to set the value of the product before starting to make the prototype. The MEMS sensor and sensor package survey were studied in order to build an accurate and stable sensor of right size and with appropriate output and a reasonable price. Pulse signals were denoised and screened through matlab and stress pattern recognition was built using a BP neural network. Finally, we built the prototype which consists of a pulse reading gadget, an analog/digital conversion part which lets the sensor gadget communicate with a computer and the matlab programming, which process the pulse signals and identifies the stress levels. The accuracy of the testing data for classifying stress is about 75%. The product cost is 100 times lower than similar existing commodity. Overall, we believe that this product will let people monitor their health and benefit from this information more conveniently and effectively than the can at present.

Introduction

Pulse Reading is the most common diagnostic method in Traditional Chinese Medicine. It has the advantages of being convenient, reliable and non-invasive. With the rapid development of modern medical science and technology, more and more companies and institutes are thinking about pulse reading as a way for people to monitor their health in daily life. However, the Chinese method of pulse reading is difficult to learn. Doctors confirm a pulse type by feeling the different patterns of the pulse impacting the finger; and this can lead to variable diagnosis by different doctors. Developing a product which is specifically designed to measure and record pulse information is a significant way to spread knowledge of Chinese medicine's diagnostic practices, and to help people check their health condition with an easy, effective and scientific method.

The project is to design a personal 'pulse reading' medical device based on Traditional Chinese Medicine, that can be used for stress recognition. Minor stress can be lead to a decline in work efficiency. Chronic stress may cause various physical manifestations such as asthma, back pain, arrhythmias, fatigue, headaches, HTN, irritable bowel syndrome and ulcers. It can also suppress the immune system. Therefore, avoiding stress is key to lessening the likelihood of various diseases. Since stress is usually not accompanied with clear pathological features, it's difficult to detect it through clinical examination. A stress monitor product will help people living in a fast paced environment.

One of the technical challenges of building the prototype involves the sensor gadget design. The sensor can't be bigger than a fingernail because that there is just 1cm between two different detecting positions. In addition, the circuit needs to be very sensitive to pressure due to the application of the device with three different pressures and the need to detect pulses that may be very weak. The sensor package should provide three sensors, adjustable to individual differences of pulse position and width. The packaging should also keep the sensor under stable pressure during pulse-taking.

Processing the pulse signal and extracting the characteristics for stress recognition is also a very important procedure. However, due to the limited accuracy of the sensor, and to outside disturbance, about 30% of pulse data it sends to a computer is abnormal. This requires developing complex criterions to screen for the abnormal data. Another unresolved issue is that there is no other reliable judgment for stress situation for use in identifying and classifying the data.

Literature Review

1. State of the art products in market

Considering the product's characteristic of being a portable household pulse diagnosis device that gives people information about the condition of their health, there are several similar commercial products on the market. They can be split into four main groups.

The first group is that of products being made by global medical device companies such as GE Healthcare, Cardinal Health. These companies provide professional pulse oximeters to hospitals for patients monitoring systems or clinical diagnoses. They have abundant R&D funding, worldwide reputation and professional service; and they are cutting into the market of disease diagnoses. However, their products are very expensive- e.g., the GE Pulse Oximeter is about $400 and so large that it cannot be marketed for household use.

The second group involves new venture such as AccuPulse and FirstPulse. These companies are working on portable and household pulse oximeters with reasonable pricing and various options- e.g., A PulseOne Fingertip Oximeter is about $30. They currently own almost all market share of household pulse oximeters. However, since these products are used primarily for measuring blood oxygen saturation, they omit some detailed pulse information.

The third group of products is those being developed by Asian research institutes such as the Shanghai University of Traditional Chinese Medicine and Japan Colin Company. These institutes are working on professional pulse diagnoses devices. Sensors of these devices are always high-definition cameras with a box that sits on the skin and takes sample image information under various pressures. Although these products are cumbersome, they are based completely on Chinese medicine concepts, providing thorough pulse information with high accuracy. The ZM-III Intelligent Sphygmograph, invented at the Shanghai University of

TCM is one of the most advanced and accurate pulse diagnosis devices. It Consists of a single-head pulse signal energy converter, a pulse signal amplifier, an A/D converter, and dialectical pulse analysis software. It can automatically collect the pulse signal, intelligently analyze and process the characteristics of the pulse graphic and make classifications based on different pulse qualities like position, rate, rhythm, strength and so on. It can also simulate human inspection and inquiry giving the examiner an indication of health condition. Most of these products are still in pre-clinical study phase, without workable business models. For example, the price of ZM-III is about $6000. It is mainly used in hospitals and with limited commercialization.

Products made by smart mobile phone app developers such as CMG Research are the last group. They use the cellphone's inside sensors, like those in the camera and earphone to capture heart rate, providing users with a friendly and simple interface to measure and record their daily pulse rate or even share it on Facebook or another social network. However, without high accuracy and stability and comprehensive pulse information, these apps can't capture major market share for a daily use medical device.

2. The Present State of Research on Pulse Signal Processing.

There are 28 types of pulse described, by metaphor, in Traditional Chinese Medicine. As part of the process of objectifying TCM diagnosis, research on signal processing is being used to analyze the characteristic values of pulse data sampled by sensors in order to quantify and classify different types of pulse automatically and accurately. The main methods for signal processing are time-domain processing, frequency-domain processing, time-frequency representation, sample training and clustering.

The time-domain processing method which is the most common method mainly analyzes characteristics corresponding to time such as the magnitude of the main peak and second peak, the area of pulse waveform and the angle between curve and axis. The first derivative of pulse signal in time domain is also used for supplemental analysis.

The frequency-domain processing method has become an important method for analyzing complex vibration signals, over recent years. Although it is not as wide-spread as time-domain processing, advances have been made though this method. For example, in 1981, Shanghai Pulse Cooperative Group found that a pregnancy smooth pulse and a pathological smooth pulse have big differences in frequency-domain by spectrometer; and in 1983, scientists from Taiwan and Canada found that there are big differences between pulse signal in the frequency-domain of healthy people and patients.

Time-Frequency Representation (TFR) is a view of a signal (taken to be a function of time) represented over both time and frequency. TFRs are often complex-value fields over time and frequency, where the modulus of the field represents ‘energy density’ or amplitude, and the argument of the field represents phase. Common TFRs are short-time Fourier transform and wavelet transform.

Sample training and clustering is a novel type of method. The classic one is called BP neural network. It uses several characteristics of clinical pulse samples as network input that trains the network to build the pulse classifier. For example, the pulse amplitude, under different pulse pressure, is used as a characteristic of the classifier for floating and deep pulse; the average heart rate is used for slow and rapid pulse. In 2008, Lanzhou University of Technology, China designed the fatigue recognition with neural network.

Methodology

1. Sensor Gadget Building:

1.1 Sensor survey

There were three different sensors which could be used in the project. These are the piezoelectric sensor, the optical sensor and the MEMS sensor. I did the survey of the MEMS sensor while my teammates did surveys on other sensors.

1.2 Choosing the sensor and the amplification circuit design

This part was done by my teammate, Alice.

1.3 Sensor package design

I did the Sensor package design. There were several problems that needed to be solved for the sensor packaging. These were: (1) the package had to allow pulse-taking under three different stable pressure levels; and (2) the design had to ensure that three different sensors were adaptable to individual differences of pulse position and width. After a survey of similar existing products such as the pulse oximeter and blood pressure meter, I decided on the fingertip model which is shown in Fig.1 below

Figure 1

With this design, people can feel the pulse by themselves and there is also a warning system to tell people whether the pressure is stable or not.

2. Communication with computer and smartphone

This part was done by teammates, Alice and Terry.

3. Signal Processing and Stress Recognition

This part was done by me.

3.1 Data Collecting

In order to build a relationship between pulse information and stress, pulse data were collected on a young man and a young woman, once a day last for five days, using the sensor gadget we made

a. Time

Pulse-taking should be performed at a time when the tester is relaxed and calm, keeping breathing regular and natural.

b. Posture

The correct posture of the tester during pulse-taking should be sitting straight with his arms naturally extended at the same elevation as the heart, wrist extended, palm facing upward, fingers slightly bent and with a soft cushion placed beneath the wrist.

c. Position

Pulse is sampled at three different positions on the wrist—Distal, Middle and Proximal in turn.

Distal: This position is located adjacent and distal to the middle position and is 2cm long.

Middle: This position is located medial to the styloid process of the radius at the wrist and is 2cm long.

Proximal: This position is located adjacent and proximal to the middle position and is 2.3cm long.

d. Strength of Pressure

Pulse is sampled under three different pressure levels.

Light level: The finger lightly rests on the skin so the tester can just feel the pulse though the fingertip.

Middle level: The pressure on the skin is between light and deep.

Deep level: the last moment before tester can’t feel the pulse while the finger is pressing down to the bones and tendons.

e. Duration

The time spent taking the pulse under one pressure level should be about 15 seconds.

3.2 Signal Preprocessing

Pulse waveform in time-domain and frequency-domain are shown in Fig.2. The sample frequency of sensor is 200Hz.

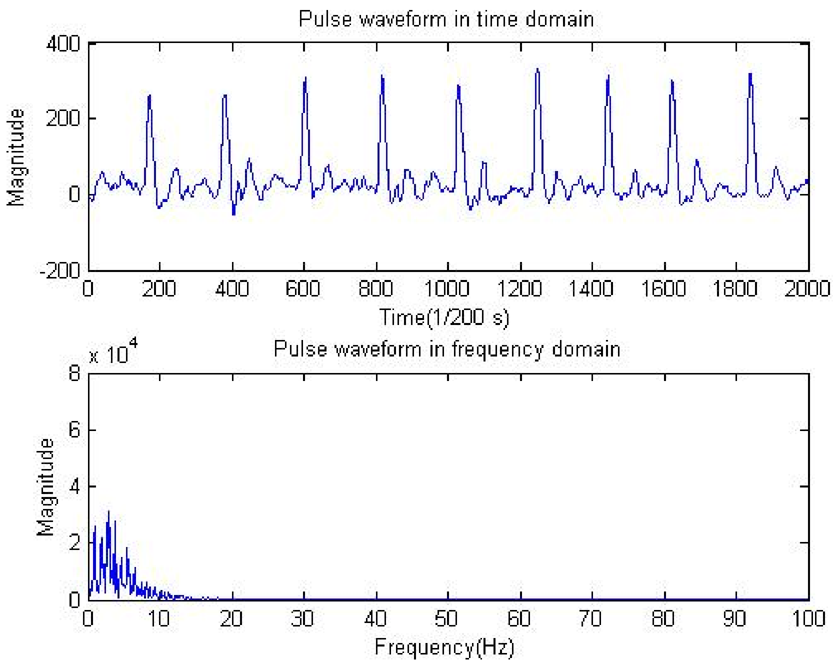

Figure 2

According to Figure 1, the frequency of normal pulse signal is less than 20Hz, and nearly 99% of pulse energy distributes in the area from 0Hz to 10Hz. There are two main noises during pulse-taking: (1) baseline wander caused by finger shaking and breathing, the frequency is usually less than 1Hz; (2) power frequency interference which is 60Hz. Based on this, a Butterworth low pass filter is designed by Matlab and used to denoise the original pulse signal. The amplitude-frequency response curve of filter and pulse waveform in time domain after filter are shown in Fig.3 and Fig.4.

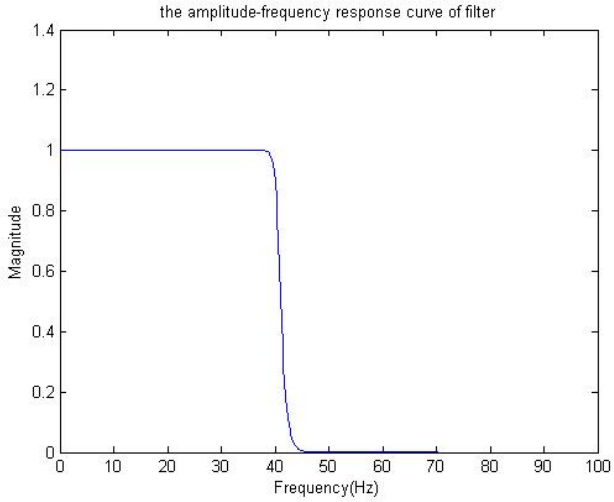

Figure 3

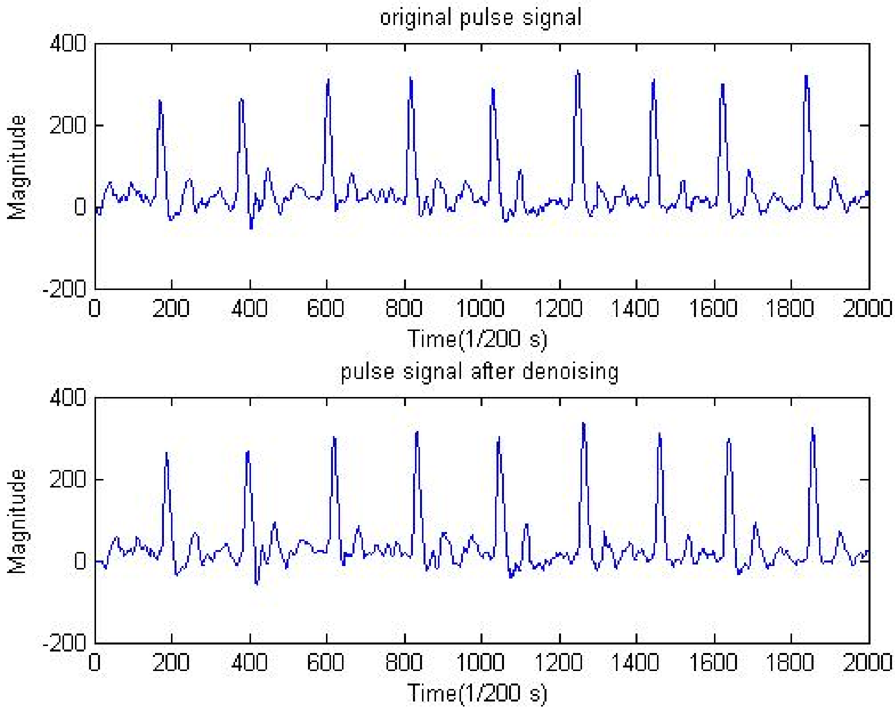

Figure 4

3.3 Data Screening

Although the pulse signal is denoised by a Butterworth filter, there are still some abnormal pulse waveforms which will lead to an inaccurate or wrong result. Abnormal pulse waveforms, defined as an unstable stage, are caused by a weak or deep pulse or body movements. Fig.5 below shows the normal pulse waveform and the three most common abnormal pulse waveforms.

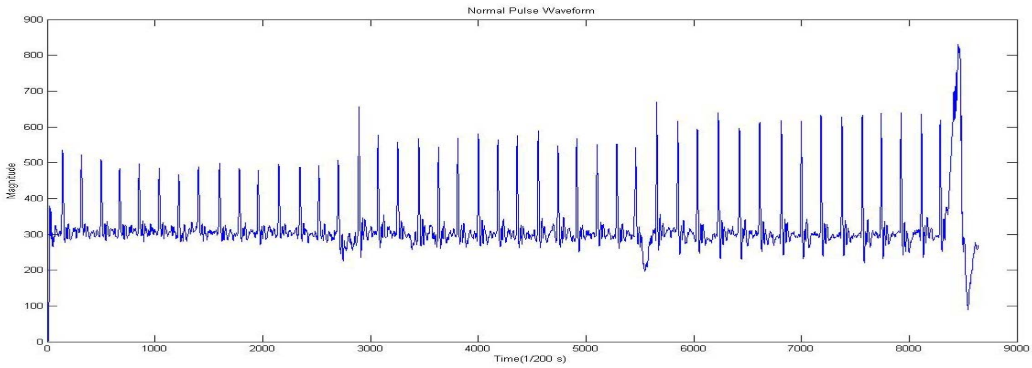

Figure 5a Normal Pulse Waveform

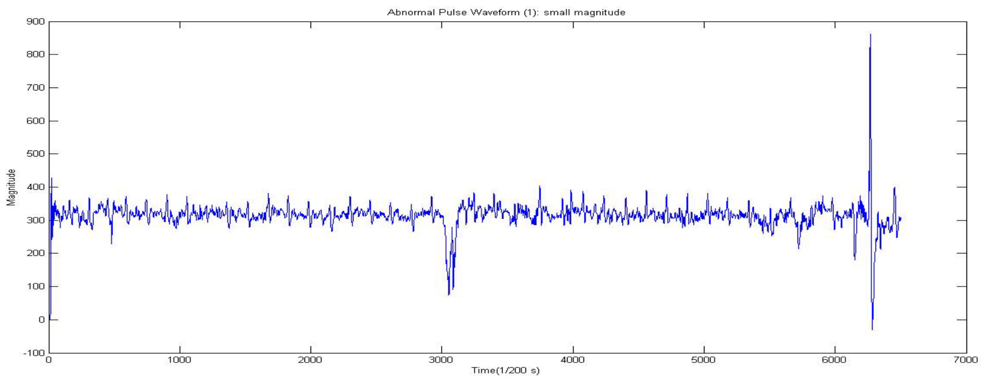

Figure 5b Abnormal Pulse Waveform 1: small magnitude

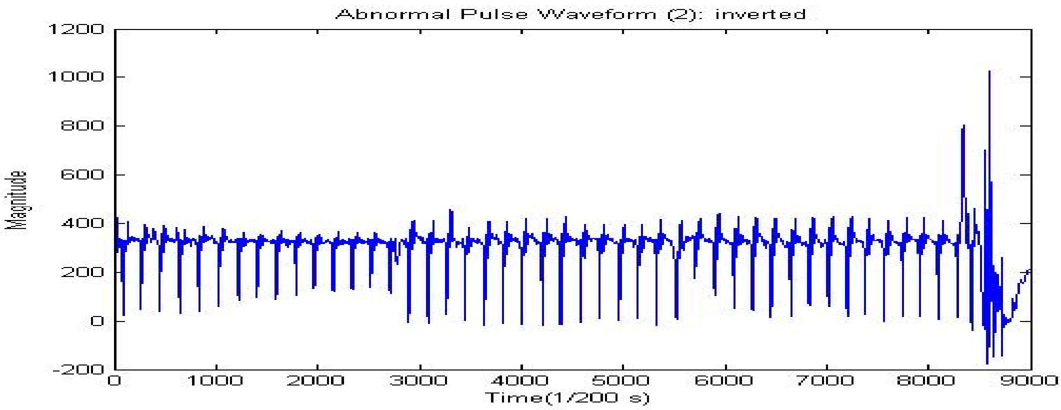

Figure 5c Abnormal Pulse Waveform 2: inverted

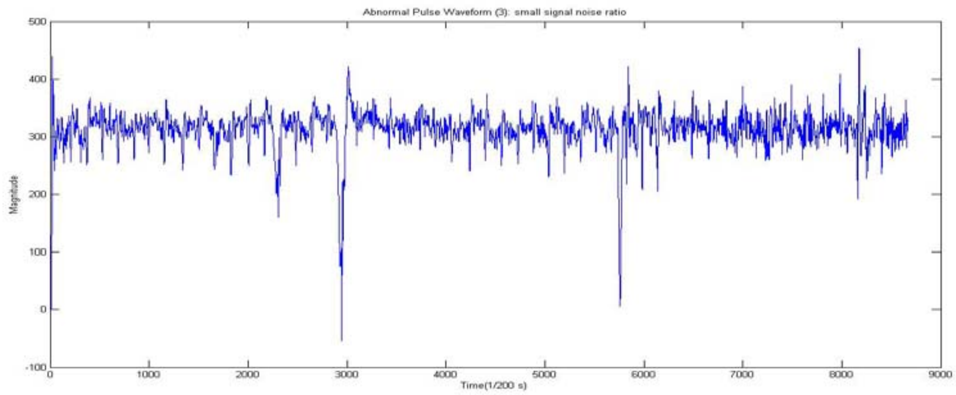

Figure 5d Abnormal Pulse Waveform 3: small SNR

In order to screen the normal pulse data, several criterions are designed to classify the normal and abnormal pulse data. Fig.6 below shows the definition of some special points in pulse waveforms which will be used as the criterion.

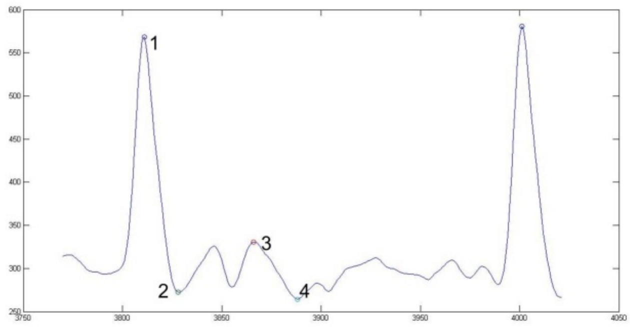

Figure 6

In Fig.6, point 1 is the peak of the pulse signal; point 2 is the trough of the pulse signal; point 3 is the second peak during every pulse period; point 4 is the lowest point between every two main peaks.

The criterions are: (1) Assume Amp equal to y1-y2. If y1-y2<=85, it is small magnitude pulse waveform shown in Fig 5b; (2) If (y2-y4)/Amp>=0.8, it is inverted pulse waveform shown in Fig 5c; (3) If (y3-y2)/Amp>=0.5, it is small SNR pulse waveform shown in Fig 5d; (4) If Amp is 1.4 times bigger or 0.6 times smaller than the Amp of two peaks next to it, it is an abnormal pulse waveform because the amplitude is much bigger or smaller than the others. If a main peak satisfies at least one of the criterions mentioned above, it is assumed as a 'bad point'. Bad points will not be used in the analysis. In addition, if there are more than four bad points in any eight periods, this period is assumed to be an unstable stage and the waveform of this period is abnormal. Any data in an unstable stage will not be used to analyze a stress situation until the period changes to a stable stage.

Fig.7 shows pulse waveforms based on these criterion. The peak and tough of data which will be used to analyze the stress situation are marked as 'o'.

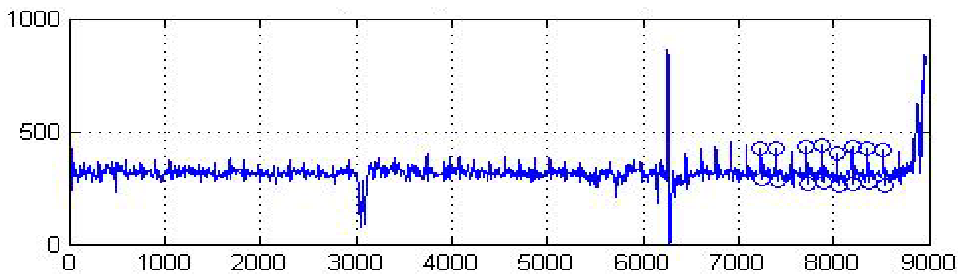

Figure 7

3.4 Analysis of characteristic variables for stress identification

According to Chinese Medicine doctors' experience, the pulse, in relaxed situation, is more regular than it is in stressful situations. This means the fluctuation of amplitude and frequency of pulse will be more intensive when people feel stressful. Based on this, the pulse amplitude and frequency in every period are analyzed. Fig.8 below shows the testing normal distribution curve and the frequency histogram of pulse amplitude and frequency, respectively.

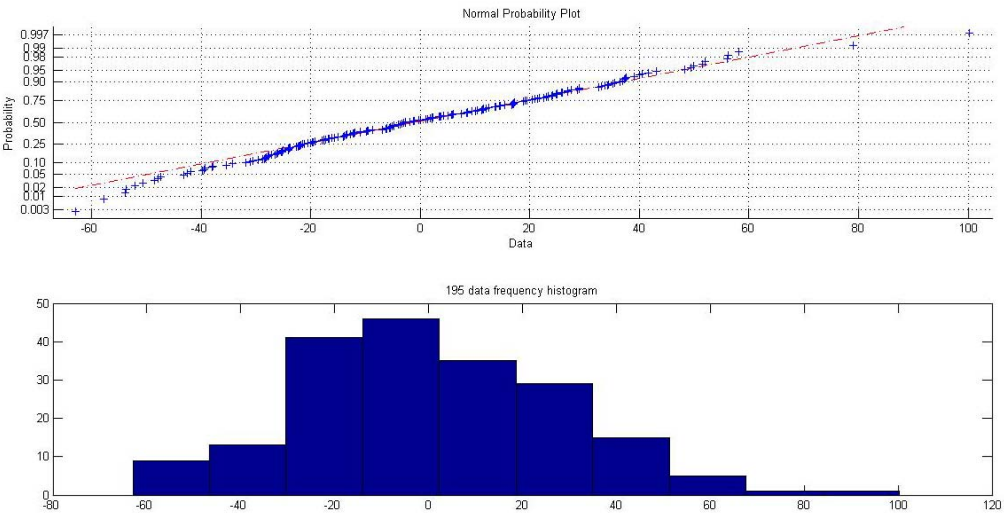

Figure 8 Testing of Amplitude

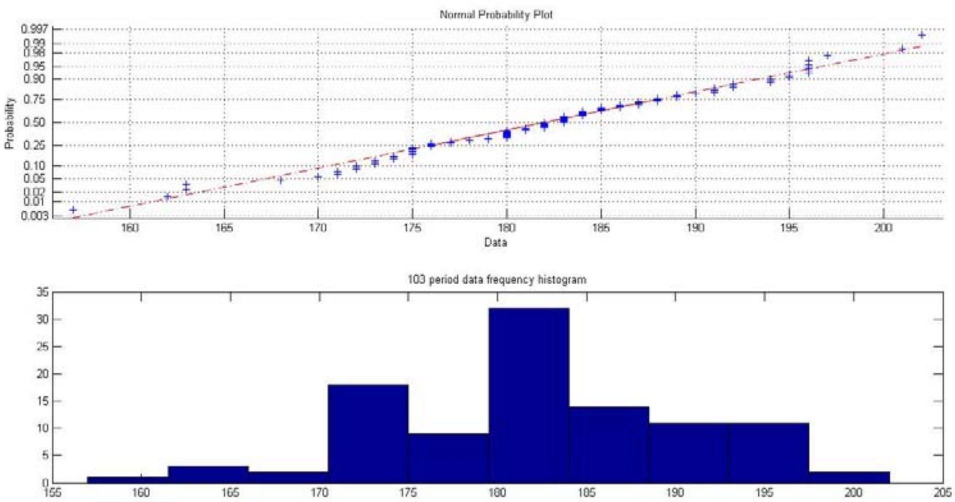

Figure 9 Testing of Frequency

Since the value of pulse amplitude is affected by sampling pressure, they are normalized by subtracting the means of pulse amplitude in every stable stage. If data is normally distributed, the testing normal distribution curve of data would be a straight line. In Fig.8 and Fig.9, pulse amplitude and frequency are both assumed as normal distribution. So the variances of normal distribution of data in every stable stage are an estimate of maximum likelihood. The table below shows the variances of data in every stable stage. Data are named by people, date and stable stage number. For example, 'A1_2' represents the second stable data stage sampled from people A in day 1. Note: tester A in day 5 and tester B in day 4 and 5 don't have any stable data.

Table 1

Data	Variances of Amplitude	Variances of Frequency	Data	Variances of Amplitude	Variances of Frequency	Data	Variances of Amplitude	Variances of Frequency
A1_1	16.02885	6.960204	A2_1	34.53595	6.804976	A3_1	41.7836	14.648
A1_2	15.94121	8.610518	A2_2	29.90225	8.322154	A3_2	43.9321	16.5616
A1_3	22.49563	7.79969	A2_3	21.51744	6.599423	A4_1	16.7647	8.4532
A1_4	17.97029	7.146812				A4_2	21.3547	9.1157
A1_5	19.68722	7.440165						
Data	Variances of Amplitude	Variances of Frequency	Data	Variances of Amplitude	Variances of Frequency	Data	Variances of Amplitude	Variances of Frequency
B1_1	29.16684	17.34956	B2_1	11.39954	3.681518	B3_1	45.48716	5.535314
B1_2	37.71257	11.44968	B2_2	22.63411	4.301163	B3_2	37.00095	4.894117
B1_3	28.53465	7.991826	B2_3	15.8399	7.491583	B3_3	42.31367	6.485882
B1_4	40.47806	4.781106				B3_4	24.4357	3.919325
B1_5	32.65962	4.638007				B3_5	44.04638	11.38013

Analysis assumes data sampled in one day and from one person is representing the same stress situation. In this table, the variances of amplitude of data sampled from the same person, on the same day are on the same level; while the variances of frequency on the same day are not. So it is better to use the variances of amplitude to identify the stress situation.

3.5 Stress Pattern Recognition

With pulse amplitude as characteristic value, a BP neural network of stress recognition is built by using the Matlab neural pattern recognition tool. The neural network is comprised of two layers which are a hidden layer consisting of 20 neurons and an output layer consisting of 3 neurons. It has three outputs according to Table 1 in which 'A1', 'A4' and 'B2' correspond to relaxed situation, 'A2' and 'B1' correspond to light stressful situation and 'T3' and 'A3' correspond to stressful situation. 75% of data are used for training the network, 15% for validation and the rest is used for testing. Fig.10 below shows the confusion matrix of this network.

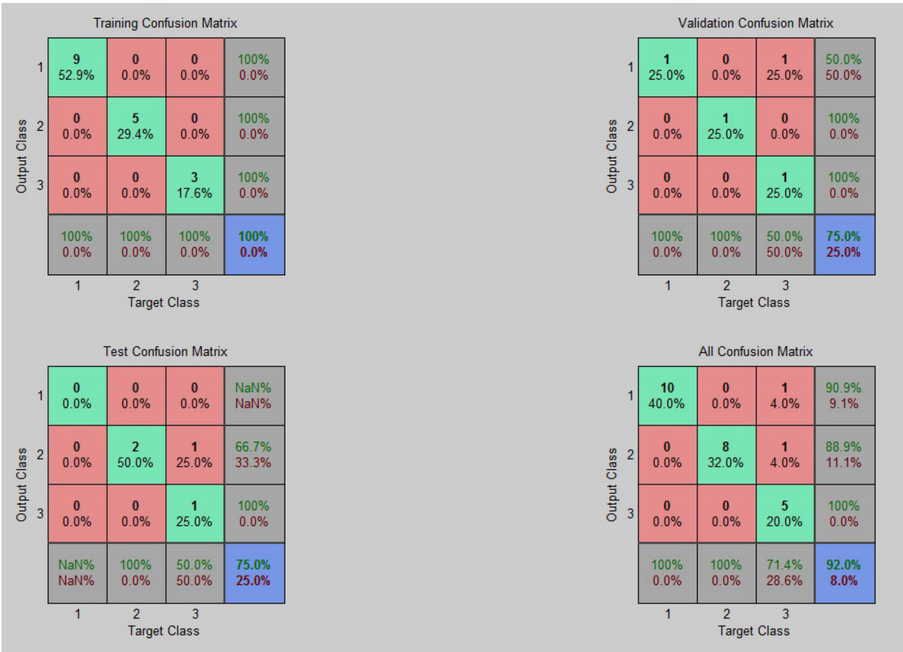

Figure 10

Discussion

A Built Prototype for Pulse Reading, Communication with Computers and Stress Recognition (as shown in Fig.11 below)

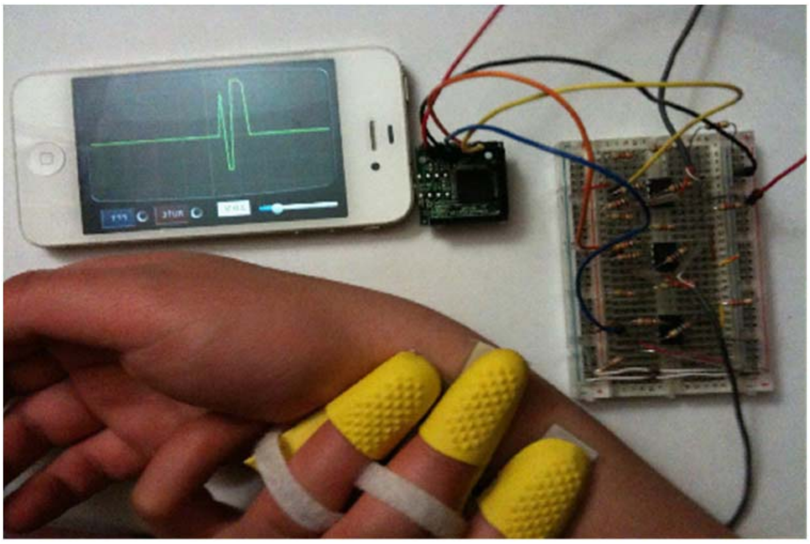

Figure 11

Three SDT1-028K membrane piezoelectric sensors, which are packed with fingertips and connected with an amplification circuit, allowed the gadget to read the pulse. Arduino analog/digital conversion with an USB port is used to send data from the sensor gadget to the computer. The data is read and stored in a PC by Python and PySerial and are denoised and screened by Matlab. The variance of pulse amplitude is used as a characteristic for identifying stress with the BP neural network classifier. The accuracy of the testing data is about 75%.

Result Details:

- The Product's Value

The project realized a product with a novel value which is read pulse information based on Traditional Chinese Medicine pulse reading concepts for stress recognition and monitoring. The product can read pulses in three different positions and under three different pressure levels cannot be done by the pulse oximeter and smartphone apps.

- Sensor Gadget: Portable and Cheap vs. Accurate and Stable

The membrane sensor with fingertip package instead of a traditional vacuum cell and camera, which are used in professional pulse diagnoses devices, lets the product be portable and cheap and usable by the average person. However, about 30% of the data sampled by the sensor is abnormal and cannot be used. This is because of the sensor’s defects of the pulse are too weak or deep or the sensor is affected by body movements. In order to improve the accuracy, the sensor and electrical parts need to be modified to read weaker pulse signal. In addition, the packaging part should be revised to reduce the affect by body movements. The fingertip package which is used in the prototype asks people to feel their own pulse and then adjust the pressure level and the position by themselves. This effectively reduces the effect of different pulse positions and widths among people. However it is difficult for people to hold a perfectly stable and standard pressure. This leads to fluctuations of amplitude and an inaccurate stress result. While the packaging for a product like the electronic sphygmomanometer can avoid the effect of unstable pressure, it does not allow for adjusting the sensor position. Future work should be done to balance the trade offs between artificial pressure and machine pressure.

- Communication with a Smartphone or a Computer.

Communication with a smartphone plays a very important role in the use of a portable product. While several methods tried by my team failed to develop this ability for our product, continuing work in this area would be worthwhile. In addition, although the prototype includes the communication with a computer, it cannot dynamically read, show and analyze the data. This is a big limitation for a future commercial product. In order to be competitive in the exiting market, it is necessary to focus on these communication issues.

- Stress Recognition

Stress recognition is based on both Chinese Medicine doctors’ experience and modern signal processing technology. Although the method for signal denoising and data screening are correct and effective as shown in Fig.7, the amount of data is too small. In addition, there is no other independent way of identifying people’s stress levels during the pulse-taking. So the variances of amplitude as a characteristic of stress recognition, is just based on an assumption. So in order to improve the accuracy of stress recognition, we need to sample more pulse data and develop a reliable way to identify the true stress situation of subjects supplying experimental data. Moreover, it is also better to analyze the pulse though different methods like frequency-domain and TFRs to receive different characteristics as input of neural networks and to improve the precision of neural networks.

Conclusion

From this project, I studied the theory and technology of Traditional Chinese Medicine pulse reading and modern pulse signal processing. I learned how to use Matlab to do basic signal processing and data statistics like Butterworth low pass filter, normal distribution estimation and BP neural network. I also did a survey on MEMS sensors and sensor packaging. I and my two teammates built the prototype. Compared to existing commercial products, the prototype balances the trade offs between reasonable pricing and accuracy. It also has a novel design concept and purpose which is TCM pulse reading for stress recognition. However, there are some weaknesses:

- The sensor and electrical part are not accurate enough to take a really weak pulse such as that of old person;
- The sensor packaging can't effectively reduce the effects of body movements;
- The sensor gadget can't communicate with a smartphone. A PC can't dynamically read, show and analyze the pulse signal.
- Data and characteristics used in the BP neural network for stress recognition are small. There is no other stress judgment to identify the sample stress situation.

Based on these limitations, future work should include improving the sensor gadget for accuracy and stability, communication with a smartphone, better communication with a computer and more experimentation on stress recognition based on reliable and independent judgments of true stress.

TCM is an extensive and profound system, developed though thousands of years of clinical practice. The human pulse signal can now be quantified and processed by modern technology. Therefore, if accuracy and stability issue can be worked out in the future, this sensor gadget can potentially be designed to identify different types of pulses and give people a diagnoses and recommendations about various health issues.

Reference:

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[2] en.wikipedia.org/wiki/Stress

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