A R search Based on BCG S gnal D tection D vice

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Abstract—Cardiovascular disease is one of the main diseases threatening human healthy. Currently, the main method to detect cardiac function is electrocardiogram (ECG). However, with the development of sensors and signal detection technology, many scholars have accepted to use ballistocardiogram (BCG) signal to detect cardiac function. The system of collecting the BCG signal is the newest non-invasive way to diagnose the cardiovascular disease. From now on, the collective of BCG signal has developed a lot, and the real-time BCG signal detections have many different methods which include sitting, standing, lying, ear band, wrist-mounted, wearable and so on. All those detections can detect the BCG signal, but the quality of the signal is different with the different detection method and algorithm. To make knowledge of BCG for many scholars, the paper summaries the different gestures to detect BCG and introduces the development of BCG signal in detail at present.

Keywords—BCG signal; detected gesture; sensor

I. INTRODUCTION

Cardiovascular disease is one of the main diseases threatening human healthy. So the detection of cardiac function becomes a more and more important problem. Currently there are two mainly methods to detect cardiac function: ECG (Electrocardiogram, ECG) and BCG (Ballistocardiogram, BCG).

Detection of the ECG signal has been very mature. However, with the development of medical technology, the methods of detecting important physiological signals gradually shift from invasive detection to minimally invasive or non-invasive detection, and then into the development of non-contact detection. These non-contact detections of physiological signals' techniques are paid more attention[1]. BCG signal is not a new concept, and the earliest records could be dated back to 1887. The study of BCG restarted in 1940s[2]. Till now, BCG signal is more and more perfect, at the same time, the sensitivity of sensors have significantly increased, from weighing sensor[3], pressure sensor[4], EMFi sensor [5], bathroom scales sensor and fiber sensor[6-7]. The real-time BCG signal detections have many different methods which include sitting, standing, lying, ear band, wrist-mounted, wearable and so on. In this paper, we summarize the different gestures to detect BCG and introduce the development of BCG signal in detail.

II. BCG SIGNAL DETECTING SYSTEM

A. *Sitting detection system*

In beginning, BCG signal is detected by using weighing sensor.

In the year of 2011, Xu Wang at el used weighting sensor to design a chair system to detect BCG. This system could derive respiration component from BCG signal. The ECG and nasal thermistor signals were recorded simultaneously as reference signals. The results showed that, compared with the reference data, the extracted pulse waveform was synchronized and the average error rate of quantitative assessment was feasible[8]. Yanbo Yu et al developed a home chair system to detect BCG signal which was collected by resistance strain weighting sensor. The system, which consisted of signal processing module and signal collecting module, could synchronously and clearly acquired BCG signal during the cardiac cycle[9].

Jianwei Su et al presented a BCG measurement system to obtain BCG signal from a subject sitting on a chair which installed three load-cell sensors platform. The measurement relied on sensing pressure variation on the seat related to cardiovascular cycles. Receiving signal was by Micro2440 board and displayed the results. Fangfang Jiang et al established mathematical model about BCG signal detection system in chair and used MATLAB to simulate waveform in time domain[11].

With time goes on, the sensitivity of sensor has significantly increased. Now, a sensor which is named EMFi is applied widely.

J.M.Kim et al developed a system that could measure ECG and BCG of a patient on wheelchair moving or pausing and transmit measured signals on a remote server through CDMA(code division multiple access) network[13]. In 2006, Junnila et al, College of signal processing technology in the university Tampere and Tampere University Hospital, presented a force-sensitive chair to detect BCG signal. We can see it in Fig .1[14]. They installed EMFi sensor, which was cut off the same size as rear seat and backrest, on the ordinary office chair. When the subject was seated on the chair, the change of EMFi sensor thickness, which was caused the force of heart beat in the vertical direction by the subject, could cause the change of charge. And then these charges can change voltage signal by pre-amplifier, and then they could get BCG signal by low-pass filter. Meanwhile, synchronous ECG signal can be used as calibration of the cardiac cycle, the analysis of the signal could get the characteristics of young healthy, healthy elderly and elderly healthy subjects different BCG signal[15][16].

Figure 1. Force-sensitive chairs BCG signal detection device

In 2013, JingZhang et al presented BCG detection system. They used EMFi sensor to collect signal, and processed the signal by amplifying, filtering and frequency notch to get BCG signal. Then they compared the synchronous ECG signal and BCG signal. They got the conclusion that the BCG and ECG had great relevance to calculate heart rate[17].

On the other hand, weighting sensor, EMFi sensor are electronic based and susceptible to electromagnetic interference, which may be a problem in some clinical applications, e.g., Magnetic Resonance Imaging (MRI). Fiber optic sensor is a better candidate in medical application because of its inherent immune to electromagnetic interference.

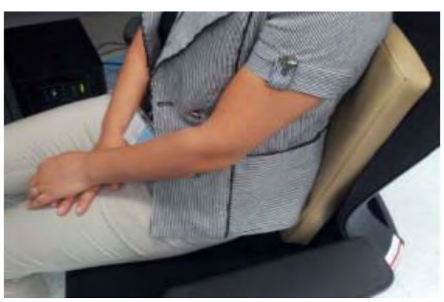

Figure 2. smart cushion

Chacko John Deepu designed a smart cushion for real-time heart rate monitoring. Show in Fig .2. The cushion comprised of an integrated micro-bending fiber sensor, which recorded the BCG signal without direct skin-electrode contact, and an optical transceiver that did signal amplification, digitization, and pre-filtering[18].

The following waveform, shown in Fig .3, is collected by the smart cushion.

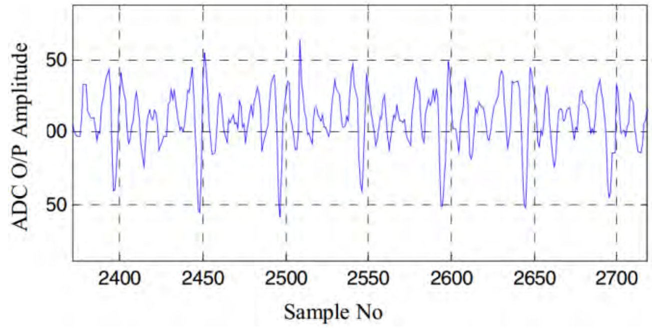

Figure 3. BCG Signal from smart cushion

Processing this BCG signal, the authors used this algorithm includes 6 steps, as shown in Fig .4. The BCG samples were filtered using a 2-10 Hz band-pass FIR filter with a 40dB attenuation to remove the low and high frequency impulse noises. The amplitude swing of the resultant signal was enhanced by conducting a cubing (x^3) operation on the filtered signal while keeping the signal sign intact. In the next step, a moving average operation was performed over 0.06 second (3 samples), in order to filter out any momentary upswing/downswing. The width of the BCG IJK complex was greater than this duration and hence was not affected. The filtered output was further smoothened by computing the absolute value and averaging over 0.3 second (15 samples) before doing a cone detection and comparing to a detection threshold. The outputs from various stages were illustrated in Fig .5[18].

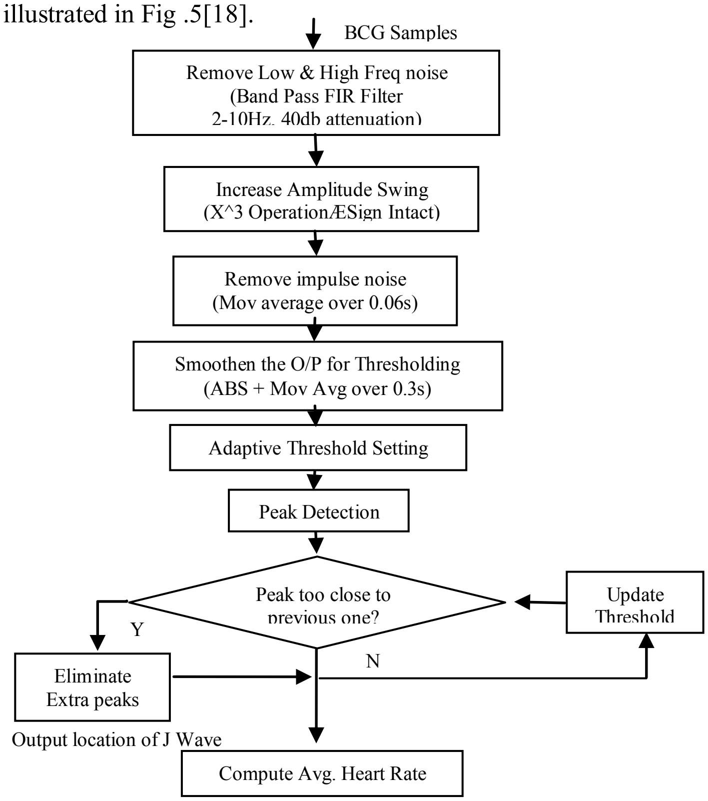

Figure 4. BCG heart rate detection flow chart.

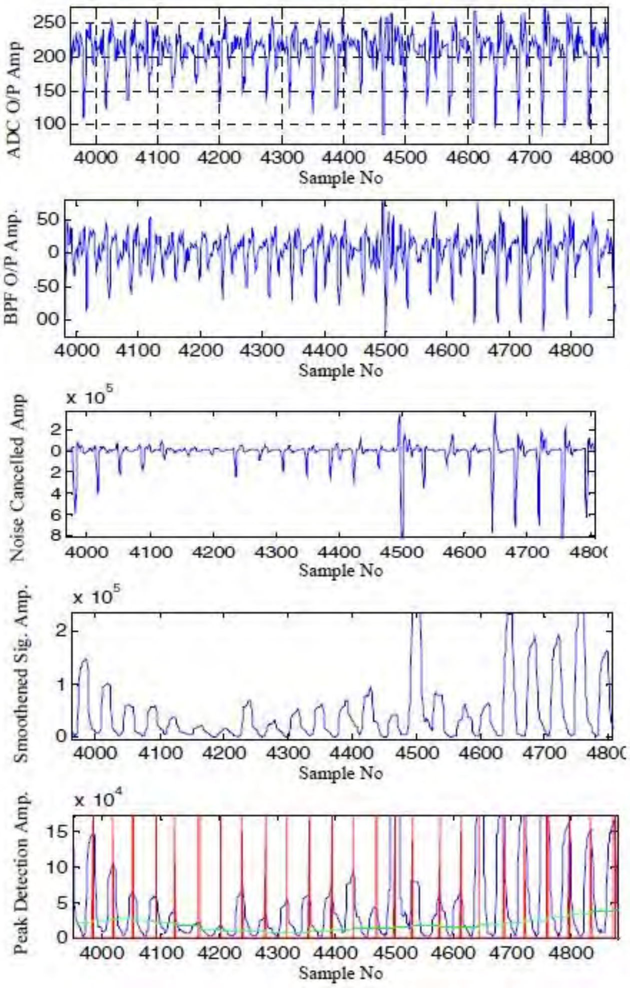

Figure 5. Outputs in BCG signal processing: (a) original input;(b) band-pass filtered signal; (c) after x3and moving average;(d) absolute value and moving average; (e) after peak detection.[18]

B. *Standing detection system*

Landaeta et al used electronic scales to detect human standing BCG signal and concluded the human heart rate. In this system, the subject could wear shoes and socks[19]. Chunwu Wang designed a precision A / D converter module signal detection system which based on the theory of BCG. The system used non-invasive detection method. The subject didn't need to wear electrodes and could wear normal clothing, stand on the monitoring platform which could realize non-feeling BCG signal recording. This system was easy to record daily activity of cardiac mechanical, and also could be applied to the long-term cardiac monitoring in the family[20].

Stanford University Inan et al modified a commercially available bathroom scale to enable unobtrusive and robust cardiovascular monitoring in the home.

Handlebar electrodes were interfaced to an ultra-low power, two-electrode ECG acquisition circuit providing consistent and clean heartbeat timing information. In addition, the footpad electrodes were used to detect lower-body electromyogram (EMG) and lowerbody impedance plethysmogram(IPG) signals using two parallel circuits. BCG signal was the component of bodyweight that varies with the time[22]. At the same year, the same university Dookun Park[23] improved the device. They presented a preliminary approach for heartbeat detection on a weighing scale, using a combined heartbeat detector and an ensemble method. First, two independent sub-detectors were implemented based on the BCG and lower-body IPG signals. Then, the results of these sub-detectors were combined using a higher level decision maker. The IPG signal could be used to supplement the information lost in the BCG[24][25]. The result showed the combination significantly improved over individual detector, with a resulting interval accuracy of 97%.

In 2012, Giovangrand et al reported on the preliminary deployment of a bathroom scale-based BCG system for in-hospital monitoring of patient with heart failure[26]. Show in Fig .6. The system was designed to be robust and user-friendly, with dual BCG and ECG capabilities. The BCG was measured from a modified bathroom scale, while the ECG (used as timing reference) was measured using dry handlebar electrodes. The signal conditioning and digitization circuits were USB-powered, and data acquisition performed using a netbook.

In 2010, Delia H.Diaz et al developed an algorithm to detect single-foot BCG signal and extracted heart rate[27].

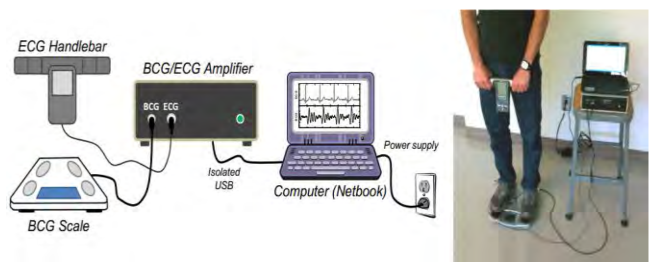

Figure 6 (a): BCG/ECG detection device (b): the processing of BCG/ECG detection

C. *Lying detection system*

In the application of clinical practicing, lying BCG signal detection device is earlier used.

In 1981, Alihanka designed electrostatic SENSITIVE mattress (Static Charge Sensitive Bed, SCSB), the principle shown in Fig .7.

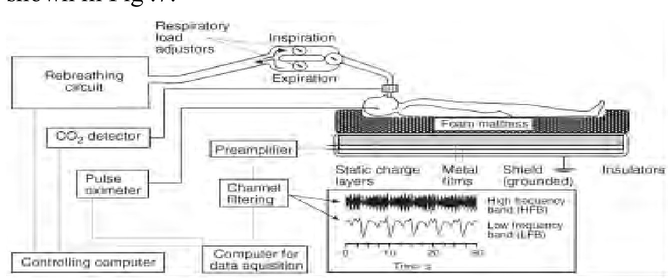

Figure 7.the constitution of a charge sensitive mattress

Mattresses were embedded in two different dielectric constants of the metal plate and a large capacitor. When the subjects lying on SCSB that any one of the tiny vibrations on the surface could cause friction between the two metal plates to produce the charge and was large capacitance pickup. This time you could record the beating heart of the case. Meanwhile, SCSB could be used to obtain synchronized breathing and body movement signal, to monitor sleeping apnea, and to evaluate sleeping quality [28]. Jansen et al used SCSB to collect the heart rate, breathing and body movements in three different sports synthesized signal, and analyzed their frequency and used the analog filter to separate these three signals, in which representatives of the low frequency was breathing exercises, the high frequency signal was the heartbeat[29] .

With the widespread use of BCG signals in clinical practice, in 2001, Sun Yu Meng, Beijing Biomedical Research and Development Center, who designed an inflatable mattress sensitive microswitches (Micro Movement Sensitive Mattress, MMSM), showed each small action of the human body surface which could cause changes in MMSM airbag gas pressure. And this pressure sensor could transform into electrical signals, amplifying and then filtering, finally, the signals recorded by computer, shown in Fig .6 [30] .

In 2004, Watanabe, T et al basing on pneumatic noninvasive biometrics sleep estimation method and aerodynamic methods measured the relationship of night of sleep, sleep stages, and a biological signal. In the result, basing on the transfer equation in the state of the observer, the design of a classifier based on the observed relationship. In recent years, because of previous large number of theoretical and experimental basis in BCG signal detection, lying BCG signal detection device became more scientific and accurate [31].

Maki. H mentioned to an non-invasive system which could monitor clinical patients who needed long-term care or heart rate and respiratory of the elderly in Engineering Medicine and Biology Society (EMBC). The Changes of the shape and the coil spring vibration in mattress could adjust the intensity of the received infrared signal, and then it could change the physiological parameters such as heart pulse rate, respiration and body movements. Furthermore physiological parameters were received by the infrared ray intensity which obtained in low, high and band pass filter[32].

In 2012 EMBC, Bruser, C et al improved the long-term monitoring of heart (and breathing) rhythm obvious non-invasive vibration sensors and signal processing. By placing a new ordinary optical BCG mattress underneath sensors to monitor vital signs, at the same time, they analyzed the spatial sensitivity. Compared to traditional a more traditional single-motor sensor BCG system, showed that the proposed multi-channel optical system may reduce the estimated error rate of heart beat rate, even though, that made it possible to analysis complex breathing pattern [33].

D. Others

In addition to sitting, standing, lying posture of the three most common BCG signal detection device, there are other types of BCG signal detection devices, such as wrist-worn, worn ear, sitting as well as standing and so on.

In 2003, Najib T. Ayas designed a diagnosis of obstructive sleep apnea (OSA) wrist-worn device (Watch_PAT100). By judging PSG sleep and respiratory activity, peripheral arterial tonometry (PAT) of Watch_PAT data used by signal attenuation, and when blood oxygen saturation, if heart rate changed, a computer algorithm would automatically calculate the hourly dynamic analysis to measure the frequency of sleep apnea events that resulted in a PAT apnea-hypopnea index (AHI). The results showed that Watch_PAT could reasonably and accurately detect OSA signals. Therefore, Watch_PAT was a useful way to diagnose OSA [34].

As to the ear-worn style, studies show that ear is ideal location to monitor physical mechanical changes.

He, DD proposed an integrated vital signs monitor which could be worn in the ear at the Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE. This BCG signal detecting means consisted of a 25mm×25mm differential capacitance electrode made by fabric. So that BCG could provide continuous signals of heart rate and respiration rate with relation to cardiac output and blood pressure. And ears remain upright relative to the same direction compare to the heart, which simplified the calculation of the pulse propagation time[35]. The following year, He, D.D and others improved this device by shaping a hearing aid appearance, and wirelessly connected to a computer to record and analyzed the data. This means used the ear as anchoring points and a heart monitor acceleration meter probe consisting of triaxial MEMS. In the experiment, the head BCG and the head ECG intervals or RJ delay between the peak, the presence of noise signal can be extracted [36] .

With the continuous improvement and development of the performance of signal detection device, in 2012, Northeastern University Chunwu Wang designed a new type of BCG detection system which was suitable for sitting and standing detection. This detected system fixed sensor on two hard flat to constitute detection platform. The platform can be achieved standing detection on the ground. The result showed that the accuracy rate of heart rate up to 98.2%. It laid the foundation for the long-term cardiac and respiratory care in BCG signal[37].

III. CONCLUSION

BCG signal detection plays a more and more important role in cardiac function during our daily life. Development of sensor makes BCG signal more convinced. Different posture to detect BCG can be suitable for different subjects. It reflects the detection of BCG signal conveniently, quickly, real-time and accurately.

ACKNOWLEDGMENT

This work has been funded by the Fundamental Research Funds for the Central Universities(N130319001) and Northeastern University Students' Innovation and Entrepreneurship training program funds.

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