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# Computer-aided diagnostic tool for human vital signals detection

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**Abstract**

This paper describes the development and implementation of a simple and easy-to-use healthcare system for monitoring the severity of cardiovascular disease (CVD) by measuring and analyzing the pulse wave velocity (PWV) values under MATLAB environment. The developed home healthcare system includes graphic user interface (GUI) that presents the measured data into a simple and friendly program. It consists of patient information part and data analysis that is able to detect the severity of CVD. The design has been validated on human subjects, results showed that the computer-aided diagnostic tool would be serve as a new easy-to-use healthcare tool for long term monitoring of patients at home due to its properties of non-invasive, effort-independent, and continuous monitoring.

***Keywords:*** *Graphic user interface, cardiovascular disease, pulse wave velocity, electrocardiography, plethysmography*

## 1. Introduction

The World Health Organization refers the cardiovascular disease (CVD) as the worldwide leading cause of death, resulting in a number of annually deceased people higher than from any other cause, about 31% of all global deaths due to CVD in 2012 and this number will be increased to 23.6 million by 2030 [1]. Approximately 20% of local Chinese adults have CVD in China [2]. China is one of the largest developing countries in both area and population. The country's economic situation does not allow for the allocation of sufficient public funds for cardiovascular healthcare. Pervious study suggested that early diagnosis of CVD could prevent further complications, leading to improvement of patient's quality of life and, for long term, can decrease the costs of the medical system [3]. To achieve this goal, it is necessary to long term monitoring of the patients especially to monitor their habitat during sleeping and daily activities.

Arterial stiffness is a well-established independent indicator of coronary events and CVD outcome [4]. Pulse wave velocity (PWV) is widely recognized as a useful non-invasive approach to access arterial stiffness and severity of CAD, and it is correlated with many cardiovascular risk factors, including age, blood pressure, pulse pressure, hypertrophy and heart diseases [5]. PWV is the velocity of the blood pressure wave as it travels a given distance between two anatomic sites within the arterial system [6]. It is normally measured at trunk (aortic PWV), arm and leg [7]. Aortic PWV (aPWV) is related to the mechanical properties of aortic stiffness that has a prognostic role in various diseases include CVD [8]. Faster aPWV is indicative of stiffer the vessel, studies showed that each 1 m/s aPWV increase is associated with 7% increased cardiovascular event risk in a 60 years old man after correction for traditional cardiovascular risk factors [9]. A number of methods have been used to measure aPWV including applanation tonometry and biomedical imaging methods [10-14]. Applanation tonometry is the most common approach used clinically for aPWV estimation. In general, measurements are performed by recording pressure waveforms at the carotid artery followed by the femoral artery, with an Electrocardiography (ECG) signal being recorded simultaneously. The mean time difference and the arterial path length between the two recording sites are used to calculate the aPWV.

Previous studies found that the arterial flow velocity was different after exercise or during sleep apnea [15]. However, it is not convenient and not economic to use a commercial system for long term monitoring of PWV during sleep. The purpose of this study was to develop a compact and easy-to-use wireless healthcare system based on an external electronic board and a computer for the real-time and long term monitoring of cardiovascular activities at home. Virtual instrumentation has been investigated as it has advantages in developing user-defined tools for control, process, and visualization of data. This paper presents the development and implementation of virtual instrumentation for healthcare application running on a computer. Additionally, a graphical user interface (GUI) tool was developed to estimate 10-year CVD risk and lifetime CVD risk as well as record, assess and analysis of human vital signs. The system can be used as a useful healthcare tool for long term monitoring cardiac status at home especially in developing countries.

## 2. Methods

Figure 1 shows the proposed healthcare monitor system that contains one ECG board with ECG sensor, one PPG board with finger wearable PPG sensor, one Crowduino ATMega328 microcontroller, a Bluetooth board and a GUI. The measured ECG and PPG data can be transferred to a computer through a Bluetooth connector or USB cable for data analysis using the developed GUI tool.

### 2.1 Graphic user interface (GUI) design

A GUI tool was developed under MATLAB environment to provide a user-friendly tool for the analysis and visualization of human vital signals. Figure 2 shows the screen shot of the designed GUI, which includes patient information, CVD risk estimator, results display and analysis, and quantification of CVD features based on the measured human vital signals. The patient information section allows the user to record the patients' personal information, emergency contact and medical information. Clicking the "CVD Risk Estimator" button after recording basic patient information, the CVD risk estimator window appears on the screen as shown in Figure 2(c), which shows 10-year CVD risk values and lifetime CVD risk values.

The CVD risk tool was developed using the published information from Framingham Heart Study Cardiovascular Disease 10-Year BMI-Based Risk Score Calculator [16], Framingham Heart Study General Cardiovascular Disease 30-Year Lipid-Based and BMI-Based Calculators [17], as well as ACC/AHA Pooled Cohort Equations CV Risk Calculator. Clicking the "Results" button after recording patient information, the data window will appear on the screen (see Figure 2(d)) that allows the users to select the measured data from the database by clicking the "Upload file" button. After that, the "Analysis" button will appear on the screen for analysing the measured vital signals from human subjects.

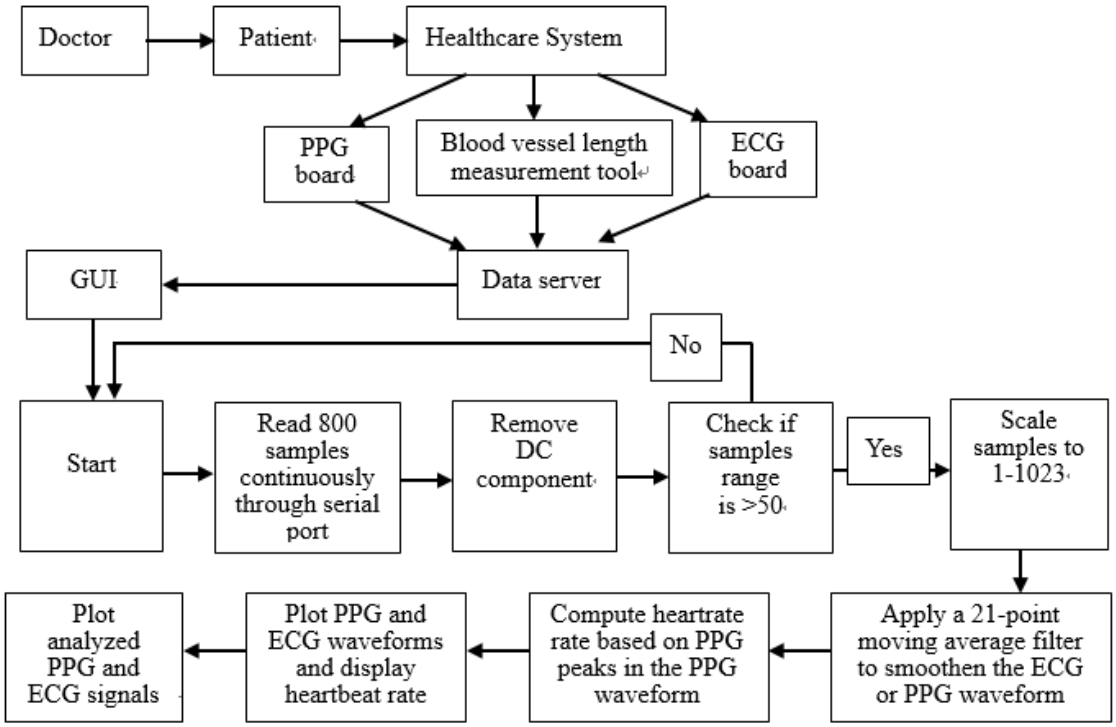


Figure 1: Flowchart of the system and software running on MATLAB GUI

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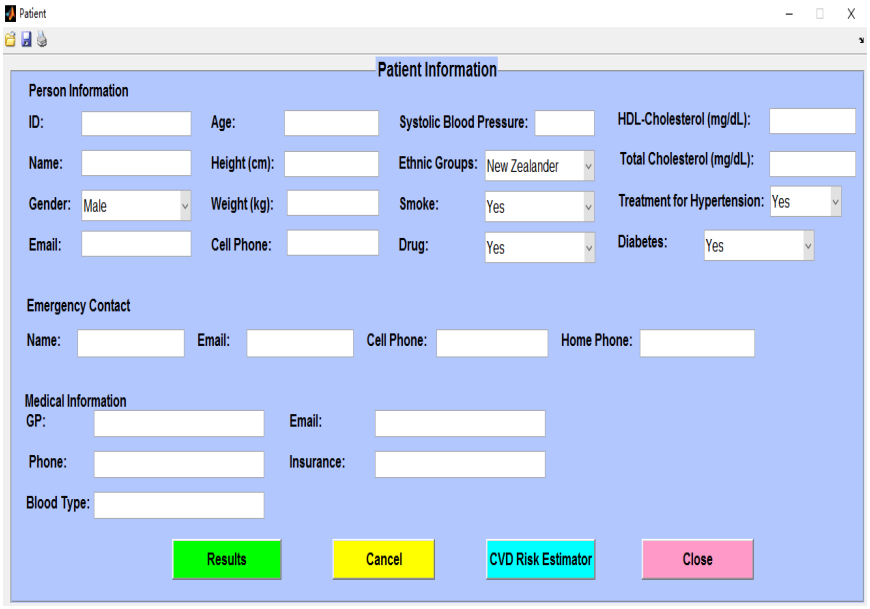
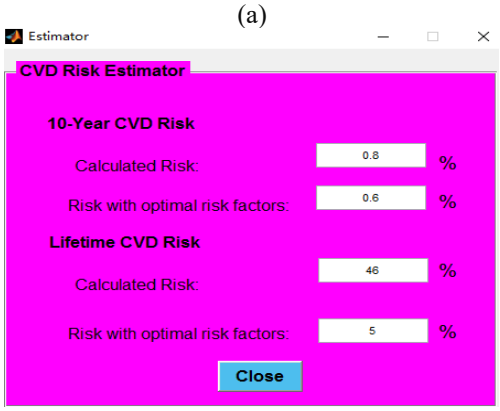
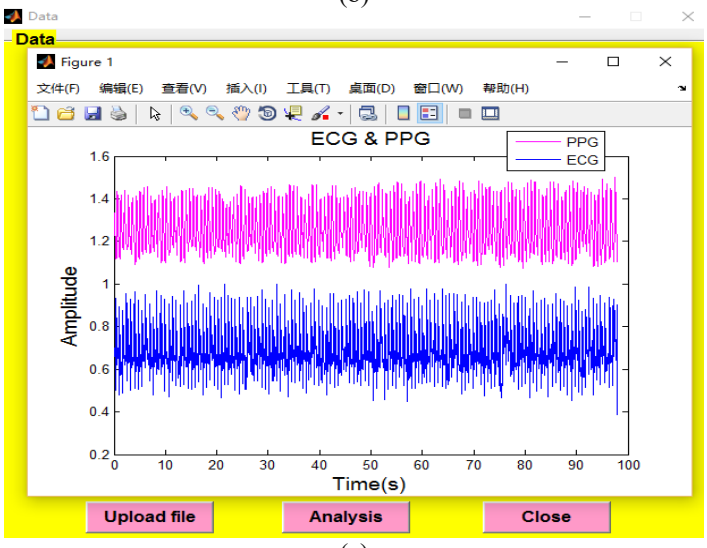



(a)




(b)




(c)

Fig. 2: (a) Patient information screen (b) CVD risk estimator screen (c) Data displaying screen

## 2.2 Hardware system design

Footnotes should be typed in singled-line spacing at the bottom of the page and column where it is cited. Footnotes should be rare. The hardware system was developed using one Crowduino board that contains an ATMega328 microcontroller with a 14 bits A/D converter for gathering and converting the data from the analog module, and a wireless transceiver for data transmission. The Crowduino ATMega328 microcontroller was programmed to scan in the same cycle, both the ECG and PPG channels, with sampling rate of 9 per millisecond, converting the signals from analog to digital. The ECG sensor board was made to detect ECG signals by measuring the skin potentials using 3 electrodes placed on the skin surface. The technique uses the R-wave extracted from the ECG signal as the beginning of the ventricular contraction, which is the start moment of the pulse wave and travels from the heart to distal regions. The PPG sensor board was made to record the blood pulse wave by using a finger wearable phototransistor sensor. The arrival moment of the pulse wave to the index of the left hand was determined from the PPG signal.

Figure 1 displays the flowchart for displaying ECG and PPG waveforms as well as calculating heartbeat rate using the GUI tool. The GUI tool first reads 800 consecutive samples sent by Arduino sensor board. The DC component (minima of 800 samples) was subtracted from the samples, followed by computing the samples range. If the range of samples is greater than, the recorded data considered as valid ECG or PPG signals, otherwise, considered as noise. The noise would happen when ECG or PPG sensors are faulty or disconnected. The samples were scaled for full swing of display and then a 21-point moving average filter was applied to remove all unwanted measurement (such as noise) in the measurement data. The resulting samples were plotted against time to obtain a clean and smooth ECG and PPG waveforms. The first 10 samples and the last 10 samples were removed when applying the moving average filter.

## 2.3. PWV and heart rate measurement

PWV and heartbeat rate was computed based on the measured ECG and PPG signals. Three consecutive peaks in the PPG waveform based on where the slope of the curve changes from positive to negative, and the magnitude of the signal was greater than 80% of the maxima of all the samples. Time difference Δt between any two peaks can be computed from the following equation

$$\Delta t = t \times (S_{i+1} - S_i) \qquad (1)$$

Where $S_i$ is the number of samples when PPG waveform reaches to the first peak value, $S_{i+1}$ is the number of samples when PPG waveform reaches the next peak value, t is sampling rate.

Two heart rates were computed from the three consecutive PPG peaks and their average value was computed as an instantaneous heartbeat rate. The PPT can be computed based on the expression

$$PPT = t \times (SR_i - ST_i) \qquad (2)$$

Where $SR_i$ is the number of samples when ECG waveform reaches the ith peak value, $ST_i$ is the number of samples when PPG waveform reaches the ith peak value at the same scale range with ECG signals, t is sampling rate.

The PWV was computed based on

$$PWV = \frac{B_L \times f_s}{|Index(ECG) - Index(PPG)|} \qquad (3)$$

Where $B_L$ denotes the blood vessel length which can be measured using anatomical landmarks for detecting the heart position, the aortic branch and brachial trunk. $f_s$ means the sampling frequency, Index(ECG) and Index(PPG) are the peak values of ECG and PPG signals.

## 2.4. Human testing

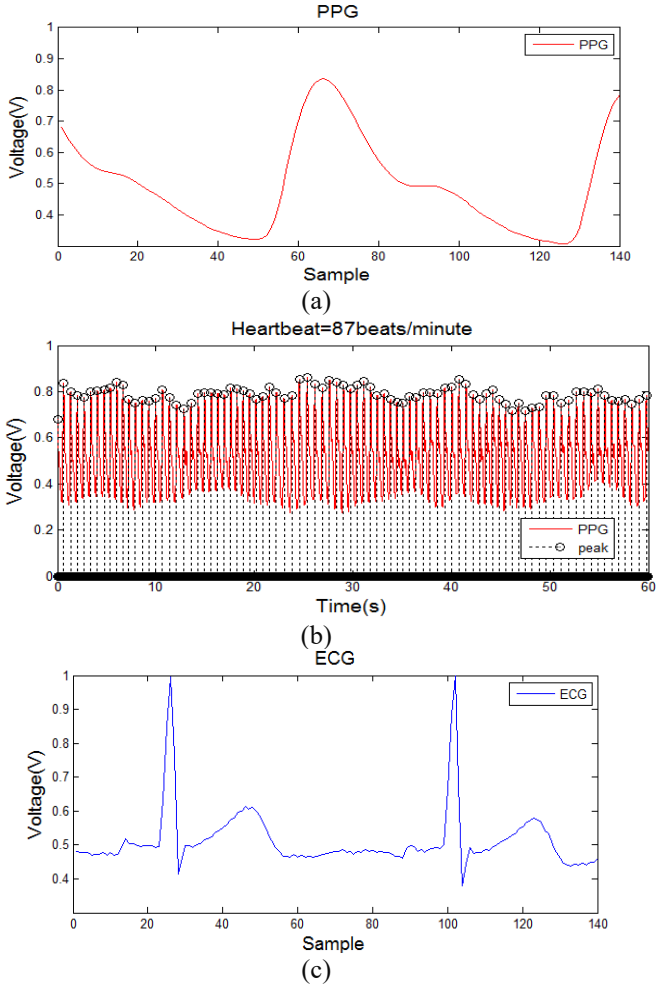
To evaluate the proposed GUI-based healthcare system, ten human subjects were invited to join the test at the Institute of Biomedical Technologies (IBTec), Auckland University of Technology, New Zealand. This study was approved by the Ethics Review Board of the Auckland University of Technology (Protocol number: 14/47). Five healthy male and five healthy female volunteers (age: 25-45 years, body mass index: 20-28kg/m2) were recruited. Experiments were conducted from 8 am to 11 am in a quiet environment with a room temperature of 20°C.

All participants were suggested to have no smoking and caffeine ingestion at least 12 hours prior to the experiment. The test subject was placed on bed in the supine position. The acquisition procedures performed simultaneously for 120 seconds at a sampling rate of 9 ms using the self-developed portable device. The standard lead I configuration was used for recording ECG signals. A finger wearable PPG sensor was placed on the left hand index finger to record PPG signals. Both measured signals were transferred through Crowduino board and wireless blue tooth sensor board to a computer, and then the GUI tool was used to display and analyse the recorded data.

## 3. Results

Figure 2(b) demonstrates the CVD risk estimation results of a 40-year-old male participant, who is New Zealander and nonsmoker. Figure 2(c) shows the original ECG and PPG signals and the analyzed results are shown in Fig.3, the heartbeat rate (87 beats/min) was computed from the heart movement signals. The identified peaks were marked with a circle (O) symbol. Figure 3(e) and Figure 3(f) presents the variation in time of the heartbeat rate and PWV recorded from the 40-year-old male participant, respectively.

Figure 4 shows original, reconstructed, compressed signals and noise removed ECG signals using different techniques, respectively. Figure 5 demonstrates original, reconstructed, compressed signals and noise removed PPG signals using different techniques, respectively.



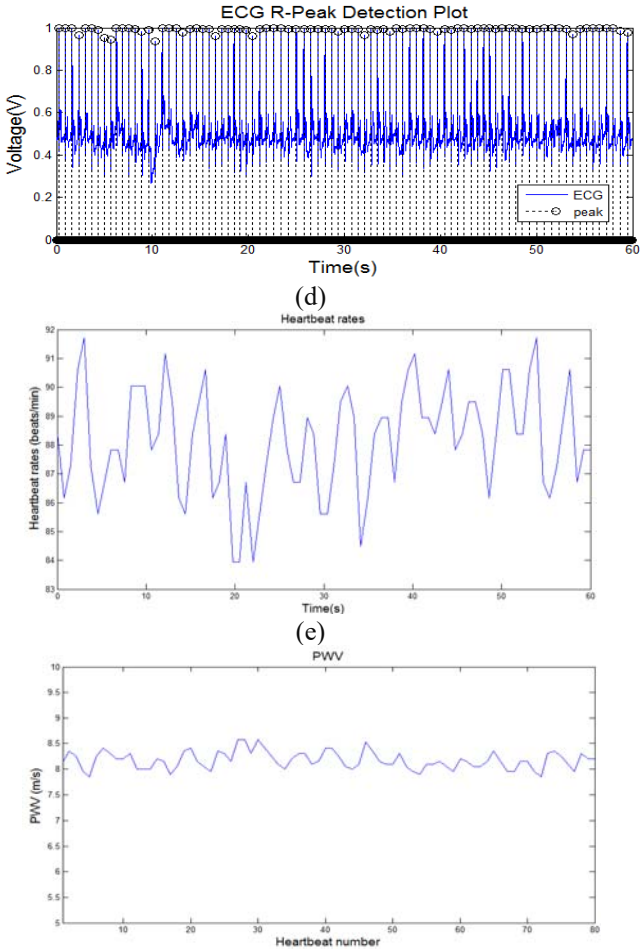
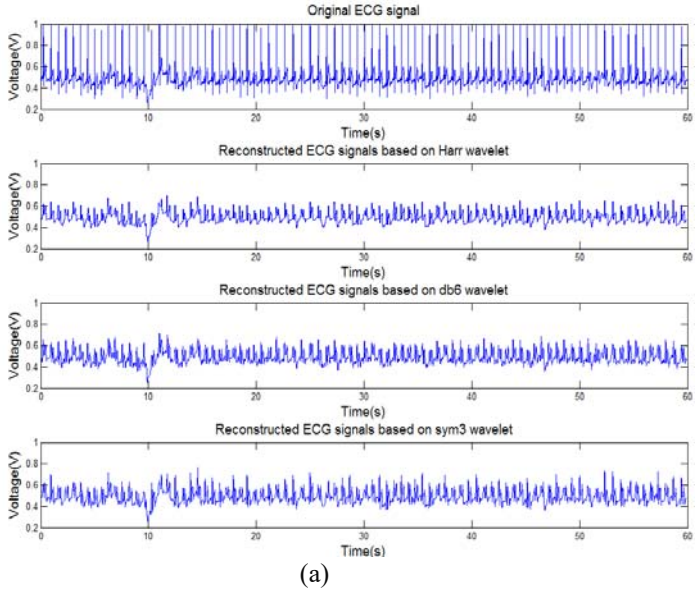
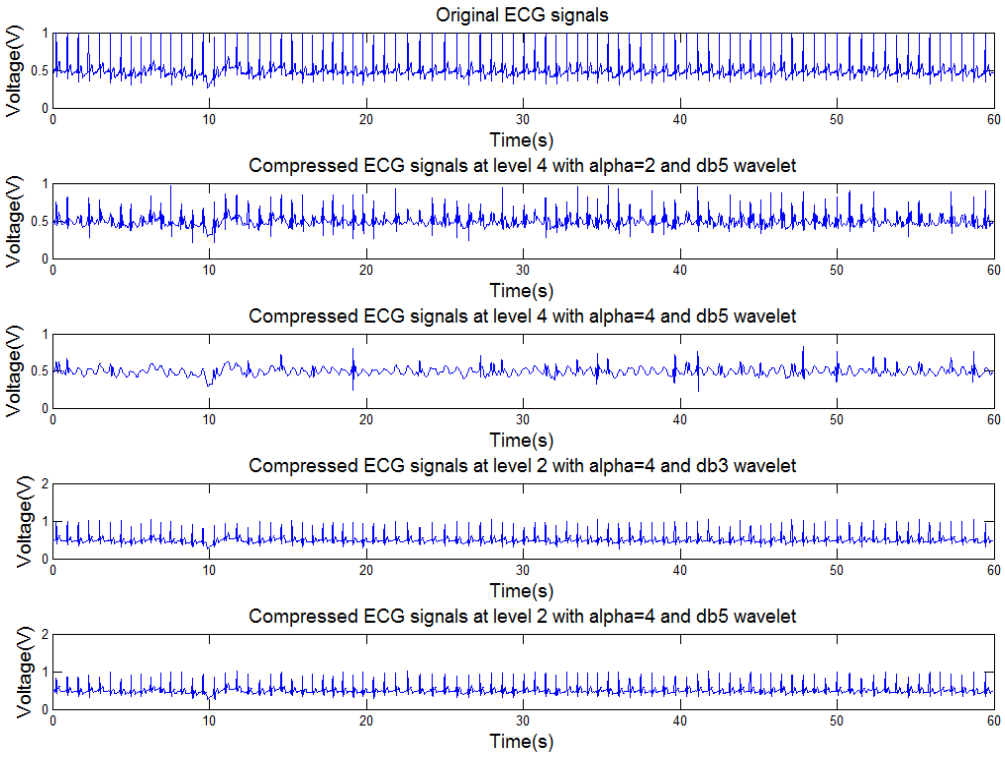




Figure 3: (a) PPG signal (b) PPG signals with identified peaks and heartbeat rate (c) ECG signals (d) ECG signals with identified peaks (e) Heartbeat rates (f) PWV recorded



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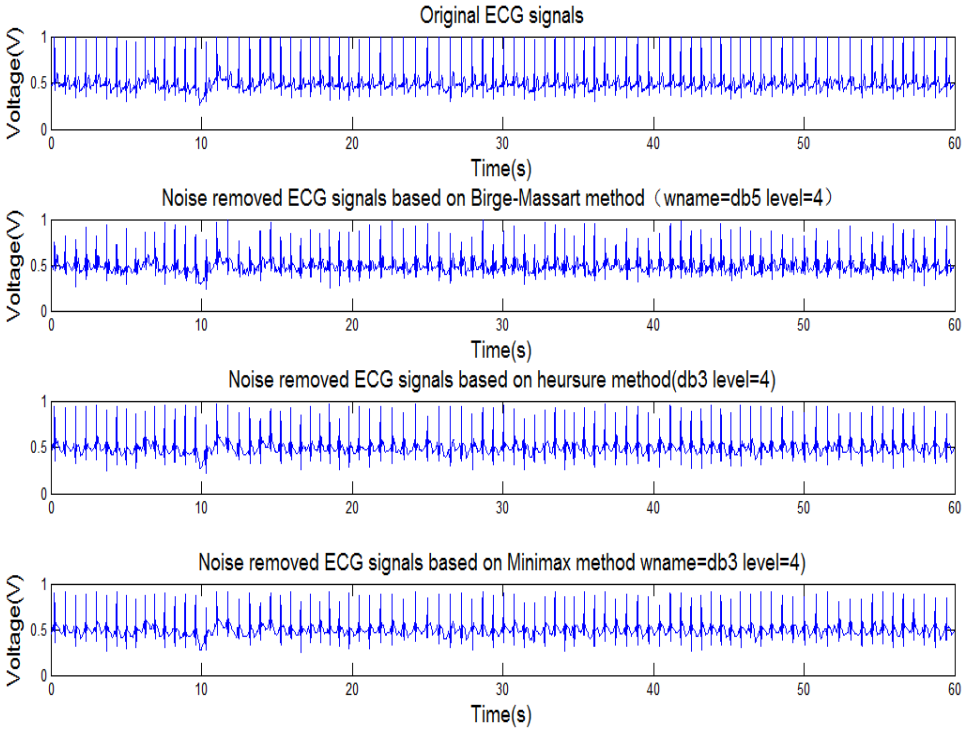
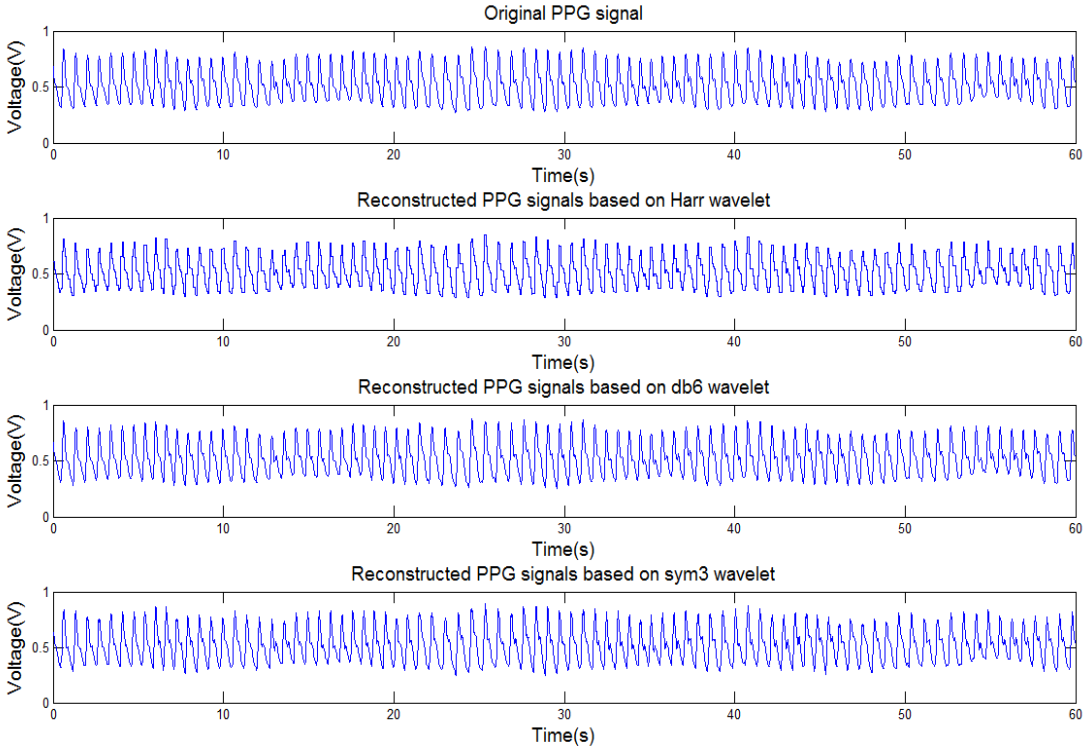
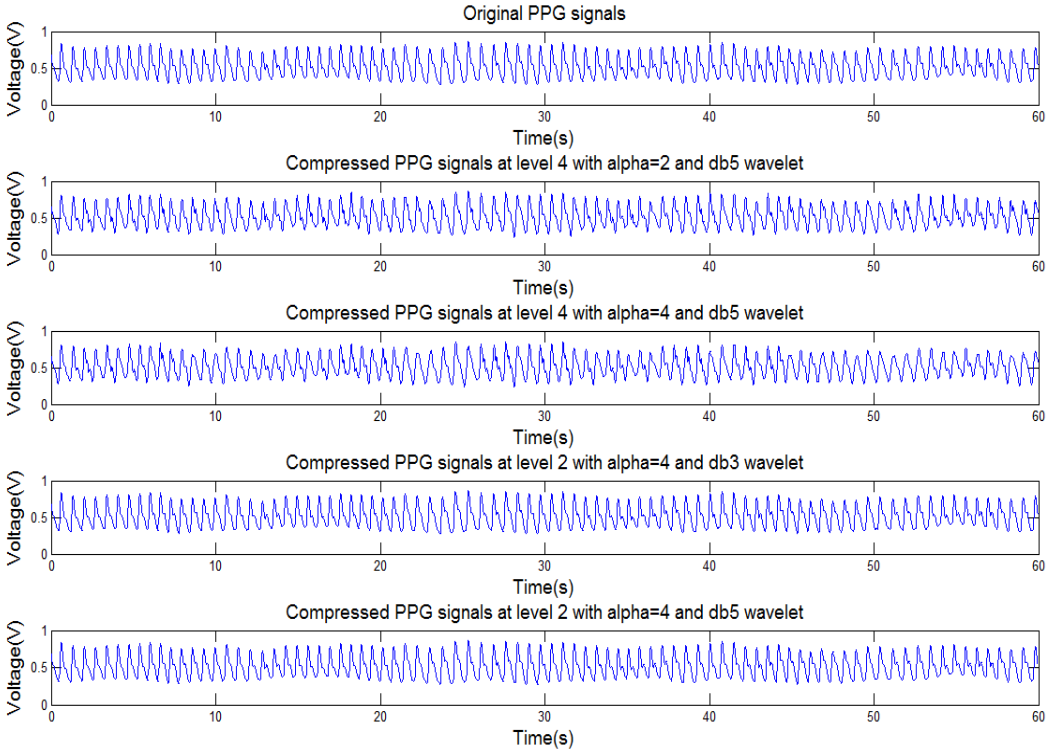



(c)

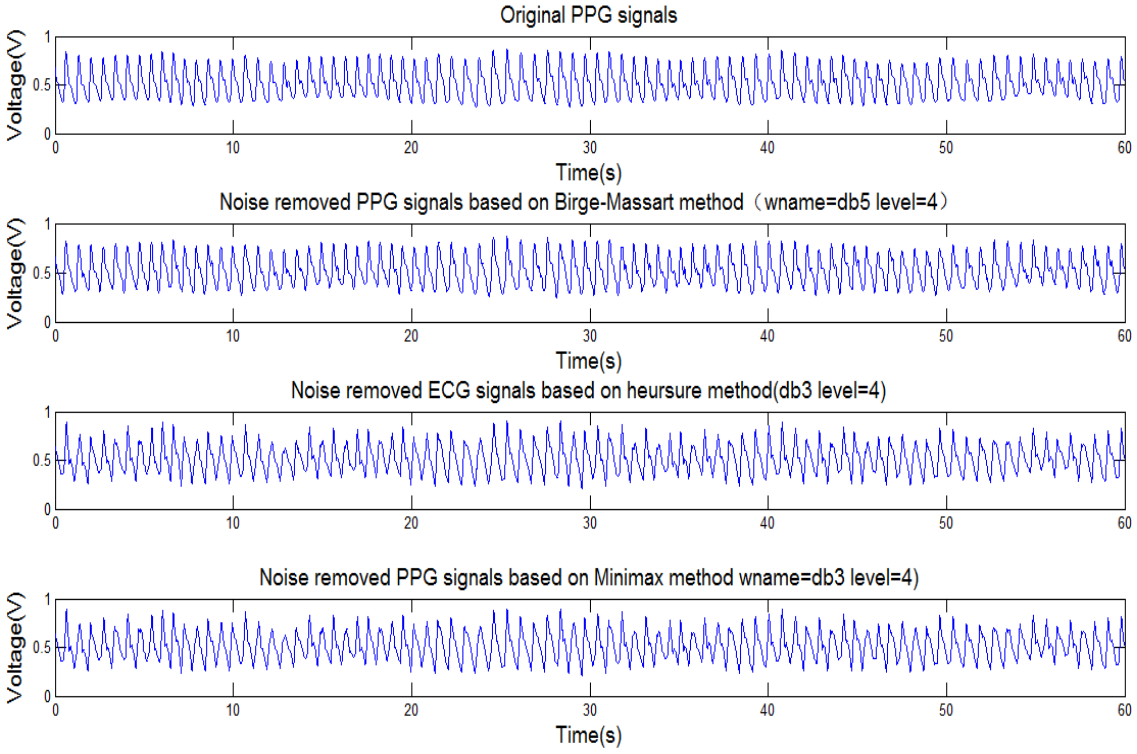
Figure 4: (a) Original ECG and reconstructed ECG signals (b) Original ECG and compressed ECG signals (c) Original ECG and noise removed ECG signals


Original PPG signal
Reconstructed PPG signals based on Harr wavelet
Reconstructed PPG signals based on db6 wavelet
Reconstructed PPG signals based on sym3 wavelet
Voltage(V)
Time(s)

(a)


Original PPG signals
Compressed PPG signals at level 4 with alpha=2 and db5 wavelet
Compressed PPG signals at level 4 with alpha=4 and db5 wavelet
Compressed PPG signals at level 2 with alpha=4 and db3 wavelet
Compressed PPG signals at level 2 with alpha=4 and db5 wavelet
Voltage(V)
Time(s)

(b)




(c)

Figure 5 : (a) Original PPG and reconstructed PPG signals (b) Original PPG and compressed PPG signals (c) Original PPG and noise removed PPG signals

## 4. Discussion

Experimental measurements on human subjects were performed to validate the design. The system successfully recorded and analysed ECG and PPG waveforms from human subjects. The GUI tool contains several features includes CVD risk estimator, heartbeat rate computing, reconstructed measured data using various methods, noise removed using different techniques, and computing PPT, heartbeat rates and PWV values based on the measured ECG and PPG signals. The system has an ability to transfer the recorded data to a personal computer through a commercial blue tooth sensor board or a USB cable. The current version of GUI tool displays the near-real-time ECG and PPG waveforms and heart rate but does not record correct data all the time. Data correction was required before data recording. Compared to existing systems, the expensive data acquisition unit was replaced by the GUI tool to guide and analyse the measured data, which greatly simplifies the practical implement of the measurements and reduces costs. Some significant advantages of the system include compactness, easy-to-use, safe and easy to manufacture.

In summary, an easy-to-use GUI-based healthcare system was presented in this study, which may become a useful home healthcare tool for long term monitoring cardiac status across a large population in developing countries. This data would not only contribute valuable information to the scientific literature but also provide new insights into ways to improve the diagnostic process of CVD.

## Acknowledgments

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