Classification of Pathologic and Innocent Heart Murmur Based on Multimedia Presentations of Acoustic Heart Signals

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***Abstract*— 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. However, very few physicians can establish medical diagnosis just by using the technique of listening of heart sounds called auscultation. Spectral composition of acoustic heart beat signals in children without heart murmur (Normal), and with pathologic heart murmur of Ventricular Septal Defect (VSD) were compared with innocent Still's murmur (Still) as to determine the parameters of the Still's murmur. Goertzel algorithm implementation can provide a basic understanding of the spectral compositions of the heart sounds and murmurs. Still's murmur is analyzed in more detail because it is incorrectly diagnosed by many doctors. The graphic illustrations in this paper include 3D graphic presentation of heart sound signals as the main achievement of the paper.**

Keywords-3D graphic presentation of a heart sound; Goertzel algorithm; Still's heart murmur; time-frequency composition.

I. INTRODUCTION

It is well known that there are correlations between the health state of the heart and the sound produced by its beating. The quality of finding of the cardiac auscultation is influenced by previous knowledge, experience and even musical talent [1]. Heart auscultation, defined as the process of interpreting acoustic waves produced by the mechanical action of heart is a noninvasive, 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. 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, either there are no murmurs or there are innocent murmurs on a healthy heart [3].

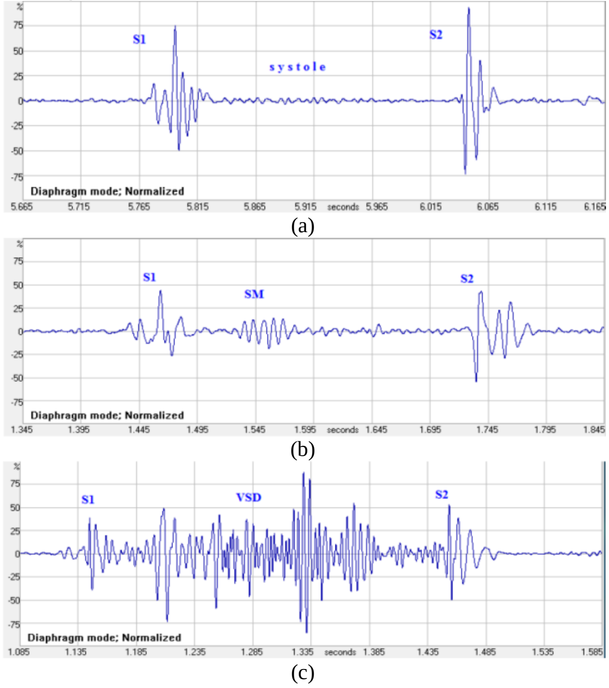
The sound emitted by a normal cardiac cycle is composed of the first heart sound (S1), a time period between the first and second heart sound called systole, a second heart sound (S2) and a time period between the second (S2) and first heart sound (S1) called diastole. Heart murmurs are extra sounds (noise) heard through systole or diastole. Systolic heart murmurs can be physiologic (innocent) without disease and pathologic caused by heart diseases. Innocent vibratory murmur was described for the first time in 1909 by an English paediatrician George F. Still (1868-1941) [4]. A good example of pathologic murmur is harsh systolic murmur of ventricular septal defect (VSD) caused by turbulent blood flow through a defect („a hole") in ventricular septum. Cardiac auscultation, especially cardiac auscultation in children is a skill difficult to master. The human ears and stethoscope are not perfectly adapted to the heart sounds. Heart sound and murmurs are nonstationary in time and are arranged in the low frequency range. However, acoustic stethoscopes will be used for a long time but will gradually be repressed by electronic stethoscopes [5].

Spectral analysis of the heart sound data in most of published studies was obtained by applying a Fast Fourier Transform (FFT) and/or Wavelet Transform (WT) [2][6][7][8][9]. In this paper, the Goertzel algorithm was used and obtained results could be compared with FFT and WT. The algorithm was introduced by Gerald Goertzel (1920-2002) in 1958 [10].

The paper is organized as follows. In Section II, recording and display of heart sound signals are shortly presented. The results of tone analysis in Still's murmur are in Section III. 3D graphics presentations of a heart sounds and Still's murmur are presented in Section IV. Section V concludes the paper with final remarks.

II. ANALYSIS PROCEDURE

During the children examination in outpatient clinic by the paediatric the cardiologists, their heart sounds were recorded with an electronic stethoscope. Each soundtrack of acoustic activity of the heart was taken for a period of 8 seconds for each patient. Children were classified into three groups: children without heart murmur - Normal, children with physiological Still´s innocent murmur - Still and children with pathological murmur associated with congenital heart disease - VSD. All children were examined with ultrasound for accurate diagnosis of congenital heart disease. Fig. 1 shows one Normal, one Still and one VSD in time and Fig. 2 shows theirs spectrograms.

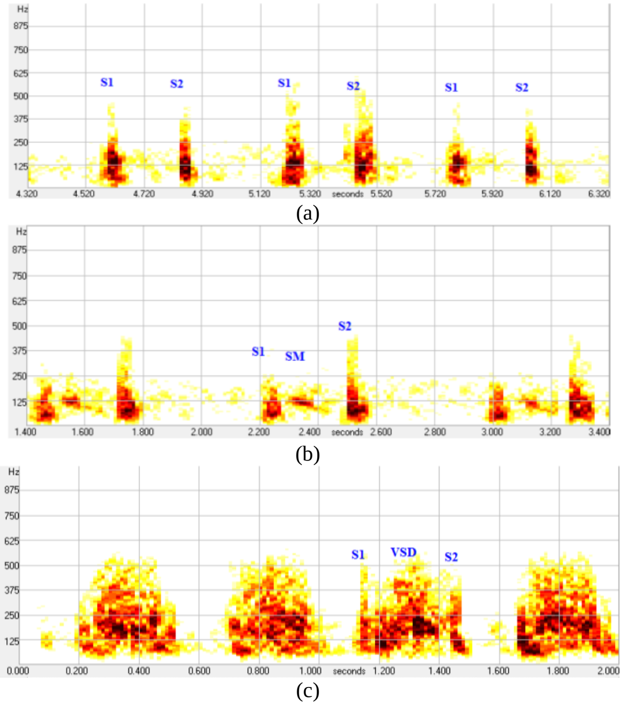


(a)

(b)

(c)

Figure 1. Heart sounds in time. (a) Normal in time. (b) Still in time. (c) VSD in time



(a)

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Figure 2 Spectrogram of heart sounds. (a) Spectrogram of Normal. (b) Spectrogram of Still. (c) Spectrogram of VSD

Heart sound signals were recorded with electronic stethoscope **3M™** Littmann® Model 4000 in e4k format. After infrared transfer to a personal computer, signals were transformed to wav format with 3M™ Littmann® Sound Analysis Software. Spectrogram (based on FFT) and time performance of heart signals can be shown by this program.

It can be seen from figures that Still begins after the end of the first heart sound (S1) and stops before the beginning of the second heart sound (S2). A Still's murmur is audible from the beginning of the systole till after the mid systole. Twenty (20) records of Still's heart murmur, 20 of VSD and 10 records without murmur were used for time and spectral energy analyzing.

Heart sounds were being recorded with sampling frequency of f_u=8000 Hz and 16 bits of mono-configuration and resolution of quantization. Further, the whole systolic duration was isolated (by hand) from the heart wav files, and recorded by name Still, VSD or Normal, depending on whether it was recording of innocent Still's murmur, pathologic murmur of VSD or signal without murmur. This optimal sound sample was then processed using digital signal analysis.

III. SOUND ANALYSIS OF STILL'S MURMUR

Pre-recorded cardiac signals of 20 children with Still's murmur are deduced for frequency of maximal sound energy and frequency bandwidth of Still's murmur i.e., Still's tone. For every cardiac signal, elapsed time of every systole is determined, and for that time interval is secluded (manually) for spectral analysis. Still begins to vibrate at the beginning of systole instantly after the end of first heart sound (S1) and stops before beginning of second heart sound (S2). Spectral analysis needs to be done in that interval. In that time interval (around 100 ms) in time frames of 20 ms, i.e., N=160 samples in discrete time spectral energy is calculated.

Tuning coefficients (fixings) of frequency are set in that order that you can get frequency resolution of 5 Hz. Likewise spectral energy on selected time frame of systole is done within lag of 5 ms or 40 samples on discreet time axis. In Fig. 3, the spectral energy is shown in 5 consecutive time frames (scanned of 40 ms of systole). Final position of Still's time interval of 20 ms (N=160) is chosen on maximal point of its spectral energy. This Still's murmur was recorded with amplification of 2x (in stethoscope) for better illustration.

In Fig. 3, the spectral energy of third time frame is marked in red which represents maximal energy amount in scanned time. That time frame represents final time position of Stills's murmur and in that frame frequency and bandwidth of Still's murmur is calculated. For this Still's murmur frequency is 130 Hz and bandwidth is around 50 Hz. In final time position Stills's murmur is musical tone and it has maximal energy.

Statistic analysis of 20 Still's murmurs resulted that tones of Still's murmur are situated on bandwidth span of 90-170 Hz, while the average tone frequency is 118,75 Hz and the average bandwidth of Still's murmur is 40,75 Hz. Frequency of tone is the frequency on which the murmur has maximal energy (top of curve in Fig. 3) and in most cases it is between 110 and 130 Hz. Frequency bandwidth

(B =Fmax-Fmin) is determined in a way that frequency of tone falls in half of strength Fmin (left of the top of curve) and Fmax (right of the top of curve).

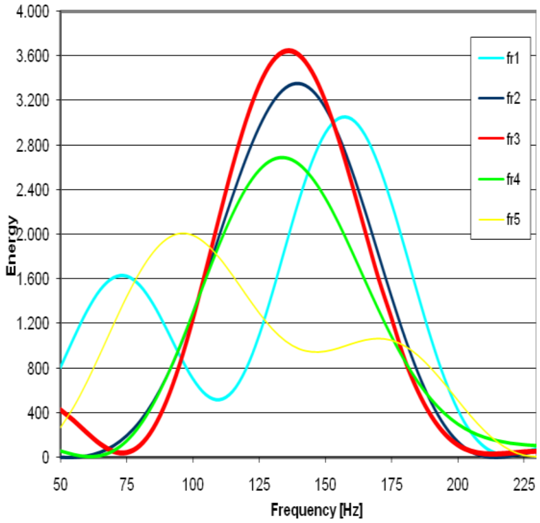

Figure 3. Final position of Still’s murmur

If we do not relocate a bit from the first tone S1 or if we analyze time frame at the end of systole we will not get Still’s musical tone because of the ending of the first tone S1 i.e., the beginning of the second tone S2.

Likewise Fig. 3 clearly shows that Still’s murmur is mainly unsteady signal. Mainly all cardiac signals are unsteady in time span. Likewise spectral energy is mostly concentrated in narrow frequency bandwidth. The conclusion from represented material is that Still’s murmurs are real musical tones and Still’s murmur is a narrowband tone. That tone oscillates in frequency and amplitude. Still’s murmur begins in higher frequency and that frequency deteriorates in time. That change (deteriorating) of frequency is similar to glissando tone played on guitar.

Likewise Still’s murmur oscillates on its amplitude during its brief lifespan (crescendo-decrescendo). Therefore Still’s murmur begins to play silently and is enhanced as it progresses and it is the loudest in the middle and after that gradually begins to decline and stops. All this occurs in systole. Still’s murmur begins at the start of systole, “plays” a bit longer than half of the systole and disappears by the next systole.

IV. 3D GRAPHIC PRESENTATION OF STILL’S MURMUR S1 AND S2

Sound, which transfers heart sound signal, carries many information about heart murmurs. In this study, systolic heart signals were analyzed. Spectral energy of VSD is chaotically distributed in a broad frequency spectrum bandwidth between 80-500 Hz and frequency of the biggest VSDs peak is bigger than 200 Hz. Spectral energy of Still and Normal is regularly distributed in narrow frequency bandwidth under 200 Hz. Still has resonance in frequency bandwidth between 90-170 Hz while Normal has no resonance. Spectral energy below 80 Hz was mainly caused by ambient noise and by late oscillations of first heart sound. At early systole there are two sounds at the same time: the late oscillations of the first heart sound in low frequency about 70 Hz and the beginning of resonance of Still’s murmur at higher frequency about 150 Hz [11]. Human ear can’t distinct it.

Fig. 4 illustrates the distribution of spectral energies of the first heart sound S1, the second heart sound S2 and Still’s murmur in final time positions. Spectral energy was calculated on time frames of 25 ms, i.e., N=200 samples in discrete time. Spectral energy was calculated with distance points of 4 Hz. This signal is amplified by 2x.

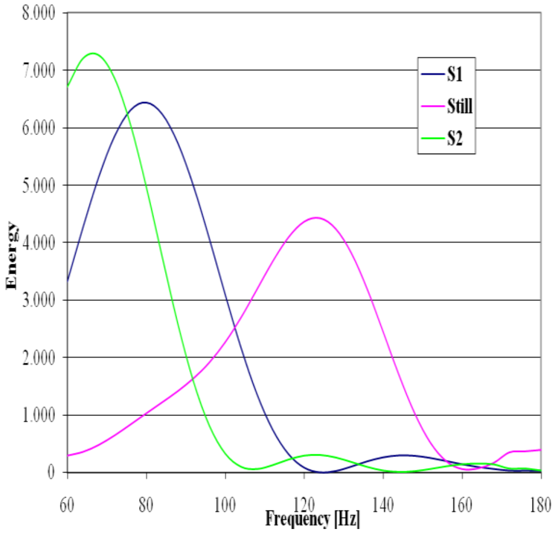

Figure 4. Comparison of the spectrum energy of Still S1 and S2

Fig. 5 and Fig. 6 illustrate 3D graphic presentations of spectral composition of one typical cardiac signal with Still’s murmur.

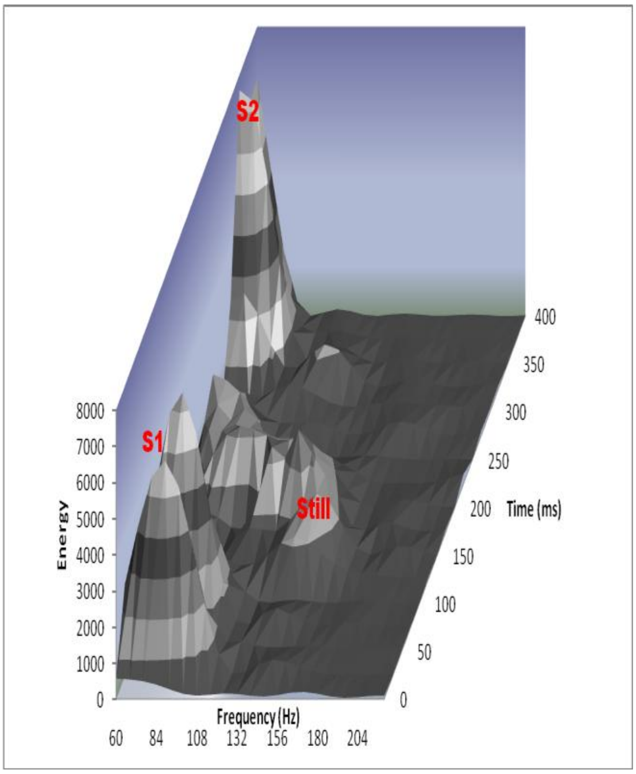

Figure 5. Time – frequency composition of Still’s heart murmur

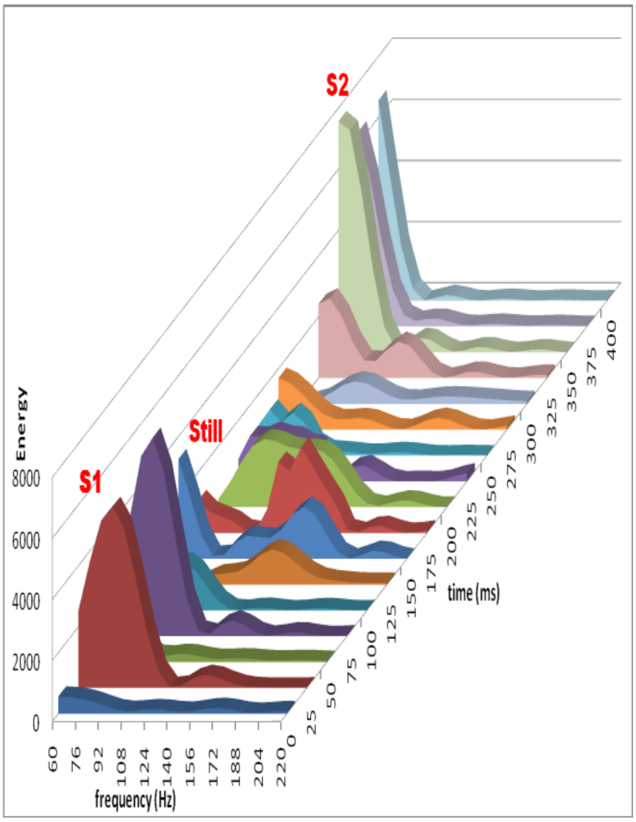

Figure 6. Time – frequency distribution of the spectrum energy of Still's heart murmur

These time-varying frequency graphic presentations show the distribution of spectral energy of heart sounds S1 and S2 as well as Still's murmur. Time frames are 25 ms, i.e., N=200 samples in discrete time and spectral energy was calculated with distance points of 8 Hz. The first heart sound S1 as well as the second heart sound S2 have bigger energy and lower frequency than Still's murmur.

V. CONCLUSION AND FUTURE WORK

Heart sounds are a good example of periodic, yet variable physiological signals [9]. Since heart sounds exhibit marked changes with time and frequency, they are therefore classified as nonstationary signals. To understand the exact feature of such signals, it is thus important, to study their time–frequency characteristics [6].

The differences between the frequency parameters and the spectral compositions of heart signals with innocent and with pathologic murmurs are determined and shown in this paper. For spectral analysis of the cardio signals (recorded by the stethoscope) the Goertzel algorithm was used. It was shown that the frequency parameters as well as the spectral compositions of innocent Still's murmur and pathologic VSD murmur clearly differed. The spectral display of the cardio signals could be diagnostic assistance system for the classification of these murmurs in other words for the health diagnosis of a patient (auscultation-visual diagnosis).

Doctors using auscultation technique for VSD murmur mostly give right diagnosis, but in case of Still's murmur incorrect diagnosis are very often. In order to help doctors in recognition of innocent Still's murmur and of course and other murmurs, it is necessary to create software solutions with graphical displays of the cardio signals spectral energy in real time. Such software would be good tool to doctors at cardiac diagnosis. This paper is one of the first steps in creating such a software package.

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REFERENCES

[1] B. Tomas and Ž. Rončević, "Spectral Analysis of Heart Murmurs in Children by Goertzel Algorithm," The First International Conference on Creative Content Technologies CONTENT 2009, November 15-20, Athens/Glyfada, Greece, pp. 612-615

[2] F. Javed, P.A. Venkatachalam, and M.H. Ahmed Fadzil, "A Signal Processing Module for the Analysis of Heart Sound and Heart Murmurs," Journal of Physics, Conference Series 34 (2006), pp. 1098-1105

[3] B. Tomas, Ž. Rončević, D. Zelenika, and A. Krtalić, "Pathologic and Inocent Heart Murmurs Classification by Spectral Analysis of Acoustic Cardiosignals," 18th Telecommunications Forum TELFOR 2010, 23-25 November, Belegrade – Serbia (in Serbian), pp. 575-578

[4] G.F. Still, "Common disorders and diseases of chilhood," 1st ed. London: Frowde, Hodder & Stoughton, 1909.

[5] Ž. Rončević, "Is there future for cardiac auscultation in children?," Paediatr Croat 2009; 53 (Supl 1), pp. 27-29 (in Croatian)
http://hpps.kbsplit.hr/hpps-2009/pdf/dok06.pdf

[6] S.M. Amin Debbal and Bereksi-Reguig Fethi, "Features for Heartbeat Sound Signal Normal and Pathological," Recent Patents on Computer Science, 2008, vol. 1, no. 1, pp. 1-8

[7] D.A. Balster, D.P. Chan, D.G. Rowland, and H.D. Allen, „Digital Acoustic Analysis of Precordial Innocent Versus Ventricular Septal Defect Murmurs in Children," The American Journal of Cardiology, 1997 Jun 1, vol. 79, no. 11, pp. 1552-1555.

[8] M. Unser and A. Aldroubi, "A Review of Wavelets in Biomedical Applications," Proceedings of the IEEE, vol. 84, no. 4, April 1996, pp. 626-638, doi: 10.1109/5.488704.

[9] G. Amit, N. Gavriely, and N. Intrator, "Cluster Analysis and Classification of Heart Sounds," Biomedical Signal Processing and Control 4 (2009), pp. 26-36

[10] G. Goertzel, "An algorithm for the evaluation of finite trigonometric series," American Mathematics Monthly, vol. 65, (January 1958), pp. 34-35

[11] M. El-Segaier, O. Lilja, S. Lukkarinen, L. Sornmo, R. Sepponen, and E. Pesonen, "Computer-Based Detection and Analysis of Heart Sound and Murmur," Annals of Biomedical Engineering, vol. 33, no. 7, July 2005, pp. 937-942
http://circ.ahajournals.org/cgi/content/full/103/22/2711