Techniques Used in Phonocardiography: A Review

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Abstract Segmentation of phonocardiogram (PCG) into its significant sound component is the initial phase in the automated diagnosis of cardiac abnormalities. The greater part of the computerized demonstrative calculation that utilized the PCG as a kind of perspective sign to identify side effects of cardiovascular variations from the norm apply time division as a pre-handling venture to separate progressive. In PCG, we identify the first and second heart sounds on recurrence space characteristics. The principal sound emerges from the mitral and tricuspid valve, and the subsequent sound brought about by the closer of aortic and pulmonary valves. For this, we are utilizing here a few methods where we can extricate the PCG signal. We can discover the fetal pulse during pregnancy around eighth week of pregnancy, as PCG is a clinical test to survey fetal prosperity during pregnancy, work, and conveyance. Wavelet transforms a strategy for procedures, as more suitable technique for preparing the FPCG signal. The wavelet technique incorporates the shifting and scaling of signal. This strategy can be utilized for examination of 1-D as well as 2-D data.

Keywords Fetal PCG · Wigner distribution · Wavelet transform · Phonocardiography · Auscultation

1 Introduction

Auscultation is the standard test performed while assessing the state of the heart framework since it is easy to perform. Auscultation is regularly accomplished utilizing a stethoscope to help the imperfect human ear in recognition of the heart sounds. Graphical recordings of heart sounds are called phonocardiograms, and a microphone gets heart sounds which are then recorded by some devices.

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1.1 History of Phonocardiography and Auscultation

Impediments of the Human Ear

Listening to the human heart (known as auscultation) is an exceptionally old and valuable procedure, which goes back to the times of Hippocrates around 400 BC, for the analysis of heart ailments and conditions (Selig 1993, Luisada 1965). The objective of auscultation is to foresee as far ahead of time as conceivable the advancement of a heart obsessive condition. Significant variables to get the greatest advantage of cardiovascular auscultation as a clinical demonstrative device incorporate the capacity to hear a wide scope of frequencies with sufficient affectability. The normal grown-up hearing reach is around 50–12,000 Hz with the ear performing best and having the best recurrence segregation between 1–2 kHz. The human ear experiences issues segregating between various frequencies of sound similarly as the volume is shifted frequently coming about in difficulties diagnosing heart murmurs and sounds; a solution for this issue is to intensify the low-recurrence sounds since high volume empowers low-recurrence sounds to be heard. Ambient noise may likewise veil cardiovascular sounds bringing about troubles perceiving the genuine heart sounds particularly in emergency clinic rooms or looking at wards which may have up to 70 dBs of encompassing commotion while the main heart sound heard at the zenith is just 20–60 dBs and the volume of the subsequent heart sound at the aortic territory is 30–70 dBs. The third and fourth heart sounds are frequently missed in light of the fact that they have exceptionally low-recurrence content and quite faint. There is also a time delay of 1 s, known as temporal summation, related to hearing the full force of a sound and the human ear cannot separate between time spans littler than 20 ms.

2 Why PCG?

Different developments prompted the PCG being preferred over the stethoscope by 1908. In 1893, K. Hurtle of Breslau portrayed a method of writing heart sounds. He associated the yield of an amplifier through an inductor whose auxiliary curl was associated with the nerve of a frog muscle arrangement which set apart on a smoked drum utilizing an appended layer. The next year the first PCGs like those being used today were recorded by William Einthoven with Gluck in Leyden utilizing Lipmann's slim electrometer which was utilized to record the main ECGs. In 1904, precordial vibrations with optical enhancements (called the Flank fragment case) were recorded by Otto Fþank in Munich. 1909, Carl J. Wiggers altered.

Straight to the point's PCG and graphically showed accounts; in any case, the technique experienced confinements in the recurrence reaction of the film which was utilized in the recurrence container. In 1907, Einthoven utilized a string galvanometer to record heart sounds; however, the issue with this technique is that there is a tremendous scope of forces of heart sounds frequently bringing about harm to the string.

For the strategies for circuitous phonocardiography or phonocardiography utilizing a string galvanometer, there was no chance to get of applying electrical filtration so acoustic filtration was utilized. This was practiced by utilizing an air spill in the cylinder associating the chest piece with the FYank capsule or microphone. In 1942, Maurice Rappaport and Howard Sprague sketched out strategies for utilization of electronic intensification and galvanometers (of an alternate sort) in phonocardiography which turned into the overwhelming method utilized in phonocardiography [1]. They detailed that in the event that low frequencies were sifted extensively, at that point the PCG looked like auscultation.

Until the time that Bell Telephone Laboratories strategy for spectroscopy was utilized to examine heart sounds and murmurs by Geckeler who named it cardiospectrography and by McKu-sick who called it spectral phonocardiography, all phonocardiography was oscillographic phonocardiography. Created during the 1950s, cardiospectrography or otherworldly phonocardiography had the ability to spread out the recurrence range by utilizing the heterodyne electronic channel which could concentrate on determined recurrence ranges. Huggins created stage separating which permitted heart sounds to be spoken to all the more precisely. With the appearance of the wide bandpass channel, homeless people were presently ready to be shown [2]. An issue existed with building up ordinary qualities for PCGs in light of the fact that the scope of sounds is gigantic extending from faint diastolic murmurs which would be spoken to by an imprint Less than 2 mm in length to an enormous checking speaking to a systolic murmur. To address this issue, voltage constraint was presented; so that in the event that one was looking for faint diastolic murmurs, the voltage could be restricted to a little range, in this way making the diastolic murmur more obvious. To make the distinguishing proof of heart sounds simpler, reference signals, for example, the ECG were presented. Frequency moving is additionally now feasible for PCG accounts making sub-perceptible frequencies discernible. Phonocardiography has not advanced as fast as other analytic strategies in view of the absence of principles in hardware and recording areas, helpless comprehension of the heart sound systems, and the multifaceted nature of PCGs, yet signal preparing has supported in the improvement of phonocardiography (Wood and Barry 1995). A significant utilization of sign preparing in the zone of phonocardiography is noise removal.

There are numerous wellsprings of commotion which may contaminate the PCG including thoracic muscular noise (Zhang et al. 1998), peristaltic intestine noise (Zhang et al. 1998), respiratory noise, fetal heart sound noise if the subject is pregnant, noise brought about by contact with the instrumentation and environment noise. The noise present for each situation relies upon the condition of the subject, the instrumentation utilized, and the environment which the PCG was recorded in Groom et al. (1956) found that the background sound level in emergency clinics and centers was very high being on the request for 60–70 dBs. A sound verification room was developed which decreased commotion levels on the request for 35 dBs. The impact of noise on the auscultatory performance of forty specialists was estimated under stimulated stethoscope assessments [3]. The normal consequences of the gathering showed that similar murmurs heard in the sound verification room must be expanded multiple times in force to be heard under ordinary commotion conditions in facilities and emergency clinics. Decreasing medical clinic commotion levels to the order of 35 dBs would not be affordable with the exception of on account of a sound-confirmation looking at room which isn't reasonable. Faint heart murmurs, which are all the time of the most significance in diagnosing early coronary illness, might be handily concealed by surrounding commotion. Subsequently, usually discovered degrees of foundation noise genuinely hinder the capacity of the clinical expert to observe heart murmurs through a regular stethoscope. Recording the heart sounds through phonocardiograms and applying noise removal methods may uncover faint heart murmurs which already would have gone undetected.

3 The Recording Process

The PCG recording is made by setting the stethoscope ordinarily on the aortic zone. The patient is advised to be still and tranquil, lean forward a piece, and hold their breath if conceivable. The PCG is recorded for around 30–60 s utilizing the chronicle framework portrayed. A jack is connected to the Escope. The yield of the jack is associated with channel 12 of the A/D converter and sampled at 2500 Hz well over the Nyquist frequency for heart sounds (around 1000 Hz is about the most noteworthy recurrence (Selig 1993)) [4]. Consciousness of the sounds made by the pulses to antiquated occasions. Developing an instrument to record it might go back to Robert Hooke (1635–1703), who expressed "There may likewise be a chance of finding the inside movements and activities of bodies—regardless of whether creature, vegetable, or mineral, by the sound they make." The soonest known instances of phonocardiography date to the 1800s [5].

Checking and recording hardware for phonocardiography was created through the 1930s and 1940s. Normalization started by 1950, when the primary worldwide meeting was held in Paris. A phonocardiogram framework produced by Beckman Instruments was utilized on at any rate one of the Project Gemini kept an eye on spaceflights (1965–1966) to screen the heartbeat of space explorers on the flight. It was one of numerous Beckman Instruments specific for and utilized by NASA. John Keefer recorded a patent for a phonocardiogram test system in 1970 while he was a worker of the US government. The first patent depiction demonstrates that it is a device which by means of electrical voltage copies the human heart's sounds. Human heart itself is the most significant organ of the body which gives blood to all parts of body using pump-like action. Throughout the siphoning activity, mechanical and electrical exercises are completed bringing about the progression of blood. Figure 1 frameworks a model of all of ECG and PPG signals [6]. Despite ECG and PPG, phonocardiogram (PCG), the record of the sounds and murmurs made by heart during a cardiovascular cycle, can be effectively used to study and screen the activities of heart [7].

Such type of sounds is typically recorded by using a device which is called as phonocardiograph. The mechanical activity of the heart generally produces four

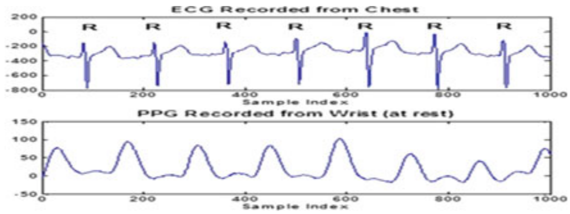

Fig. 1 Example of ECG and PPG signal [4]

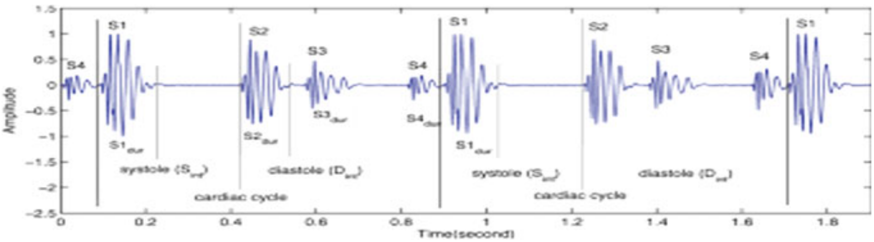

Fig. 2 An example of PCG signal [4]

different sounds S1, S2, S3, and S4. S1 and S2 can be heard from human ear because other two are just unusual or noisy signal [8].

Cardiac cycle is a continuous or cyclic process as shown in Fig. 2, and the above signal consists of four different sounds such as S1, S2, S3, and S4 [3, 5, 7–10].

4 Techniques

The methodologies proposed for customized assessment of PCG signals can be arranged into frequency domain, time domain, and time–frequency domain [11]. In the going with, we talk about the time and frequency domain [2].

4.1 Time and Frequency Examination

The broadest procedure for assessment relies upon the time domain. Here, examination is finished on signal itself. Statistics alike mean, mode, median, peak value, and then peak-to-peak value of signal is used throughout the process.

As shown in Fig. 3, P1 and P2 are the peak values, A1 and A2 are peak to peak of the signal, and P1 and P2 are timespans that speak to highlights of S1 and S2. The overall portrayal of signal in time domain is introduced in Eq. 1 $f(t)$ which is displayed by adequacy A, recurrence ω, and stage θ. Every one of these boundaries just as various insights got from these boundaries have been utilized as highlights

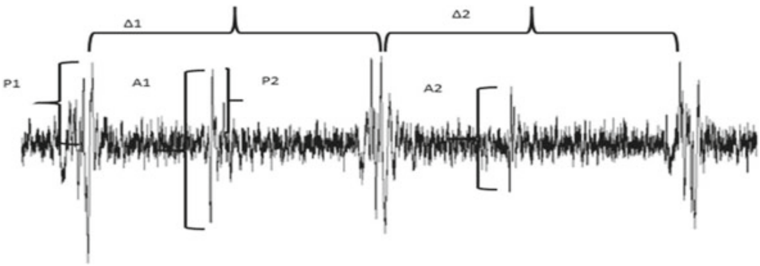

Fig. 3 Analysis of PCG signal in time domain [4]

for limitation and grouping [10]

$$f(t) = A \sin(\omega * t + \theta) \quad (1)$$

Due to the cyclostationary nature of the PCG signal, a signal cannot be localized in time and frequency because of vulnerability guideline restriction. Therefore, time-recurrence examination of PCG signals is researched in various investigations. Such techniques generally include short time frequency transform (STFT), time–frequency portrayals like Wigner–Ville, wavelet transform, and empirical mode decomposition (EMD) [12, 13].

5 Techniques Used for PCG Signal Analysis

5.1 Utilizing Wigner Distribution

The Wigner distribution function (WDF) is utilized in signal handling as a change in time–frequency analysis. The WDF was first proposed in quite a while to represent quantum redresses to old-style measurable mechanics in 1932 by Eugene Wigner, and it is of significance in quantum mechanics in stage space (see, by method of correlation: Wigner semi likelihood appropriation, additionally called the Wigner work or the Wigner–Ville conveyance) [14].

Given the common arithmetical structure between position energy and time–frequency conjugate sets, it additionally helpfully serves in signal preparing, as a change in time-recurrence examination, the subject of this article. Contrasted with short time frequency transform, for example, the Gabor transform, the Wigner distribution function can furnish higher clearness in some cases.

5.2 For Interior Point Algorithm

Interior point calculations for solving LPs are right now picking up prominence over customary simplex techniques. The current work inspects the adequacy of the preconditioned conjugate inclination (PCG) technique for the symmetric positive unequivocal ordinary conditions. What is more, we examine the utilization of a PCG variation for the inconclusive enlarged conditions.

5.3 For Utilizing AI in Content Generation

PCG strategies are fundamentally as wide and changed as their likely executions. Utilizing models from the reference's own work, this reference presents six pragmatic approaches to actualize AI-driven procedural substance age in games [10]. The strategy clarified will be helpful in the case of building a PCG-based game or to prepare a more created game.

5.4 Using Pattern Recognition Technique

About the usage of a demonstrative framework as a finder and a classifier; for head illnesses. Example acknowledgment is utilized to give human acknowledgment insight to machine which is required in picture preparing. Example acknowledgment is utilized to remove important highlights from given picture/video tests and is utilized in PC vision for different applications like organic and biomedical imaging.

5.5 For VLSI Format Improvement

Very enormous scope incorporation (VLSI) is characterized as an innovation that permits the development and interconnection of huge numbers (a huge number of) semiconductors on a solitary coordinated circuit. Incorporated circuit is an assortment of at least one doors created on a solitary silicon chip. The significant target in planning of VLSI incorporated circuits is in general chip region decrease. Hereditary algorithm is an iterative and evolutional approach that could be applied to VLSI module position issue. In this paper, a genetic algorithm-based methodology is proposed to lessen the chip zone by methods for successful situation of the modules. The modules are set dependent on best-fit position esteems. Significant position limitations are considered so as to deliver successful situation.

5.6 Finite Impulse Response Filter

In signal setting up, a constrained inspiration response (FIR) channel is a channel whose drive response (or response to any restricted length input) is of constrained term, since it settles to center in constrained time [15]. This is instead of tremendous drive response (IIR) channels, which may have internal information and may continue responding uncertainly (regularly decaying). The inspiration response (i.e., the yield on account of a Kronecker delta commitment) of a Nth-demand discrete-time FIR channel props up accurately $N + 1$ models (from first nonzero segment through last nonzero segment) before it by then settles to zero. FIR channels can be discrete time or steady time and mechanized or straightforward. In numerical examination and viable assessment, a discrete wavelet change (DWT) is any wavelet change for which the wavelets are discretely tested. Likewise with other wavelet changes, a key bit of leeway it has over Fourier changes is fleeting goal: it catches both recurrence and area data (area in time).

6 Wavelet Transform-Based Analysis

6.1 Extraction of Phonocardiogram Signals Utilizing Continuous and Discrete Wavelet Transform:

Prior to beginning the wavelet method, we should know the major of wavelet [4]. What is wavelet? wavelet can be characterized as “A waveform got from heart audio effect with a constrained term and having zero normal worth.” These wavelets are like the sine waves utilized in Fourier series analysis. These sinusoidal waves reach out from $-\infty$ to $+\infty$ having a smooth and unsurprising waveform while wavelets are asymmetric and irregular. The wavelet strategy incorporates the shifting and scaling of original signal or mother wavelet. This wavelet method can be utilized for analysis of two-dimensional information as well as one-dimensional [16–19].

A. **Continuous Wavelet Transform**

Fourier series analysis of any signal should be possible with the following condition:

$$F(w) = \int_{-\infty}^{+\infty} f(t)e^{-jwt}\mathrm{d}t$$

Continuous wavelet transform can be performed with the following condition:

$$C(\text{Scale, Position}) = \int_{-\infty}^{+\infty} f(t)(\text{Scale, Position, } t)\mathrm{d}t$$

It signifies "Sum for overall time of signal multiplied by scaled and shifted versions of wavelet function is Continuous Wavelet Transform" [19].

B. **Discrete Wavelet Transform**

In discrete wavelet transform, the following two segments are utilized.

- Scaling Component
- Wavelet Component.

Suppose $X(n)$ is sample signal where $n = 0, 1, 2, \ldots, N - 1$ and $i =$ scaling factor and $j =$ shifting factor.

Scaling Function:

$$M(\emptyset)(I, j) = \frac{1}{\sqrt{N}} \sum X(n).\emptyset(n)(i, j)$$

Wavelet Function:

$$M(\alpha)(i, j) = \frac{1}{\sqrt{N}} \sum X(n).\alpha(n)(i, j)$$

where $\frac{1}{\sqrt{N}}$ is normalization factor.

Now discrete wavelet transform can be written as

$$X(a, b) = \int_{-\infty}^{+\infty} f(t) \frac{1}{\sqrt{a}} \propto .\left\{\frac{t - b}{a}\right\} \mathrm{d}t$$

6.2 Extraction of Phonocardiography Signal Utilizing FIR Filter

For reducing the artifact noise that emerges when taking fetal PCG recording from abdominal area of pregnant woman. For testing, we pick stimulated fPCG database containing 37 records and assessment dependent on SNR determination and Bland–Altman statistics and SD [13].

Basics of FIR channel

The noise which stays in the band can be eliminated by FIR filter.

1. Filtrations are productive for improving SNR.
2. Noise reduction is referred to as non-recursive channel having multiple posts situated at the beginning which causes a channel delay.

Results of FIR channel

1. Currently, just two databases that contain clinically gained constant fetal PCG information are accessible.

2. Synthetic databases called simulated fetal PCGs which is open by means of Physio Bank archive [2].

This database represents series of 37 single-channel synthetic abdominal fetal PCGs according to different fetal conditions and recording conditions created utilizing simulation software with length of 8 min [3].

7 Application of PCG

7.1 *Fetal Phonocardiography*

Fetal heart rate is greater than typical grown-up. Physiological fHR changes during pregnancy around eighth week of pregnancy this heart rate stabilize and extend from 120 to 160 beats for every minute (bpm). Fetal PCG is completely noninvasive, and no energy is sent to the mother's fetus. Signal can be captured by using the sensor on mother's abdominal area without utilizing a gel.

Noninvasive sensor ranges from 0.1 to 200 Hz with an amplifier and an anti-aliasing filter. The fetal ECG offers the opportunities for beat-to-beat fHR estimation since the QRS-complex gives a perfect fiducial point [14].

7.2 *Esophageal PCG*

Esophageal phonocardiography (ePCG) has the positive conditions that specific heart sounds are gotten which are close to their origin of sites, while in standard surface phonocardiography (sPCG) debilitating of the vibration occurs in the path to the microphone. The damage of directional sensitivity of an accelerometer-type microphone has been removed by building biaxial microphone; with the guide of an electronic axes rotation, turn, perfect record of heart vibrations in the even plane is practiced. ePCG has its own clinical importance because of diagnosing of the mitral valve regurgitating forward (MR) better than standard PCG, especially in patients who have prosthetic valves in both mitral and aortic gaps where left ventricular angiography cannot perform with no issue. Concerning extent of the recipient in the throat it has been set up that such countless vital vibrational models can be recorded at different heights.

8 Suggested Application

- Remote detecting of sub 50 micron removals
- Adult and fetal phonocardiography and phonography

- Remote estimations of consistent materials in airstreams
- Infrasound force estimation
- Biomedical instrumentation
- Low-cost and low force confocal microscopy
- Cell culture estimation.

9 Conclusion

The PCG recording is made by setting the stethoscope ordinarily on the aortic zone. The patient is advised to be still and tranquil, lean forward a piece, and hold their breath if conceivable, and the above-mentioned are various techniques used for de-noising the PCG signal. After de-noising, the signal one can easily utilize the filtered signal as in biomedical instrumentation and other suggested applications.

References

1. Debbal SM, Bereksi-Reguig F (2008) Computerized heart sounds analysis. Comput Biol Med 38:263–280
2. Goda MÁ, Hajas P (2016) Morphological determination of pathological PCG signals by time and frequency domain analysis. In: Computing in cardiology conference (CinC), pp 1133–1136
3. Abdollahpur M et al (2016) Cycle selection and neuro-voting system for classifying heart sound recordings. Comput Cardiol 43:176–238
4. Shahid I, Imran S, Usman A (2018) Localization and classification of heart beats in phonocardiography signals —a comprehensive review. J Adv Sig Process 2018(1):26
5. Abo-Zahhad M et al (2011) A comparative approach between cepstral features for human authentication using heart sounds. Signal mage Video Process 10:843–851
6. Abbas AK, Bassam R (2009) Phonocardiography signal processing. Synthesis Lect Biomed Eng 4(I):1–194
7. NivithaVarghees V et al (2014) A novel heart sound activity detection framework for automated heart sound analysis. Biomed Signal Process Control 13:174–188
8. Deng S-W, Han J-Q (2016) Towards heart sound classification without segmentation via autocorrelation feature and diffusion maps. Futur Gener Comput Syst 60:13–21
9. Kao W-C, Wei C-C (2011) Automatic phonocardiography signal analysis for detection heart valve disorders. Expert Syst Appl 38(6):6458–6468
10. Yan Z et al (2010) The moment segmentation analysis of heart sound pattern. Comput Methods Programs Biomed 98(2):140–150
11. Bertrand O, Bohorquez J, Pernier J (1994) Time-frequency digital filtering based on an invertible wavelet transform: an application to evoked potentials. IEEE Trans Biomed Eng 41(1):77–88
12. Manasrakshit SD (2018) An efficient ECG denoising methodology using empirical mode decomposition and adaptive switching mean filter. Biomed Signal Process Control 40:140–148
13. Huang N, Shen Z, Long S, Wu M, Shih H, Zheng Q, Yen N, Tung C, Liu H (1998) The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis. Proc R Soc A Math Phys Eng Sci 454:903–995
14. Salman AH, Ahmadi N, Mengko R, Langi AZ, Mengko TL (2015) Performance comparison of denoising methods for heart sound signal. In: 2015 International symposium on intelligent signal processing and communication systems (ISPACS), November 9–12

15. Jaros R et al (2018) Use of a FIR filter for fetal phonocardiography processing. Department of Cybernetics and Biomedical Engineering, Faculty of Electrical Engineering and Computer Science, VSB–Technical University of Czech Republic
16. Jagriti Bhatore, Vinod K Sonkar (2016) An optimized analysis of phonocardogram signals using discrete wavelet transform. Int J Softw Hardware Res Eng 4:27–63
17. Boussaa M et al (2016) Comparison of MFCC and DWT features extractors applied to PCG classification. In: 11th International conference on intelligent systems: theories and applications (SITA). IEEE, New York
18. Jain PK, Tiwari AK (2016) An adaptive method for shrinking of wavelet coefficients for phonocardiogram denoising. Elsevier, New York, pp 1–5
19. Jain PK, Tiwari AK (2017) An adaptive thresholding method for the wavelet based denoising of phonocardiogram signal. Biomed Signal Process Control 38:388–399