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Simulation Recording of an ECG, PCG, and PPG for Feature Extractions

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Abstract

Recently, the development of the field of biomedical engineering has led to a renewed interest in detection of several events. In this paper a new approach used to detect specific parameter and relations between three biomedical signals that used in clinical diagnosis. These include the phonocardiography (PCG), electrocardiography (ECG) and photoplethysmography (PPG) or sometimes it called the carotid pulse related to the position of electrode.

Comparisons between three cases (two normal cases and one abnormal case) are used to indicate the delay that may occurred due to the deficiency of the cardiac muscle or valve in an abnormal case.

The results shown that S_1 and S_2, first and second sound of the heart respectively, can be determined from another signal like ECG. Moreover, the position of QRS complex and the end of T wave could be estimated by using PPG signal.

***Keywords**: Cardiac Signal, ECG, PCG, carotid pulse, PPG, signal processing, feature extraction.*

1. Introduction

wave that cannot be readily identified (even visually), especially when murmurs Biomedical signals particularly the signals that related with the most important organ such as the heart are received an important view of interest.

Akay AM et al. identified the diastolic segment of the PCG, which is required in some applications in cardiovascular diagnosis such as detection of coronary occlusions using autoregressive modeling of diastolic heart sounds. [1] Shaver et al. [2] and Reddy et al. [3] included S_2 in the part of their article on systolic sounds. However as in the case of S_1, S_2 is also a nonspecific vibrational are presented. Given the temporal relationship between the T wave and S_2, it may appear that the former may be used to identify the latter. This, however, may not always be possible in practice, as the T wave is often a low-amplitude and smooth wave and is sometime not recorded at all. ST segment elevation or depression may make even visual identification of the end of the T wave difficult. Thus the T wave is not a reliable indicator to use for identification of S_2 so it may be indicated from the carotid pulse at the beginning of dicrotic notch with some time delay which be illustrated in this paper.

2. Electrocardiogram (ECG)

The recording of the electrical activity associated with the functioning of the heart is known as electrocardiogram. ECG is a quasi-periodic, rhythmically repeating signal synchronized by the function of the heart, which acts as a generator of bioelectric events [4]. The

heart has four chambers: the upper two chambers called the atria, and the lower two chambers called the ventricles. The atria are thin-walled, low-pressure pumps that receive blood from the venous circulation. Located in the top right atrium are a group of cells that act as the primary pacemaker of the heart. Through a complex change of ionic concentration across the cell membranes, an extracellular potential field is established which then excites neighboring cells, and a cell-to-cell propagation of electrical events occurs [5]. The first ECG wave of the cardiac cycle is the P wave, which represents activation of the atria. Conduction of the cardiac impulse proceeds from the atria through a series of specialized cardiac cells (the A-V node and the His-Purkinje system). There is a short, relatively isoelectric segment following the P wave. Once the large muscle mass of the ventricles is excited, a rapid and large deflection is seen on the body surface. The excitation of the ventricles causes them to contract and provides the main force for circulating blood to the organs of the body. This large wave appears to have several components. The initial downward deflection is the Q wave, the initial upward deflection is the R wave, and the terminal downward deflection is the S wave. The polarity and actual presence of these three components depend on the position of the leads on the body as well as multitude of abnormalities that may exist. In general, the large ventricular waveform is generically called the QRS complex regardless of its makeup. Typical amplitude of QRS is 1mV for a normal human heart. Following the QRS complex is another short relatively isoelectric segment. After this short segment, the ventricles return to their electrical resting state. And a wave of repolarization is seen as a low-frequency signal known as the T wave [6]. The normal wave pattern of an electrocardiogram is shown in Figure 1.

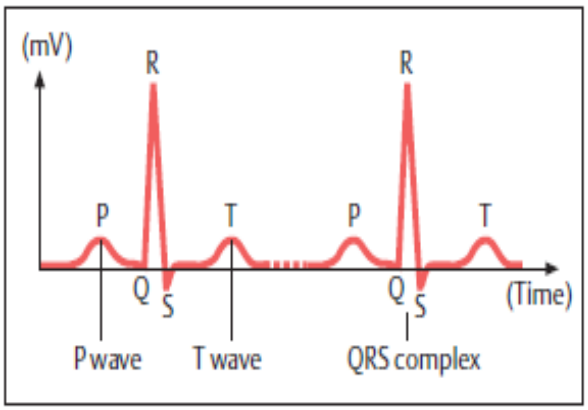

Fig.1. Four cycles of an Electrocardiogram.

3. Blood Pressure (PPG)

It also called as plethysmography signal which is related to the transducer that used in the acquisition process. Blood is pumped by the left side of the heart into the aorta, which supplies it to the arterial circuit. Due to the load resistance of the arterioles and capillaries, it loses most of its pressure and returns to the heart at a low pressure via highly distensible veins. The right side of the heart pumps it to the pulmonary circuit, which operates at a lower pressure. The heart supplies blood to both circuits as simultaneous intermittent flow pulses of variable rate and volume. The maximum pressure reached during cardiac ejection is called systolic pressure and the minimum pressure occurring at the end of a ventricular relaxation is termed as diastolic pressure. The mean arterial pressure over one cardiac cycle is approximated by adding one-third of the pulse pressure (difference between systolic and diastolic values) to the diastolic pressure. All blood pressure measurements are made with reference to the atmospheric pressure [4]. A typical blood pressure waveform is illustrated in Figure 2.

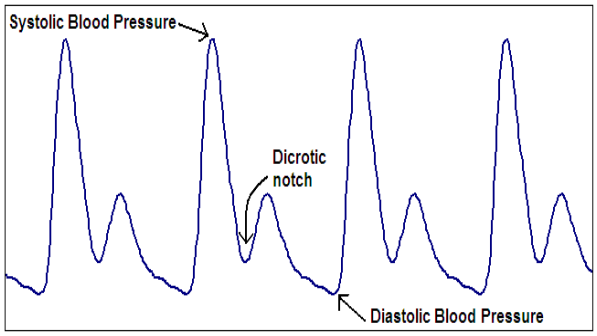

Fig. 2. Blood Pressure.

Blood pressure is the most often measured and the most intensively studied parameter in medical and physiological practice. It is a key source of information for determining hemodynamic state of the patient. By processing arterial blood pressure waveforms, one can track trends such as mean pressure and heart rate. It is also useful in estimating cardiac output, arterial compliance and peripheral resistance.

4. Phonocardiograph (PCG)

The phonocardiograph is an instrument used for recording the sounds connected with the pumping action of the heart. These sounds provide an indication of the heart rate and its rhythmicity. They also give useful information regarding effectiveness of blood pumping and valve action.

Heart sounds are diagnostically useful. Sounds produced by healthy hearts are remarkably identical and abnormal sounds always correlate to specific physical abnormalities. From the beginning till today, the principal instrument used for the clinical detection of heart sounds is the acoustical stethoscope. An improvement over the acoustal stethoscope, which usually has low fidelity, is the electronic stethoscope consisting of a microphone, an amplifier and a head set. Electronic stethoscopes can detect heart sounds which are too low in intensity or too high in frequency to be heard in a purely acoustic instrument. The phonocardiographs provide a recording of the waveforms of the heart sounds. These waveforms are diagnostically more important and revealing than the sounds themselves. The sounds are produced by the mechanical events that occur during the heart cycle. These sounds can be from the movement of the heart wall, closure of walls and turbulence and leakage of blood flow. The first sound S1, which corresponds to the R wave of the ECG, is longer in duration, lower in frequency, and greater in intensity than the second sound. The sound is produced principally by closure of the valves between the upper and lower chambers of the heart, i.e. it occurs at the termination of the atrial contraction and at the onset of the ventricular contraction. The closure of the mitral and tricuspid valve contributes largely to the first sound. The frequencies of these sounds are generally in the range of 30 to 100 Hz and the duration is between 50 to 100 ms. The second sound S2 is higher in pitch than the first, with frequencies above 100 Hz and the duration between 25 to 50 ms. This sound is produced by the slight back flow of blood into the heart before the valves close and then by the closure of the valves in the arteries leading out of the ventricles. This means that it occurs at the closure of aortic and the pulmonic valves.

The heart also produces third S3 and fourth S4 sounds but they are much lower in intensity and are normally inaudible. The third sound is produced by the inflow of blood to the ventricles and the fourth sound is produced by the contraction of the atria. These sounds are called diastolic sounds and are generally inaudible in the normal adult but are commonly heard among children [7].

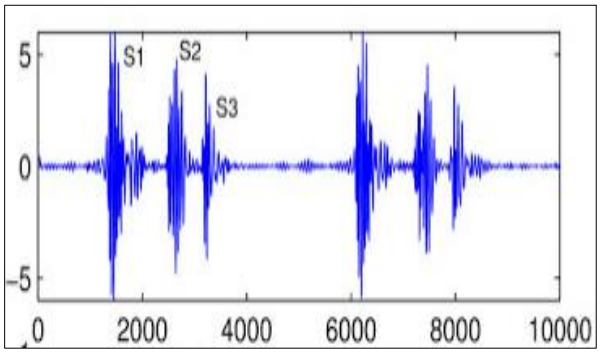

Fig. 3. Heart sound.

5. Physical Relation Between ECG, PCG and PPG

Each heartbeat begins with a signal generated by the sinoauricular (SA) node, commonly called the pacemaker. As the signal spreads through atrial muscle the atria respond by contracting (atrial systole). At this time the ventricles are relaxing (ventricular diastole) and the atrioventricular valves are open, the semilunars are closed. The ventricles are filling with blood, preparing for ejection.

The atrioventricular (AV) node picks up the pacemaker signal and, after a short delay that allows the atria to complete systole and enters diastole, sends the signal down the atrioventricular conduction system to the ventricles stimulating them to contract (ventricular systole). When the ventricles contract, ventricular pressure increases above atrial pressure and the atrioventricular valves close (1st heart sound).

Ventricular pressure continues to increase, and when it exceeds arterial pressure, the semilunars open and blood is rapidly ejected into the pulmonary trunk and aorta. The ventricles complete systole and enter diastole. As the ventricles relax ventricular pressure falls below arterial pressure and the semilunar valves close (2nd heart sound).

When ventricular pressure falls below atrial pressure, the atrioventrcular valves open and ventricular filling begins again. At this time (a period called diastasis) the atria and die ventricles are relaxed and awaiting the pacemaker to signal the next cardiac cycle.

The electrical events of the cardiac cycle can be recorded in the form of an electrocardiogram (ECG). [8].

6. Methodology

These signals are usually recorded by using surface electrodes. All the signals were recorded simultaneously with sampling rate of 1000 Hz. The dataset is available at (ftp://ftp.ieee.org/uploads/press/rangayyan/). The surface electrodes may be disposable, adhesive types or the ones, which can be used repeatedly. A ground electrode is necessary for providing a common reference for measurement. These electrodes pick up the potentials produced by the contracting muscle fibers. The signal can then be amplified and displayed on the screen of a cathode ray tube (the oscilloscope displays ECG, PCG and PPG waveforms) [4].

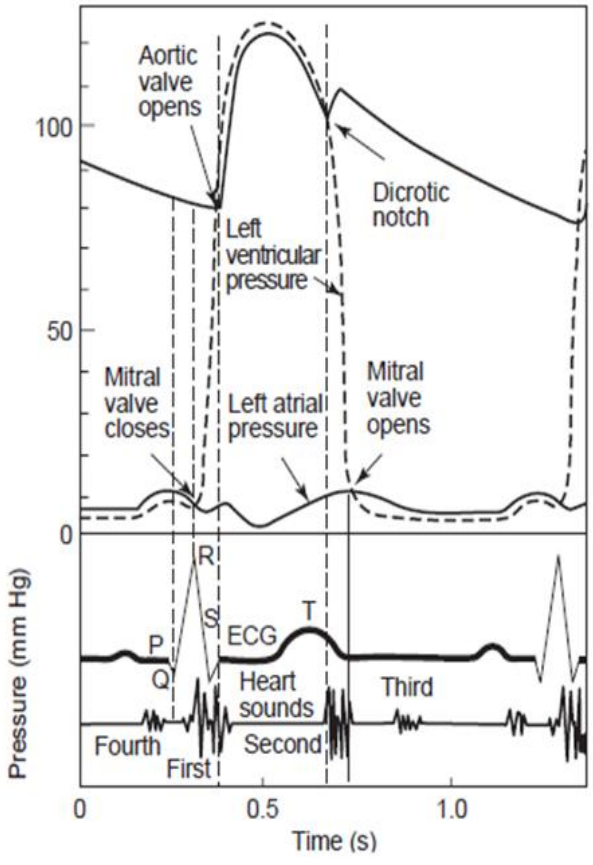

Fig. 4. Correlation of the heart sound with the electrical and mechanical events of the heart.

A schematic block diagram of the proposed system is illustrating the concept of this paper is shown in Figure 5.

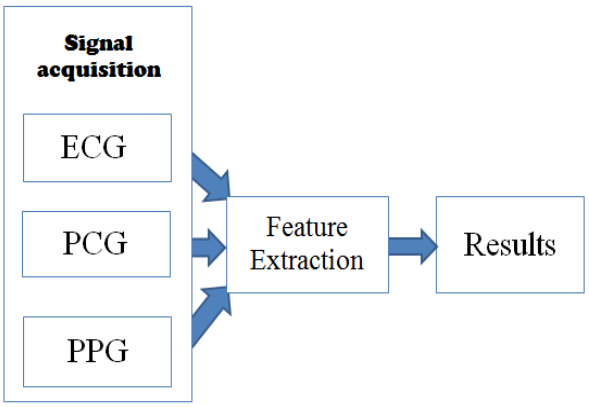

Fig. 5. Block diagram of the proposed system.

A. Signal acquisition

The ECG, carotid pulse, and PCG signals were recording from three channels with sampling frequency of 1000 Hz. The signals that used in this paper were recorded from three volunteer (adult male, male subject of 23 years) are normal and (female, 14 months) has systolic murmur, and patient suspected to have pulmonary stenosis, ventricular septa1 defect, and pulmonary hypertension [9]. The data of each person are collected using three channels data acquisition system as shown in figure 6A, 6B and 6C) below.

B. DC off set removing

The small DC offset in the signal as shown in the figure below is caused due to the instrumentation amplifier in that used in the medical equipment that used to collected the signal of interest. To remove these DC offsets, simply subtract them from the recorded raw signals as shown in Figure (7A, 7B and 7C). Now the DC offset was removed.

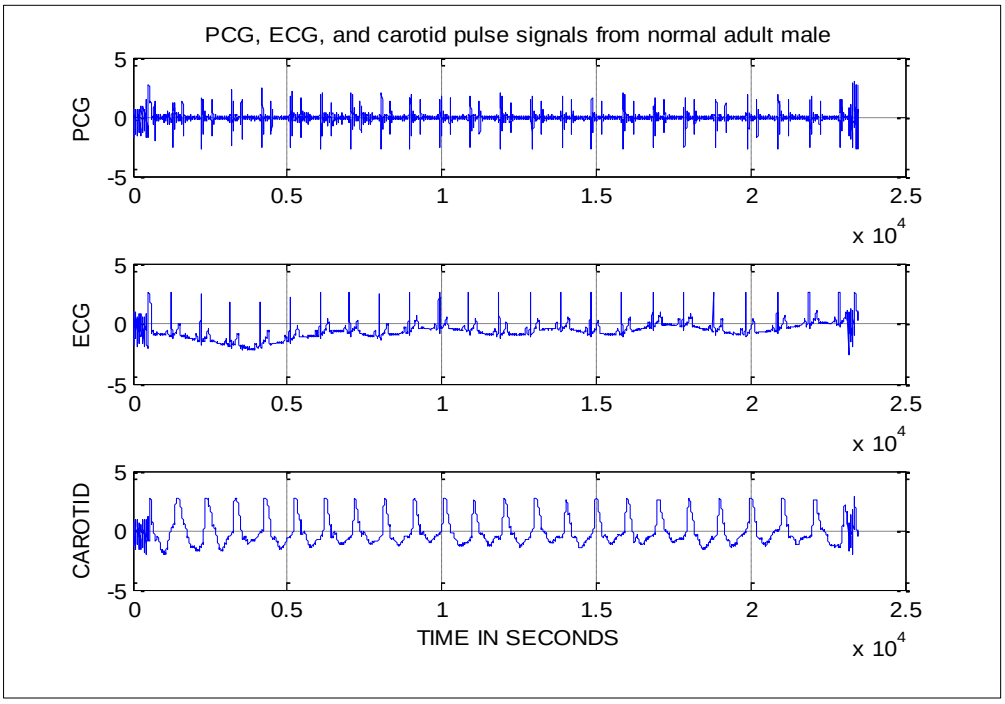

Fig. 6A. PCG, ECG and PPG pulses from normal adult male.

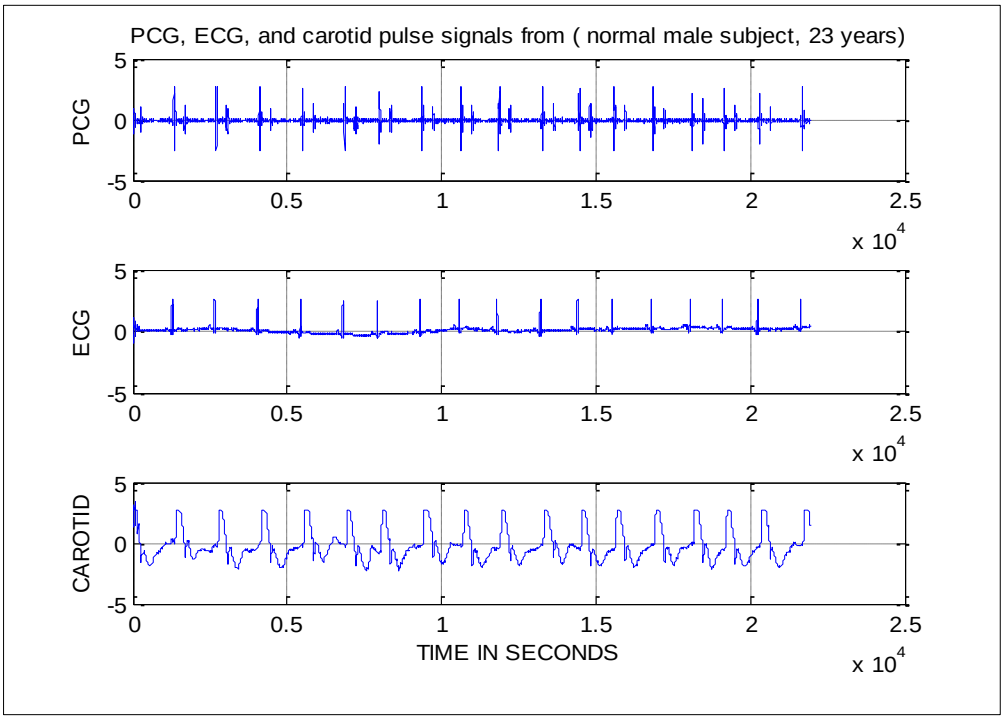

Fig. 6B. PCG, ECG and PPG pulses from normal male subject 23 years.

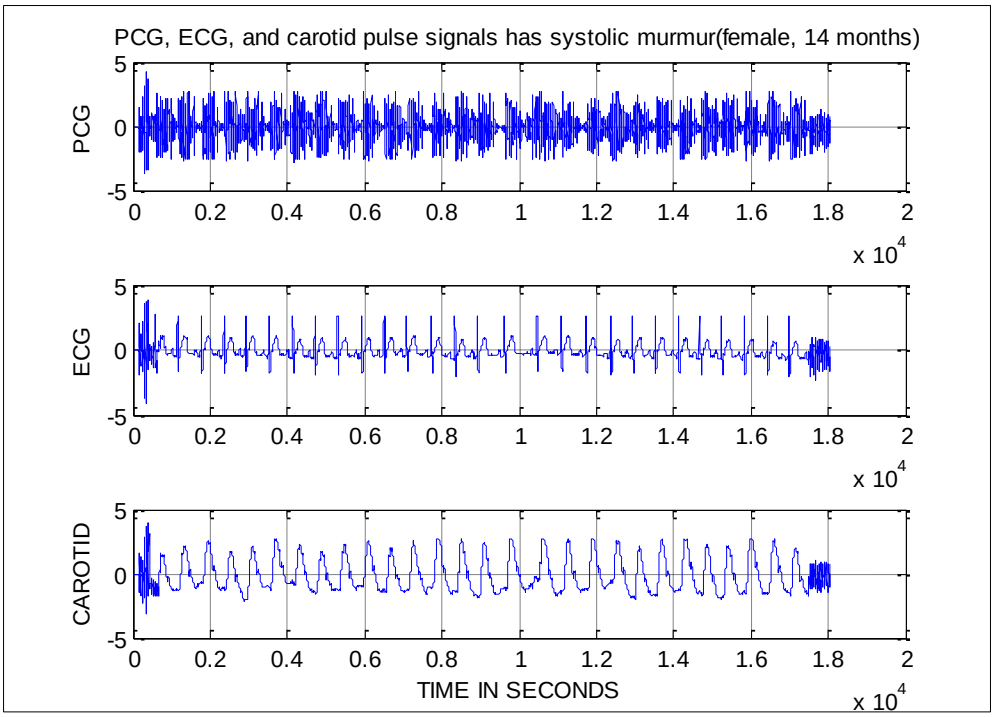

Fig. 6C. PCG, ECG and PPG pulses from abnormal female.

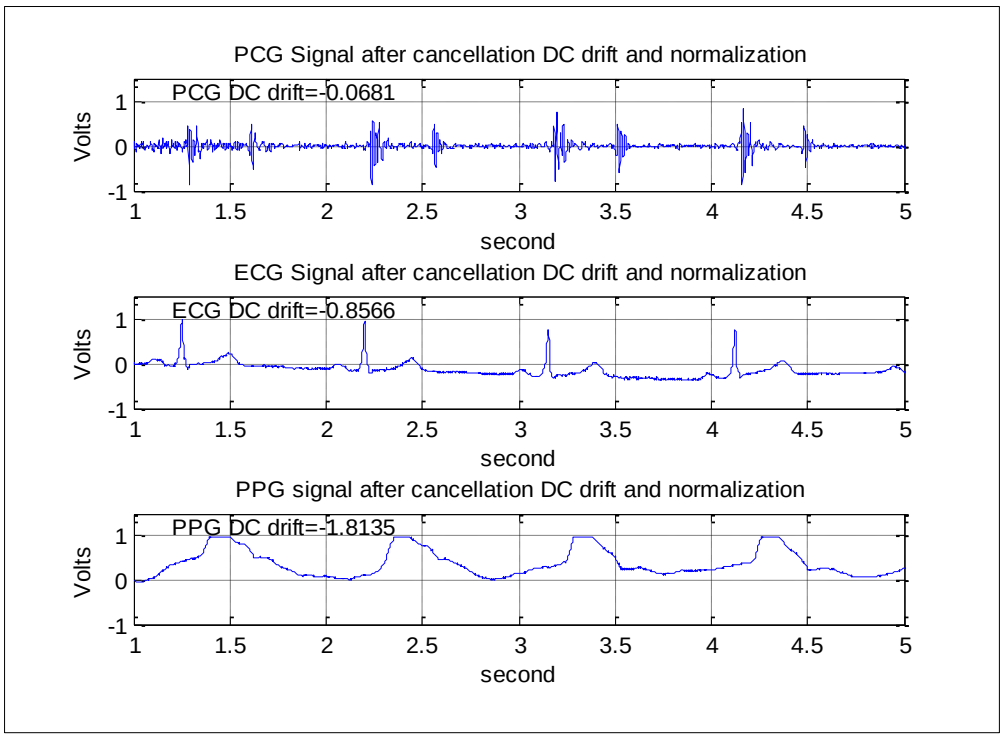

Fig. 7A. PCG, ECG and PPG pulses from normal adult male without DC drift.

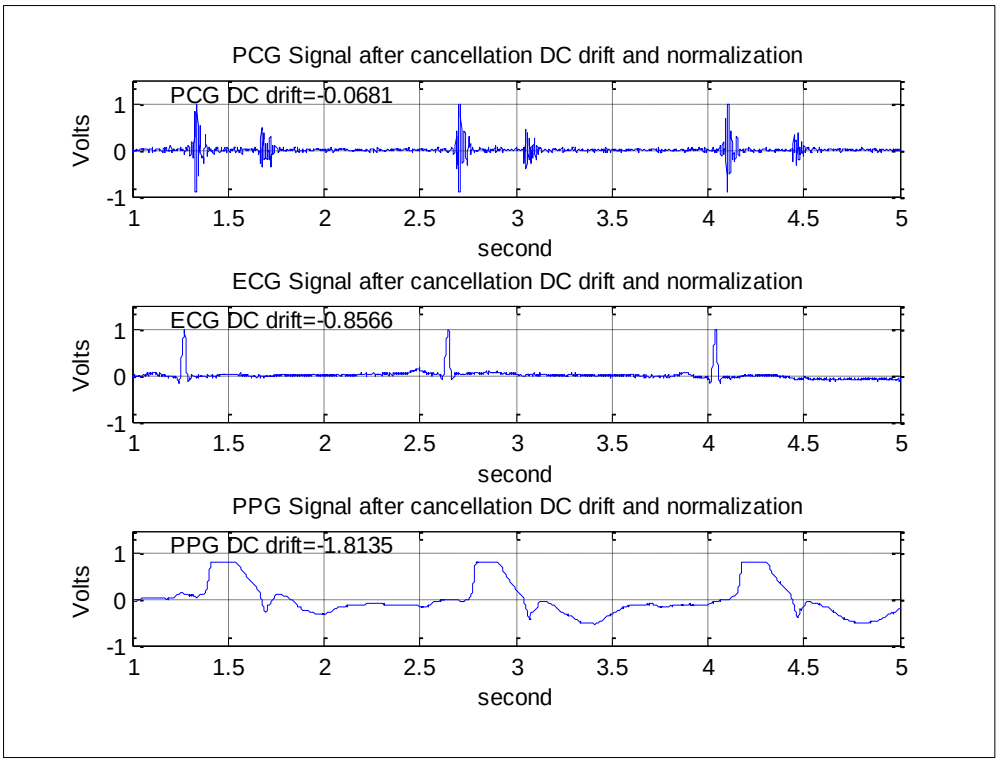

Fig. 7B. PCG, ECG and PPG pulses from normal male subject 23 years without DC drift.

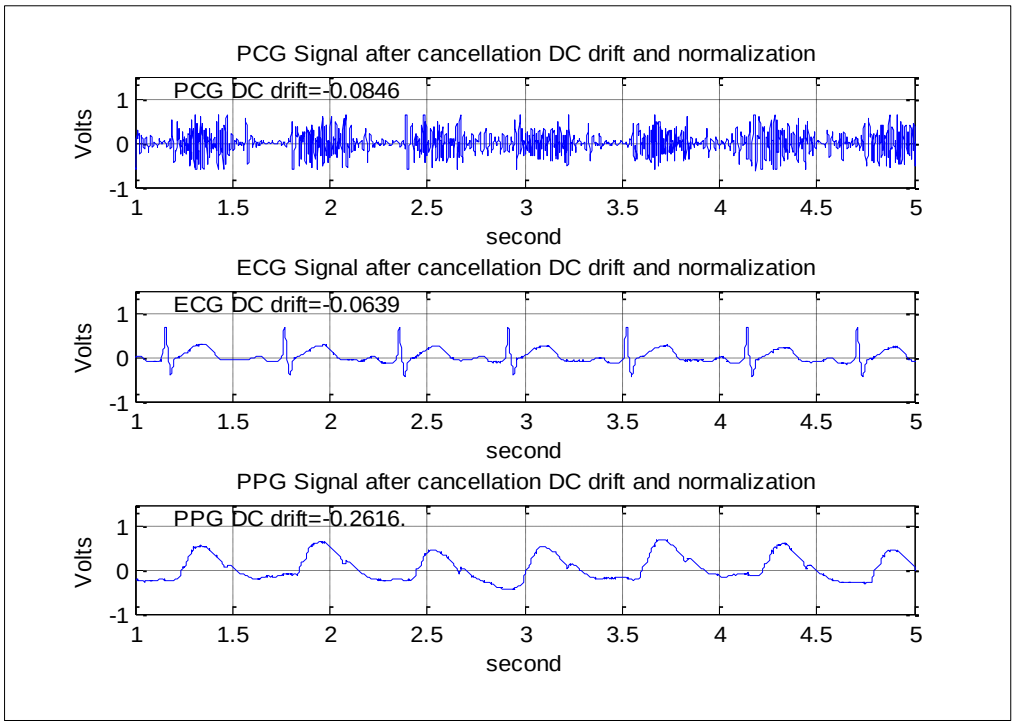

Fig. 7C. PCG, ECG and PPG pulses from abnormal female without DC drift.

7. Feature Extraction

Several statistical features can be extracted from the three causes; by calculating the maximum, minimum, mean, standard deviation, variance, and signal to noise ratio for all the three cases using Matlab programs where (max: largest elements, min: smallest elements, mean: the average value of a signal. It is found by adding all of the samples together, and divide by N as shown in the following equation:

$$mean = \frac{1}{N}\sum_{i=0}^{N-1} x_i$$

In words, sum the values in the signal, x, by letting the index, i, run from 0 to N-1. Then finish the calculation by dividing the sum by N.

std: standard deviation the standard deviation s of a data vector X:

$$std = \left(\frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2\right)^{1/2}$$

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

Where

And n is the number of elements in the sample. The two forms of the equation differ only in n-1 versus n in the divisor [10].

SNR is an engineering term for the power ratio between a signal (meaningful information) and the background noise. The biomedical signals normally have a wide dynamic range. SNRs are usually expressed in terms of the logarithmic decibel scale. In decibels, the SNR is 20 times the base-10 logarithm of the amplitude ratio, or 10 times the logarithm of the power ratio:

SNR=10 log (Es/En), where Es is the average signal amplitude and En is average noise amplitude measured

within the system bandwidth [11].

signal-to-noise ratio (SNR), which is equal to the mean divided by the standard deviation.

Another term is also used, the coefficient of variation (CV). This is defined as the standard deviation divided by the mean, multiplied by 100 percent. Better data means a higher value for the SNR and a lower value for the CV [10].

8. Delay Detection

A cardiac cycle may be divided into two important parts based upon ventricular activity: systole and diastole. The systolic part starts with S1 and ends at the beginning of S2; S1 in PCG may be begun at the same instant as the QRS complex is end, the dicrotic notch in the carotid pulse may be used to locate the beginning of S2 in PCG which is at the end of the T wave of the ECG signal. Thus, if there are both ECG and carotid pulse signals along with the PCG, it becomes possible to break the PCG into its systolic and diastolic parts [9]. The demarcation was performed by visual inspection to detect the time delays between these intervals in the three channels PCG, ECG and PPG signals and then compare between the normal and abnormal subjects with (systolic murmur due to aortic stenosis).

9. Results and Discussion

A. Feature Extraction

The following table illustrated the feature that can be extracted from the three cases.

The results are shown in Table 1, to compare between the standard deviation of the (normal cases1 and 2 and the abnormal case 3) the result shown that maximum amplitude (higher than normal) in case 3, the mean or the drift which cased due to the instrumentation amplifier is already removed during processing to reduce the base line drift noise, the fluctuation from the main axes were evidenced from the standard deviations and their variance.

The signal to noise ratio in linear scale they are within the medical instrument range due to using filters inside the instrument that used to collect the data from it.

Table 1,
The feature that can be extracted from the three cases.

		max	min	mean	std	variance	SNR(dB)
Case 1	PCG	2.9405	-2.6906	-0.068	0.4114	0.1692	7.812
	ECG	2.6660	-2.6625	-0.8566	0.6905	0.4768	0.9359
	PPG	2.7872	-2.0198	-1.8135	1.1985	1.4300	1.8084
Case 2	PCG	2.7206	-2.6364	-0.0834	0.2955	0.0873	-5.4944
	ECG	2.6671	-0.9299	0.1217	0.3201	0.1024	-4.198
	PPG	3.4103	-2.2781	-0.1774	1.3245	1.7543	-8.7321
Case 3	PCG	4.2967	-3.6714	-0.0846	0.8507	0.7237	-10.021
	ECG	3.8950	-4.0739	-0.0639	0.6569	0.4315	-10.123
	PPG	3.9780	-3.0890	-0.8566	1.333	1.7776	-7.0731

B. Delay Detection

The following figures show clearly a different time delays in the three cases at the three channels which is recorded instantaneously.

Case 1: Normal adult male

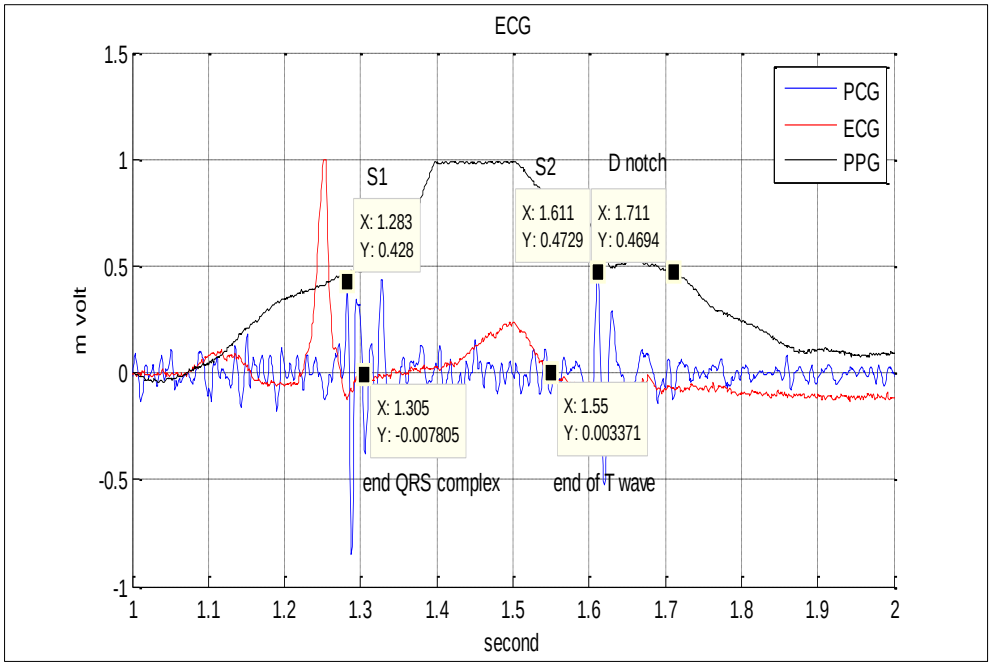

Fig. 8. Time delay between intervals case 1.

Case 2: Normal male subject 23 years

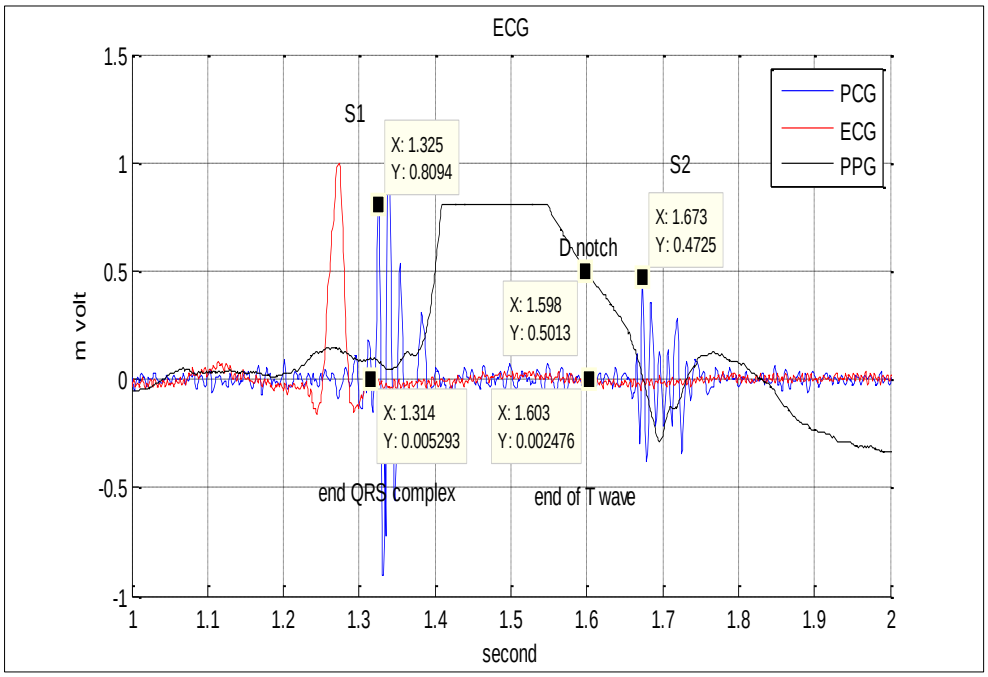

Fig. 9. Time delay between intervals case 2.

Case 3: Abnormal subjects with (systolic murmur due to aortic stenosis)

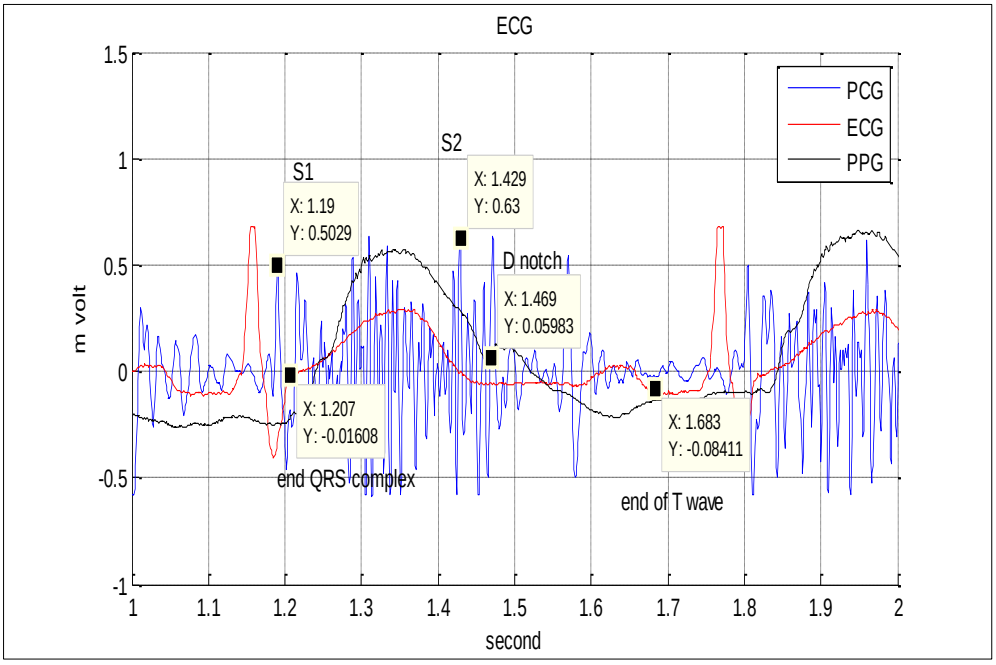

Fig. 10. Time delay between intervals case 3.

From the above recorded, signals can be used to diagnose many cardiac diseases due to the readily identifiable waveforms in the PCG, ECG, and PPG for the three cases. The PCG is a more complex signal, which cannot be visually analyzed except for the identification of features such as S1 and S2 and their components. The visual identification of S1 and S2 is possible if there are no murmurs between the sounds, and if the heart at high rates and with the presence of murmurs or premature beats, identification of S1 and S2 could be difficult. Because the ECG and PCG are concurrent phenomena, it is noticeable difference that the former is electrical while the latter is mechanical (sound or vibration).

The QRS wave in the ECG is directly related to ventricular contraction, as the summation of the action potentials of ventricular muscle cells. As the ventricles contract, causing the initial vibrations of S1. It begins immediately after the QRS complex as shown in figure 8 and 9 with small delays only comparing with the third case (patient with systolic murmur and have pulmonary stenosis, ventricular septa1 defect, and pulmonary hypertension).

The phonocardiogram and the carotid pulse can be identified from the diastolic segment of the PCG Ventricular systole ends with the closure of the aortic and pulmonary valves, the components of the second heart sound S2 (end of contraction) is also indicated by the T wave in the ECG, and S2 appears slightly after the end of the T wave. S2 may be taken to be the end of systole and the beginning of ventricular relaxation or diastole. They cannot be readily identified (even visually), especially when murmurs are present (case 3).

The relationship between the T wave, S2, and the D notch appeared in figure 8 and 9.

The T wave is simultaneously appearing with the S2, and the D notch with a small delay with respect to each other but in the normal cases the D notch used as an indicator of the end of systole or beginning of diastole event. Its evidently from case 3 the patient with systolic murmur, pulmonary stenosis, ventricular septa1 defect, and pulmonary hypertension (abnormal case) the S2, D notch and the T wave are not appeared in the same time due to the defect in the valves and cardiac muscles. This study has some limitations which need to be paid attention. First of all, it can be noted that, only 3 biological signals were predominantly simulated due to the fact that these studies need a high sensitive medical devices in addition to ethical approval in order to examine the patients. Moreover, the sample size has often been small and need for additional studies to obtain promising results. Despite these drawbacks, this study may provide a means to statistically identify the relation between ECG, PCG and PPG. Lastly, the heart is widely assessed by cardiologist doctors using visual inspections but recently a new specific medical devices are used to evaluate and predict different cardiac diseases. Finally, this study defined statistical indicators that might help medical doctors and clinicians in planning and providing a more reliable prediction of the course of the disease in addition to the optimal therapeutic program to provide cardiac patients additional years of a higher quality of life.

10. Conclusion

From the results, it can be concluded that the first heart sound (S1) and the second heart sound (S2) can be determined from other feature such as using the ECG and estimate the position of the QRS complex or the end of the T wave or from using the PPG to indicate the end of the T wave which is related to the end of the ventricular systole. In case of pathology such as murmurs the PCG and its components are not indicated in same as normal persons due to the defect in the valves and may be in the muscle itself. In this study, several statistical features can be suggested for indicating the delay that may occurr due to the deficiency of the cardiac muscle or valve in an abnormal case which might be useful and would be helped in the clinical evaluation.

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تسجيل محاكاة مخطط القلب الكهربائي، مخطط اصوات القلب، مخطط التحجم لأستخراج الخصائص

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الخلاصة

التطور في مجال هندسة الطب الحياتي الذي حصل مؤخرا، ادى الى تجديد الاهتمام بالكشف عن العديد من الاحداث . في هذا البحث استخدم نهج جديد للكشف عن معطيات و علاقات محددة بين ثلاث من الاشارات الحيوية التي تستخدم في التش خيص و هي: مخطط اصوات القلب، مخطط القلب الكهربائي و مخطط التحجم و الذي يسمى في بعض الاحيان النبضة التاجية المتعلقة بموقع القطب الكهربائي . المقارنة بين هذه الحالات الثلاث (اثنان منهما حا لتان طبيعيتان و الثالثة حالة غير طبيعية) ربما تستخدم في الكشف عن التأخير الذي قد يحدث نتيجة للقصور في العضلة القلبية او صمام قلبي في الحالات غير الطبيعية. النتائج اظهرت ان اصوات القلب (الصوت الاول و الثاني)، من الممكن حسابهما من اشارة اخرى مثل اشارة القلب الكهربائي . كذلك فأن جزء من الاشارة القلبية و نهايتها من الممكن التنبؤ بها عن طريق اشارة التحجم.