Cross-correlation Analysis of Two Heart Rate Signals Fluctuation During Blood Pressure Measurements

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الملخص

يعد تحليل تذبذب إشارة معدل ضربات القلب (HRS) عملية حاسمة لقياس عدم الاستقرار الذي يحدث أثناء خفقان القلب. في هذه الورقة، تم قياس مدى الارتباط بين إشارتين (HRS) مختلفتين باستخدام مجس من نوع DFRobot لقياس معدل ضربات القلب أثناء قياس ضغط الدم باستخدام مقياس كفة ضغط الدم القياسي من نوع AllHeart. تم إجراء هذه القياسات لشخصين مختلفين في العمر الاول يبلغ من العمر 20 عاما وضغطه طبيعي بينما الاخر يبلغ من العمر 60 عاما وضغط دمه غير طبيعي. في هذه الورقة تم استخدام منظومة تجميع بيانات نوع NI(PCI−MIO−16E−1) لتجميع بيانات إشارة معدل نبضات القلب (HRS)، بسرعة قياس تصل الى 1.25Ms/s واستخدم برنامج LabVIEW National Instruments في تحليل اشارة HRS. أظهرت النتائج الفرق بين الاشارتين للشخصين المسن والصغير لجميع مراحل قياس ضغط الدم (قبل وأثناء وبعد قياس ضغط الدم). زمن القياس يعتمد على الزمن اللازم قياس ضغط الدم لكل شخص، أي حوالي دقيقة واحدة. من خلال تحليل الاشارتين(HRS)، بينت النتائج أن معامل الارتباط المتبادل بينهما كان ضعيفا نسبيا خلال مرحلة ما بعد القياس، وذلك بسبب اضطراب خفقان القلب مباشرة بعد عملية قياس ضغط الدم مقارنة بالارتباط المتبادل قبل عملية قياس ضغط الدم (مرحلة الاسترخاء) والتي كانت قوية نسبيا. وفي هذه الدراسة ايضا تم حساب قيم تذبذب HRS بدلالة RMS لجميع المراحل، والذي من خلال هذه القيم يعطي مؤشرا جيدا لمدى خفقان القلب لكل مراحل القياس.

Abstract

Heart rate signal (HRS) fluctuation analysis is a crucial process to measure the instability that occurs during the heart palpitations.

In this paper, the cross-correlation of two different HRS measured using DFRobot heart rate sensor simultaneously with the measurement of blood pressure by using AllHeart standard blood pressure cuff gauge. This procedure was done to two people with different ages, one with a normal blood pressure (20 years old) and the other with abnormal blood pressure (60 years old). A data acquisition card NI(PCI-MIO-16E-1) was used to acquire the Heart Rate Signal (HRS) data, and analyzed by LabVIEW software National Instruments. The difference between HRS measurements for both people, the 60 years old person with an abnormal blood pressure and the 20 years old person with normal blood pressure at all stages (before, during and after blood pressure measurement, the measurement time depended on the time of measurement of each person's blood pressure, i.e. about a minute) indicates that the cross-correlation were relatively weak during the post-measurement stage. This result can be due to the disorder of heart palpitations immediately after the blood pressure measurement process compared to the cross-correlation before the blood pressure measurement process (at relax stage) which was relatively strong. The values of fluctuation of HRS in terms of RMS were calculated for all stages, which gives a good indicator for the heart palpitations of each stage measurement for two people.
Keywords. Heart Rate Signal, fluctuation heart signal(RMS), heart palpitations, blood pressure.

Introduction

The heartbeat of a human being should be amongst the most important priorities that must be regularly monitored and checked to maintain a healthy body and prevent disease. Palpitations and abnormal fluctuations of the human heart should be checked as a result of the variables that occur in the blood pathways within the blood vessels, arteries, and veins. Other variables are also taken into account such as the blood itself; viscosity and blood density.

One of the most common factors for cardiovascular disease is high blood pressure and its dangers. Accurate measurement of blood pressure is essential for proper diagnosis of high blood pressure and monitoring the effect of antihyperty. Additionally, blood pressure

(BP) is an element of cardiovascular risk prediction equations that are in turn used to guide the decision to start statins, pharmacological antihypertensive medication, and aspirin therapy [1,2]. Since 2005, several studies published by the American Heart Association (AHA) have shown scientific statements on blood pressure measurements and how to obtain an accurate reading.

Paul Muntner et. al (2019) [3] provides an updated American Heart Association (AHA) scientific statement on BP measurements in humans. In the office setting, many oscillometric devices have been validated to allow accurate BP measurements while reducing human error associated with the auscultator approach. Fully automated oscillometric devices capable of taking multiple readings even without an observer present may provide a more accurate measurement of BP than auscultation. Studies have shown substantial differences in BP when measured outside versus in an office environment.

Epidemiological evidence has indicated that the risk of cardiovascular complications associated with high blood pressure may depend not only on the magnitude of high blood pressure per sec, but also on the increase of the blood pressure variability. It has been shown that the main determinants of high blood pressure fluctuations especially in the short term are neurological effects on peripheral and heart blood vessels. In addition, evidence has been provided to show that the degree of blood pressure variability is directly related to the stiffness of large arteries. This is known to be a strong independent indicator of different cardiovascular risks of blood pressure variability (BPV, i.e short, medium, and long term BPV with a focus on different components of potential BP changes and the changes in bar flexes).

Moreover, Albatrookh et. al (2017) [5] designed a simple and effective devices to get a heart signal with the help of many linear models of SI. Relationships between the various system identification models discussed. They described the methods that fit the system structures well as the basic characteristics of the resulting models of evaluation. Experiments conducted using different types of SI models on real-world heart signal data. Also they showed the effectiveness of the proposed SI models that were demonstrated by achieving accuracy of heart rate.

In this study, the blood speed fluctuations within the arteries and veins are measured using an advanced data acquisition system achieving speeds of up to 1.25 Ms/sec. From these measurements, the amount of blood palpitation and disorder in terms of Root Mean Square (RMS) and cross-correlation of the measured signals of a young person (normal blood pressure) to the elderly person (relatively has abnormal blood pressure).

Experimental Set-up

The following section gives an overview of the experimental apparatus and setup. Two different test techniques have been used to measure the blood pressure and heart rate signal fluctuation. The first test is the Photo Plethysmo Graphy (PPG) technique consisting of a DFRobot heart rate sensor, and a data acquisition card mounted in a PC which was used to acquire the heart rate signal fluctuation ($HRS'(t)$) data. The Data Acquisition Card used is a NI(PCI-MIO-16E-1) with a sampling rate of 1.25Ms/sec. The second test is an AllHeart standard blood pressure cuff device with a maximum pressure of 300 mmHg has been used to measure systolic and diastolic blood pressure which were measured simultaneously with the measurements of the heart rate signal fluctuation ($HRS'(t)$). LabVIEW software by National Instruments was utilized in this experiment. Figure 1 show the Schematic diagram of the two test techniques.

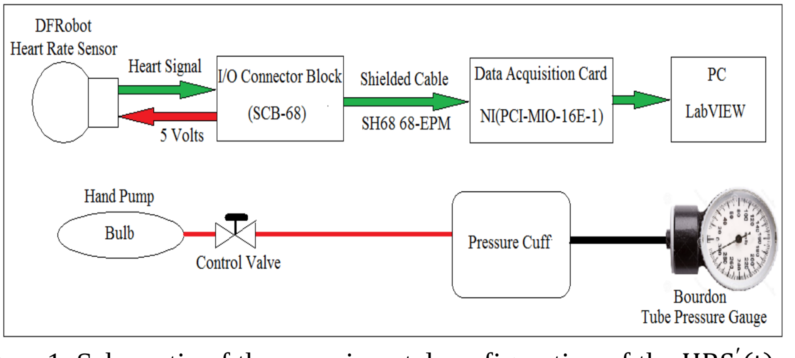

Figure 1. Schematic of the experimental configuration of the $HRS'(t)$ and blood pressure measurements

Methodology

Root Mean square of the Heart Rate Signal ($RMS_{(HRS)}$)

The $RMS_{(HRS)}$ can be calculated from the Instantaneous HRS as a function of the time (HRS(t)), the Instantaneous HRS is given by Eq. 1 . In the case of periodic HRS, the interval should be an integral number of periods. If there was no periodic HRS, the interval should be long enough to make the value obtained essentially independent of small changes in the length of the interval. The fluctuation $HRS'(t)$ is the difference between the instantaneous value of the HRS(t) and the mean value $\overline{HRS}$ as expressed in eq. 2

$$HRS(t) = \overline{HRS} + HRS'(t) \qquad 1$$

Where:

$\overline{HRS}$ is the mean heart rate signal.

$HRS'(t)$ is the fluctuated heart rate signal.

From equation 1

$$\mathrm{HRS'(t)} = \mathrm{HRS(t)} - \overline{\mathrm{HRS}} \qquad 2$$

The square of fluctuation HRS is given by Eq. 3:

$$\left(\mathrm{HRS'(t)}\right)^2 = (\mathrm{HRS(t)} - \overline{\mathrm{HRS}})^2 \qquad 3$$

The mean value of the fluctuation HRS square is given by Eq. 4:

$$\overline{\left(HRS'(t)\right)^2} = \lim_{T\to\infty} \frac{1}{T} \int_0^T \left(HRS'(t)\right)^2 dt \qquad 4$$

Where:

T is the time period of the HRS

Root mean square of HRS is given by Eq. 5 and 6:

$$HRS_{(RMS)} = \sqrt{\overline{\left(HRS'(t)\right)^2}} = \sqrt{\lim_{T\to\infty} \frac{1}{T} \int_0^T \left(HRS'(t)\right)^2 dt} \qquad 5$$

$$HRS_{(RMS)} = \sqrt{\lim_{T\to\infty} \frac{1}{T} \int_0^T (HRS(t) - \overline{HRS})^2 \, dt} \qquad 6$$

Cross-correlation

Consider two signals HRS1 and HRS2 at time t, the relationship between them at two different times is often expressed as the cross-correlation function, which is given by:

$$\Re_{HRS1-HRS2}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} HRS1(t)\, HRS2(t+\tau) dt \qquad 7$$

Here the time difference, τ, is usually called delay or lag. The covariance function usually decreased towards zero and may take place with damped oscillations. The cross-correlation function approached zero at great lag values. A positive value means that the signal have the same sign, and a negative value means that opposite signs are usually expected. The cross-correlation function is similar to the auto-correlation, but is used to compare between two different signals at different instants of time. Figure 2 shows a theoretical example for two similar functions sine-sine wave. Both signals have the same frequency, amplitude, and the signals are in sine wave and saw-tooth wave. The Sine and the saw-tooth waves were generated from the signal generator, with an amplitude of 4 volts. Sampling rate and number of data acquisition system were 1000 s/sec and 5000 respectively. It can be seen that the cross-correlation of the two signals are strongly correlated, the cross-correlation curve has a maximum value at t = 0 and decreased gradually towards zero at the end the time (t = T) . Figure 3 shows the cross-correlation out-phase sine-saw tooth wave signals (weak cross-correlation). Also, it shows that the cross-correlation is completely different than sine–sine wave signals cross-correlation. The amplitude of the cross-correlation does not gradually drop to zero towards t=T.

Power spectrum of HRS

By the Fourier integral relationship given by (Dowling and Williams, 1983, Nelson and Elliott 1992), the autocorrelation function of the random process is directly related to its frequency as the following:

$$\Re_{HRS}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-1/T}^{1/T} HRS(t)\ HRS(t+\tau)dt \qquad 8$$

$$\hat{\Re}_{\mathrm{HRS}}(\omega) = \int_{-\infty}^{\infty} \Re_{\mathrm{HRS}}(\tau)e^{-i\omega\tau}\ d\tau$$
$$= 2\int_{-\infty}^{\infty} \Re_{\mathrm{HRS}}(\tau)\cos(\omega\tau)d\tau \qquad 9$$

Where;

$\Re_{\mathrm{HRS}}(\tau)$ is the Auto-correlation

$\hat{\Re}_{\mathrm{HRS}}(\omega)$ is the Fourier transform of autocorrelation function$\Re_{\mathrm{HRS}}(\tau)$.

This relationship is known as the power spectrum of the signal. [7,8]

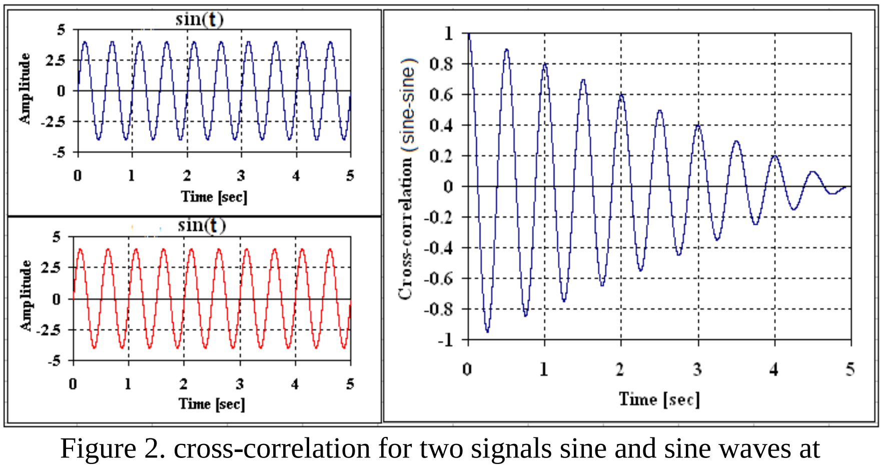

Figure 2. cross-correlation for two signals sine and sine waves at sampling rate of 1000 s/sec, and number of samples 5000

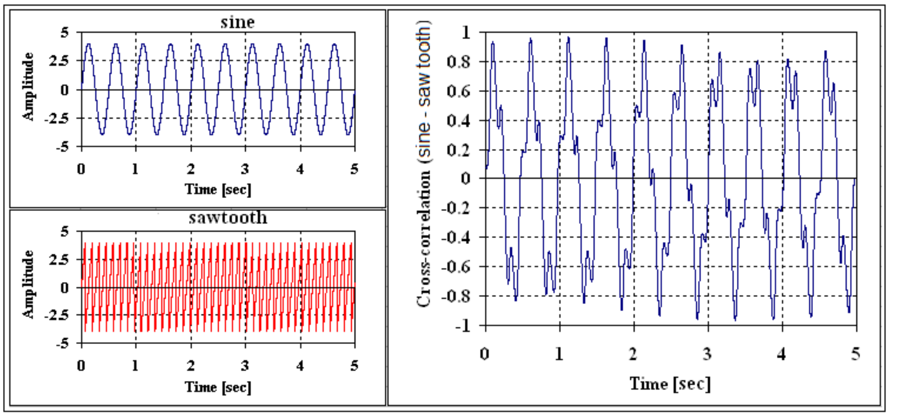

Figure 3. cross-correlation for two different signals sine wave and saw-tooth wave at sampling rate of 1000 s/sec, and number of samples 5000

Results and Discussions

Figure 4 shows the mean and the RMS of HRS fluctuation comparison of two people at different stages.

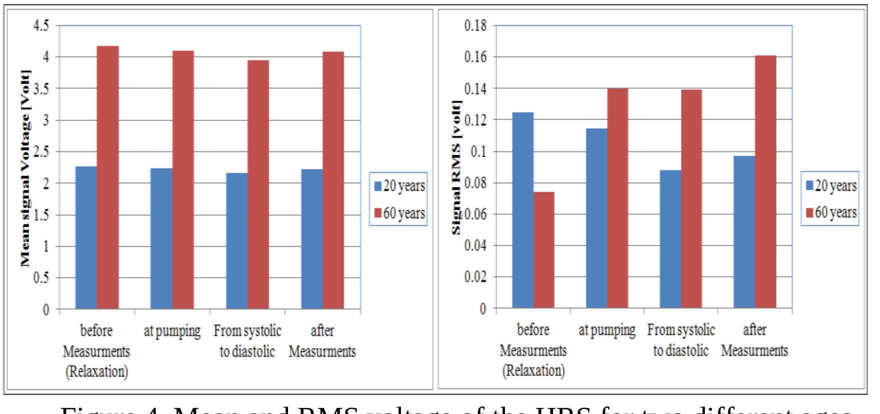

Figure 4. Mean and RMS voltage of the HRS for two different ages

Fiqures 5, 6, 7, 8 display the HRS fluctuation ($HRS'(t)$) signals at four different stages of systolic and diastolic blood pressure measurements. The power spectrum and cross-correlation ($\Re_{HRS1-HRS2}(\tau)$) have also been presented for each stage. It is clear from the figures that the measured signals of HRS fluctuation are very different for each stage and for two different people.

Stage 1

At the relax stage (before blood pressure measurements), high amplitudes of measured signals were observed for the young person as shown in Figure5. The HRSRMS of signal fluctuation were 0.125 and 0.074 for young and elderly person respectively (from Figure 4). The cross-correlation ($\Re_{HRS1-HRS2}(\tau)$) at the relax stage is strong which is similar to the cross-correlation of signals sine-sine waves. As seen in the results, both signals are in a very small phase difference and can be considered as in-phase signals.

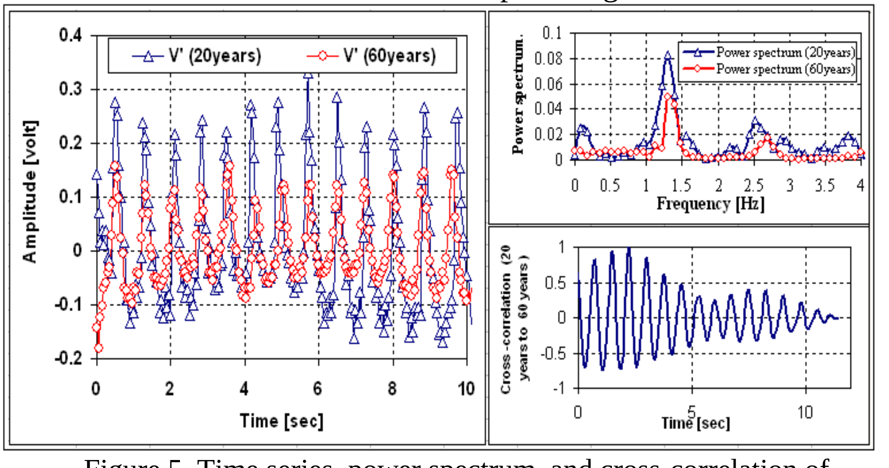

Figure 5. Time series, power spectrum, and cross-correlation of fluctuation HRS before measurements of blood pressure of young person and elderly person

Stage 2

Figure 6 shows the pumping stage. the amplitude of the HRS fluctuation ($HRS'(t)$) for both people are almost similar. For this stage, the HRSRMS are 0.1147 and 0.140 for young and elderly person respectively as shown in Figure 4.

From Figure 6, it is clear that the cross-correlation between the two signals ($\Re_{HRS1-HRS2}(\tau)$) is relatively no strong correlation between them in terms of the frequency differences (x,y as well as the shape of the fluctuated HRS ($HRS'(t)$). which is similar to the theoretical cross-correlation between two different waves, sine-sawtooth waves Also, this difference in the cross-correlation is due to the clear difference in the delay time between the two signals of the elderly and young person's $HRS'(t)$. Both signals are out of phase, after 6 seconds of measurement, the time delay is about 0.5 seconds.

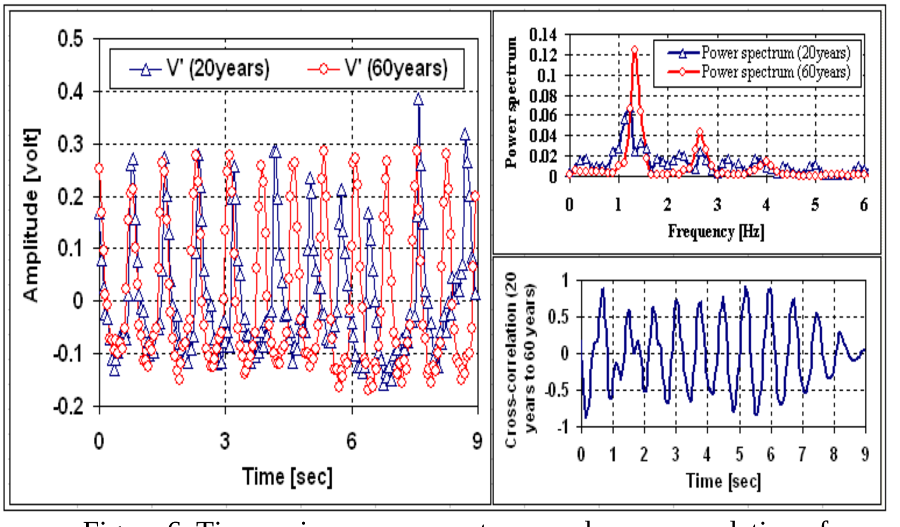

Figure 6. Time series, power spectrum, and cross-correlation of fluctuation HRS at pumping process during measurements of blood pressure of young and elderly person

Stage 3

stage 3 is the measurement of blood pressure (systolic and diastolic) as shown in Figure 7. The results show that the $HRS'(t)$ almost have similar peaks for both people. However, at the decays the elder person had lower values than the young person leading to an increase in values of the RMS for the elderly person. The values of the HRSRMS are 0.08789 and 0.139 for young and elderly person respectively. The cross-correlation ($\Re_{HRS1-HRS2}(\tau)$) is good correlation. The out of phase occurred at an earlier time compared to the previous stage (pumping stage) which occurred after 4 seconds (see Figure 4).

Stage 4

Figure 8 shows the HRS fluctuation that were measured immediately after blood pressure measurement. The result indicated that the cross-correlation $\Re_{HRS1-HRS2}(\tau)$ was very weak. The values of the HRSRMS of the elder person were higher than the

HRSRMS of the young person (0.0971 and 0.161 respectively) as well as the out of phase occurred 2 seconds earlier than stage three.

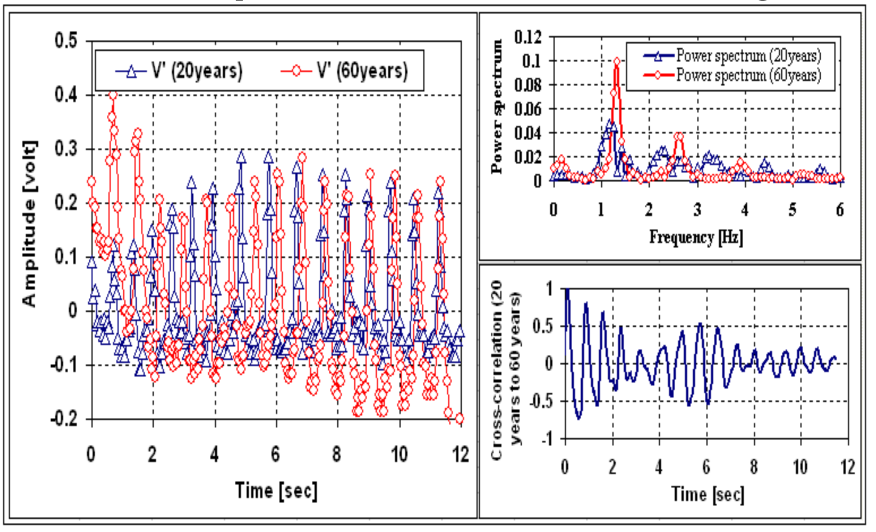

Figure 7. Time series, power spectrum, and cross-correlation of fluctuation HRS from systolic to diastolic blood pressure measurements of young and elderly person

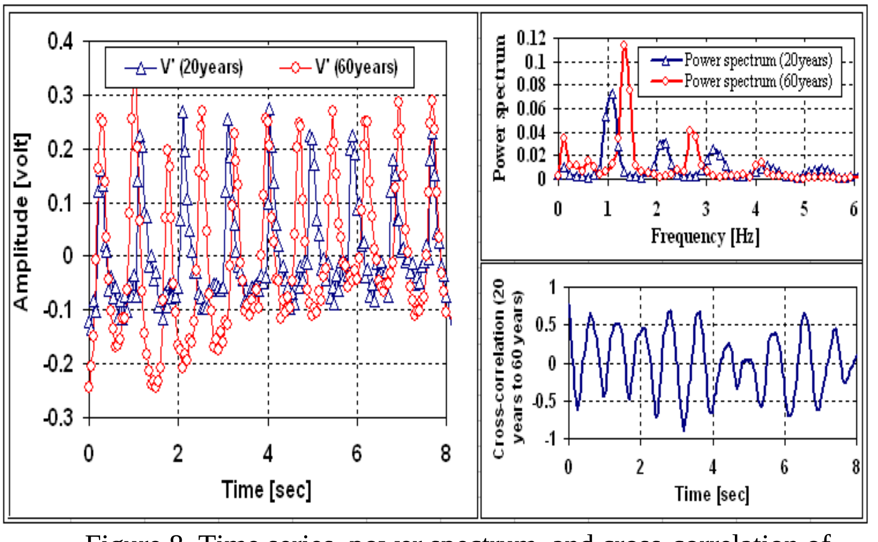

Figure 8. Time series, power spectrum, and cross-correlation of fluctuation HRS immediately after the blood pressure measurement of young and elderly person

Conclusion

In this paper, the level of signal fluctuating of the heart was measured in terms of RMS of the heart beats within the arteries and veins for two people with different ages. The young person has a normal blood pressure while the elderly person has an abnormal blood pressure.

The signals were taken at different conditions beginning of the relaxation stage, then during the measurement of systolic and diastolic blood pressure stage and finally after measuring blood pressure directly for both people. The signal fluctuations (RMS) and the power spectrum of the heart rate signal (HRS), as well as the cross-correlation for each stage between the two signals was calculated. To be more précised, the heart beats fluctuation (HRS) has been compared and analyzed. The results showed that not everyone who suffers from abnormal blood pressure has a disturbed heartbeat and vice versa. In addition, the results indicated that the cross-correlation between two people was relatively not strong; on the other hand, during the relaxation stage the cross correlation was relatively strong.

Moreover, this study concluded that the measurement of the blood pressure was the main reason for disorder of the HRS fluctuation.

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