Heart Sound Lines – Proposal of a Novel Heart Auscultation Assistant Diagnosis Tool

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Abstract- This work introduces a presentation proposal of a novel technique for phonocardiogram components interpretation (sounds and murmurs) for phonocardiogram analysis i.e. cardiac diagnosis. Determination of heart sounds position in PCG signal is an important parameter for cardiac diagnosis. Therefore, scientists and researchers constantly work on developing new and improving existing heart sounds location algorithms in PCG signal. In fact, cardiac diagnosis by auscultation i.e. PCG signal analysis is based on murmur localization. Murmur location is based on determination of murmur position in relation to the first and second heart sounds (S1 and S2). After determination of murmur location the diagnosis is determined by evaluation of murmur parameters. The authors proposed an original localization and classification algorithm of heart sounds and murmurs in this work. Performed evaluation of the algorithm shows promising results with very high accuracy. The algorithm was developed with Matlab and it uses the PCG signal as the only input source.

Keywords - Phonocardiogram (PCG), Heart sounds and heart murmur localization, Heart sound lines (HSLs) diagnosis, Murmur index

I. INTRODUCTION

Heart is a source of sound, a “live instrument” of very unstable structures. A sound produced by acoustic activity of the heart contains information about health state of the heart. The sound emitted by a normal cardiac cycle is composed of these events: the first heart sound (S1), a time period between the first and second heart sound called systole, a second heart sound (S2) and a time period between the second (S2) and first heart sound (S1) called diastole. Heart murmurs are extra sounds (noise) heard through systole (systolic murmurs), diastole (diastolic murmurs) or whole cardiac cycle (continuous murmurs). At heart health diagnosis, the most important point is the selection between a healthy heart (there are no deformations on heart) and sick heart (there are deformations on heart). Deformations of the heart are manifested through pathologic murmurs. In healthy heart there are no murmurs or there can be innocent murmurs [1]. Continuous and diastolic murmurs are pathologic. Systolic murmurs can be innocent or pathologic. Continuous murmurs are easily diagnosed by auscultation. However, classification of systolic and diastolic murmurs by using only auscultation technique is unreliable and not easy task. Therefore, the contribution of this paper is a new technique Heart Sound Lines (HSLs) which can assist physicians to make accurate heart murmur diagnoses.

The oldest, basic and primary cardiac diagnosis method is technique of listening of heart sound – auscultation. Heart auscultation, defined as the process of interpreting acoustic waves produced by the mechanical action of heart is a non-invasive, low-cost screening method and is used as fundamental tool in the diagnosis of cardiac diseases [2]. Unfortunately, heart sound interpretation by auscultations is very limited to human ear competence and depends highly on the skills and experience of the listener.

The first stethoscope was made of wood. After almost two centuries of technological developing today’s generation of physicians can use electronic stethoscopes. They have improved the value of auscultation with their remarkable abilities to enhance heart sounds. Sound processing of heart sounds and murmurs with spectral analysis is very promising [3]. Now we have various ways to use spectral analysis in computerized recognition of heart sounds and murmurs. Today’s technology allows us different representations of heart sound event. Physicians determine medical diagnosis of patients by interpretation of audio and graphic displays of heart sounds. However, despite the numerous representations of heart sound physicians mainly use the classic time display of heart sound. This representation of heart sound signal is known as phonocardiograph (PCG). Spectrogram display of heart sound signals which allows better heart sound interpretation is mainly not understood or used by physicians. Therefore, improving PCG representation (display) is necessary. The information about heart sound events received from spectral analysis and other methods needs to be adjusted to PCG representation. HSLs received from the spectral values of heart sounds are adjusted to the PCG heart sound representation. These lines show information which is difficult to obtain by auscultation and not visible in PCG.

The rest of paper is organized as follows. Subject of analysis, equipment and method are presented in section II. Experimental results are presented in section III. Section 4 concludes the paper with final remarks.

II. MATERIALS AND METHODS

A. Subjects –

A total of 374 heart sounds (178 S1, 178 S2 and 18 S3), 167 systoles and 167 diastoles were used for evaluating HSLs technique. These heart sounds events are part of 18 heart sounds recordings, which were collected from three sources. To test HSLs we used 10 artificial and 8 real heart sounds recordings. There are two groups of subjects, heart sounds without heart murmur and with innocent murmur are first group and heart sounds with pathological murmur are second group.

Five artificial recordings from the first source [4] are: one record without heart murmur (Normal) (first group) and four records with pathological murmur (second group). Four pathological murmurs are: Aortic Stenosis (AS), Pulmonary Stenosis (PS), Mitral Stenosis (MS) and Mitral Regurgitation (MR).

The other five artificial recordings from the second source [5] are: Early Systolic Murmur (ESM), Ejection Click (EC), Late Systolic Murmur (LSM), Opening Snap (OS) and Pansystolic Murmur (PM). These murmurs are pathological murmurs (second group).

The other eight recordings are real heart sounds which were recorded with an electronic stethoscope while examining the children in outpatient clinic by the senior pediatric cardiologists. All children were additionally examined with ultrasound for an accurate diagnosis of congenital heart disease. For this analysis we chose 5 innocent Still’s murmur records (first group) and 3 Ventricular Septal Defect (VSD) murmur records (second group).

B. Equipment –

Heart sound signals were recorded with an electronic stethoscope 3M™ Littmann® Model 4000 in e4k format. The signals were transformed to wav format with 3M™ Littmann® Sound Analysis Software. GoldWave Software was used to filter some poorly recorded heart sound signals i.e. due to their unclear display in PCG. The HSLs algorithm was used for heart sounds and heart murmurs localization as well as heart murmur classification. Spectral analysis of the heart sound data was done by Goertzel algorithm [6].

C. Methods –

Duration of soundtracks recorded with the stethoscope is 8 seconds, the sampling frequency is 8 kHz and resolution of quantization is 16 bits. Due to unclear visibility of first and second heart sounds on PCG display some recordings were filtered by using band pass filter 35-500 Hz (GoldWave). Also, all artificial recordings were resampled to 8kHz by using GoldWave. All 18 recordings (artificial and real) were then processed by using HSLs algorithm. Murmur diagnosis technique is based on the graphic displays of HSLs calculations. The block diagram of the application workflow process is presented in Figure 1.

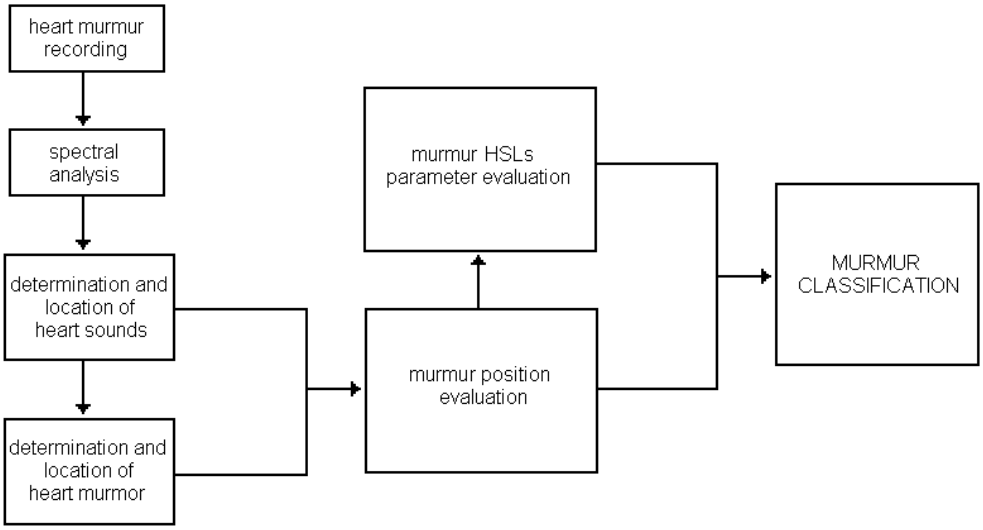

Figure 1. Block diagram of heart sounds signal processing

III. EXPERIMENT AND RESULT

HSLs - proposal of the new heart murmur diagnosis technique will help physicians to understand, determine and evaluate events in cycle PCG signals. This tool enables physicians to see three pictures on the screen. The first (upper) picture shows PCG signal. The picture below shows positions of detected heart sounds (black line) and between detected heart sounds two lines are shown, one for murmur detection (blue line) and the other for pathological diagnosis (red line) of heart murmur. If the red line has a significant value in several certain segments between detected heart sound lines (systoles or diastoles) then the displayed signal can be diagnosed as pathologic murmur. If the blue line has a significant value in several certain segments then the signal can only be diagnosed as murmur, but unfortunately we cannot diagnose whether it is pathologic or innocent murmur. Likewise, if both lines have a significant value then we can diagnose pathologic murmur. And finally on the third picture a murmur index lines are shown. This lines show locations of heart murmur and they can have different shapes and values. If the value (murmur index) is greater than 20 (>20) than this murmur is pathologic. If murmur index is less than 20 (<20) then this murmur can be pathologic or innocent murmur. The third HSLs diagnostic parameter is murmur duration between located heart sounds (S1 and S2). The idea is as follows:

- Diastolic murmurs are pathological.
- Systolic murmur is innocent or pathological if murmur lines within systoles occupy less than 60% (<60%) systole.
- Systolic murmur is pathological if murmur lines within systoles occupy more than 60% (>60%) systole.

Authors have noticed that these three parameters and shape of HSLs besides classification between innocent and pathologic murmurs can also be used to determine precise murmur type, but authors have not done that investigation.

Figure 2 and 3 illustrate heart sound lines. Heart sound lines (HSLs) of heart sound with innocent Still's murmur are presented in Figure 2 and HSLs of pathologic heart murmur of Ventricular Septal Defect (VSD) is presented in Figure 3. These presented heart sounds are without filtering. In Still the most significant is blue line, value of murmur index is less than 20 in each systole and duration of murmur is less than 60% in each systole. Therefore, based on these parameters one can conclude that it is innocent murmur. In VSD both, blue and red, lines are significant, value of murmur index is greater than 20 in majority of systoles and duration of murmur is greater than 60% in each systole. Therefore, one can conclude that it is pathologic murmur.The proposed scheme is tested using ordinarily image processing. From the simulation of the experiment results, we can draw to the conclusion that this method is robust to many kinds of watermark images.

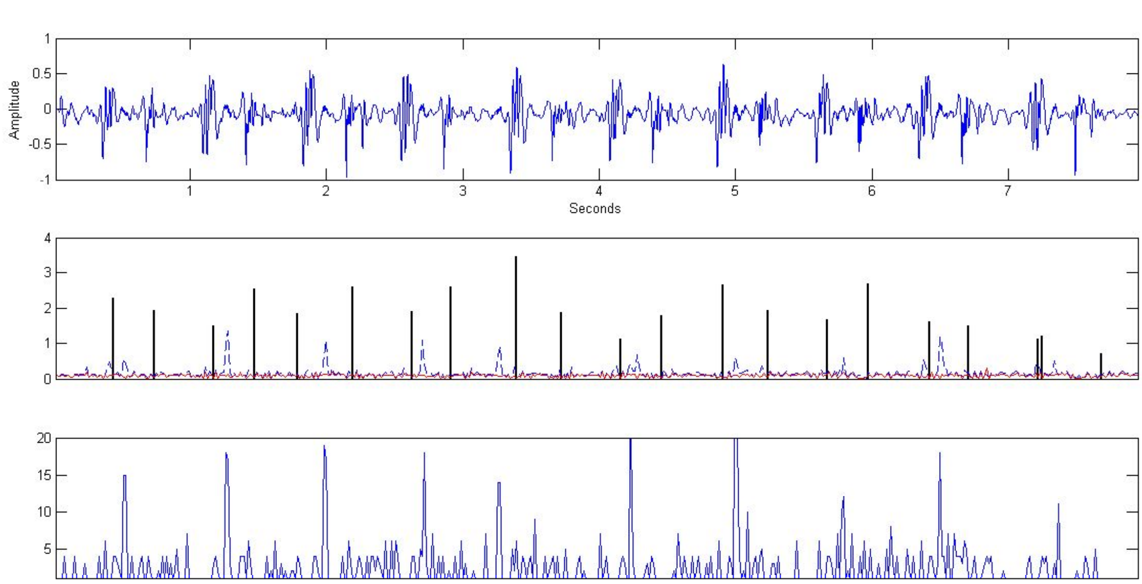

Figure 2. Heart sound lines of innocent Still heart murmur (real recording)

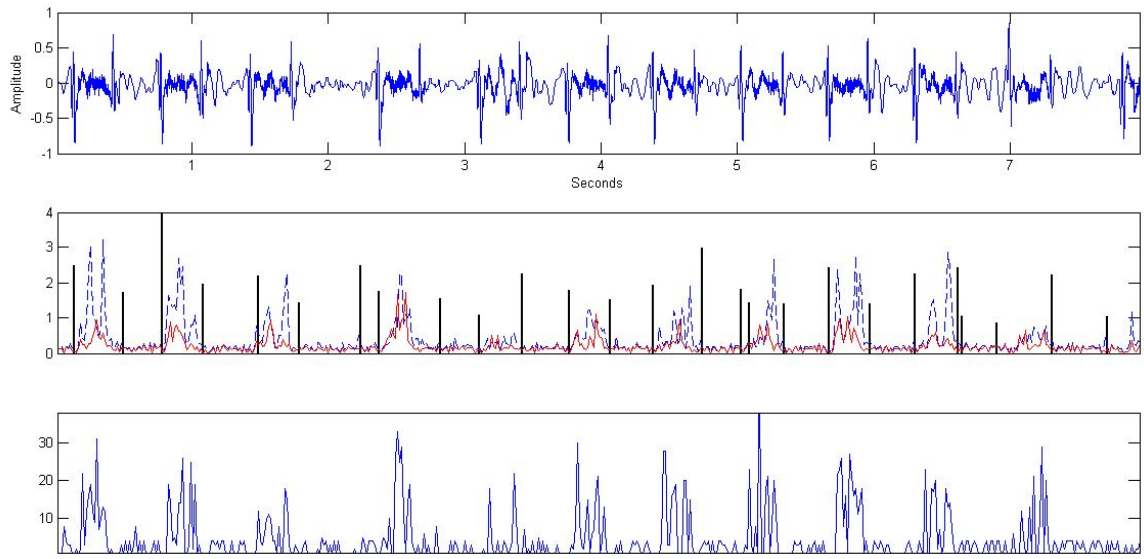

Figure 3. Heart sound lines of pathologic VSD heart murmur (real recording)

During cardiac acoustic activity heart can generate four sounds (S1, S2, S3 and S4) and variability murmur. First heart sounds (S1) demarcates the end of diastole and beginning of systole. Second heart sounds (S2) demarcates the end of systole and beginning of diastole. On Figure 2 and Figure 3 the location of S1, S2 and murmurs is shown. HSLs can also locate S3 and S4. If S3 and/or S4 exist they would appear in diastole. Figure 4 shows HSLs for one artificial heart sound with mitral regurgitation (MR). This artificial heart sound contains three heart sounds (S1, S2 and S3) and mitral regurgitation murmur in systole.

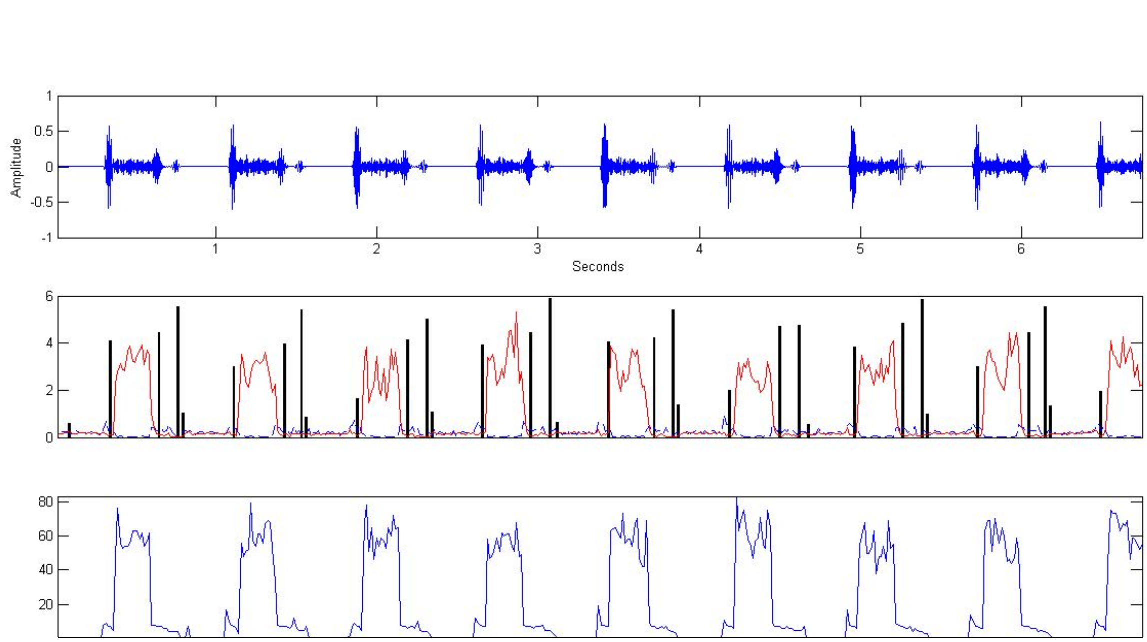

Figure 4. Heart sound lines of pathologic MR heart murmur (artificial recording)

Detection, location, segmentation of heart sounds and heart murmurs classification from the PCG signals have been studied by many authors. However, the majority of studies depend on reference to the electrocardiogram (ECG) signal or/and carotid pulse [7-10]. In recent literature authors without the help of ECG, using the PCG signal as the only source, have done location of heart sounds. They used signal processing tools such as: Shannon energy [11-14], Hidden Markov Model Transform [15-18], S-Transform [19-21], etc. The advantage of our method is that enables display of diagnostic parameters of heart sounds, which means that physicians, by using HSLs displays of heart sound, can better understand the sound of patient heart and make diagnosis more faster and accurate.

The results of HSLs sounds and murmur localization and HSLs diagnosis are show in Tables 1 and 2. The results of artificial heart sounds are shown in Table 1 while results of real heart sounds are shown in Table 2. All heart sound recordings (real and artificial) contain two heart sounds (S1 and S2), only artificial heart sound recordings of MR and MS contain three heart sounds (S1, S2 and S3). All parameters shown in Tables 1 and 2 are determined manually by visual analysis of the HSLs results, which can be seen in Figures 2, 3 and 4.

HSLs localization and diagnosis for artificial heart sound recordings are nearly 100% accurate. Only in MS murmur heart sounds are incorrectly localized. MS is murmur of low frequency as well as heart sounds (S1 and S2) and due to that HSLs misses to localize heart sounds. Also, in MS HSLs lines are blue, index of murmur is less than 20 and duration of MS murmurs in diastoles are greater than 60%. Even though there are incorrectly localized heart sounds HSLs diagnosis is accurate. MS is diastolic murmur and certainly pathologic.

From 5 Still’s and 3 VSD heart sound recordings (total 198 possible heart sounds – S1 and S2) HSLs did not locate 12 heart sounds (6%) and from 98 possible systoles there where 4 systoles where HSLs did not locate murmur (cca. 4%). In some cases heart sounds which were poorly displayed on PCG are successfully located by HSLs. HSLs is unable to detect some murmurs or heart sounds if the quality of audio recordings of heart sounds is poor. This can happened in some short time segments (surrounding murmur, movement of stethoscope etc.), and due to that some murmurs and heart sounds (one or two systoles) do not have their original characteristics.

However, what is most important, HSLs diagnosis parameters enable accurate diagnosis regardless of some heart sounds or murmurs which are not located. Also, one can conclude (from Tables 1 and 2) that HSLs diagnosis enable accurate medical diagnosis for most heart murmurs. Authors were mainly focused on Still’s murmur because it is the most common innocent murmur.

Table -1 HSLs diagnosis parameter of artificial recordings

	Heart sounds		**Heart murmurs**		**HSLs diagnosis**			
	Located	***Non located/ Falsely located***	***Located***	***Non located/ Falsely located***	***HSLs lines***	***Murmur index***	***Murmur duration***	***Diagnosis***
Normal	19	0/0	-	-	-	-	-	Without murmur
MS	19	1/3	10	0/0	blue	<20	>60%	Pathologic (Diastolic) murmur
AS	14	0/0	7	0/0	red and blue	>20 (40-70)	>60%	Pathologic murmur
MR (S1,S2,S3)	25	0/0	9	0/0	red	>20 (60-80)	>60%	Pathologic murmur
PS (S1,S2,S3)	30	0/0	10	0/0	red and blue	>20 (55-70)	>60%	Pathologic murmur
LSM	13	0/0	7	0/0	red and blue	>20 (cca. 40)	(50-60)%	Pathologic murmur
EC	13	0/0	6	0/0	red and blue	>20 (30-40)	<60% (cca. 20%)	Pathologic murmur
PSM	14	1/0	7	0/0	red and blue	>20 (30-40)	>60%	Pathologic murmur
ESM	13	0/0	7	0/0	red and blue	>20 (cca. 40)	<60% (cca. 40%)	Pathologic murmur
OS	13	0/0	6	0/0	red and blue	>20 (25-30)	<60% (cca. 20%)	Pathologic (Diastolic) murmur

HSLs diagnosis is accurate for all Still's and VSD heart sound recordings. All of 5 Still's murmurs are innocent and all VSDs are pathologic according to all three HSLs diagnosis parameters. In the case of Still's murmur value of maximal murmur indexes is between 15 and 20, in VSD is between 25 and 40. Still's murmur lines have one significant peak of short duration within systole while VSD murmur lines have more peaks and they occupy whole systole, which is shown in Figures 2 (b and c) and 3 (b and c). These results are promising and diagnosis of heart murmurs by using HSLs is very reliable.

Table -2 HSLs diagnosis parameter of real recordings

	PCG		**HSLs localization**		**HSLs diagnosis**			
	No. of heart sounds	***No. of systoles***	***Located sounds /not located***	***Located murmurs / not located***	***HSLs lines***	***Murmur index***	***Murmur duration***	***Diagnosis***
Still 1	25	12	24/1	11/1	blue	<20	<60%	Innocent murmur
Still 2	26	13	25/1	12/1	blue	<20	<60%	Innocent murmur
Still 3	20	10	20/0	10/0	blue	<20	<60%	Innocent murmur
Still 4	20	10	19/1	9/1	blue	<20	<60%	Innocent murmur
Still 5	26	13	23/3	12/1	blue	<20	<60%	Innocent murmur
VSD 1	28	14	24/4	14/0	red and blue	>20	>60%	Pathologic murmur
VSD 2	30	15	28/2	15/0	red	>20	>60%	Pathologic murmur
VSD 3	23	11	23	11/0	red and blue	>20	>60%	Pathologic murmur

IV.CONCLUSION

The authors are developing a computer program package that will help physicians in auscultation diagnostic. The idea is to show events in PCG signals with graphic lines. The display of heart sound lines PCG signals will enable visual representation of information content of PCG signals. HSLs will help physician to easier understand some of the events in diagnostic segments of heart sound cycle (systole, diastole, heart sounds and murmur), by distinguishing between different lines colors, values of index murmur and estimating duration of murmur. It will also help them to determine the diagnosis of the patient by listening to heart sounds (auscultation) and visual view of that sounds (HSLs). It is shown that HSLs is accurate. Also, authors purpose was to create simple to use heart murmur diagnosis technique and authors believe HSLs technique can become a commercial diagnosis tool with great accessibility and low cost.

V. ACKNOWLEDGMENTS

We thank Rončević Željko, M.D., Ph.D., Pediatric Cardiologist at Clinical Hospital Mostar and assistant Professor of Pediatrics at Mostar University School of Medicine - Bosnia and Herzegovina, for heart sounds recordings and medical assistance. Authors developed own HSLs program packet and HSLs presentation diagrams. The authors declare that they do not have a direct financial relation with the commercial identity mentioned in this paper that might lead to a conflict of interest, such as financial gain.

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