Cardiac Auscultation Improvement by Objective Criteria Computing

Maamar Ahfir Izzet Kale

Abstract - In this paper, a novel approach for an automated algorithm design for cardiac murmurs detection and classification has been developed.

Keywords: Heart sounds analysis, heart murmurs, objective criteria

1. Introduction

The decision to determine whether a cardiac murmur exists or not, is purely subjective and is not always shared by primary care physicians. Physicians range their listening findings from grade 1 to grade 6 (subjective score of audibility). Although murmurs ranged from 4 to 6 are all easily detected by a traditional stethoscope, those ranged from 3 down to 1 may escape to the primary care physicians listening. But even if they are detected, the humain ear is not able to determine if the detected murmur is systolic or diastolic in timing, with respect to the first heart and the second heart sounds of the cardiac cycle of a normal functioning heart. Because murmurs timing is a key caracteristic to determine their classes and types, then the representation technique of digitized auscultation heart sounds as a Phonocardiogram (PCG) for visualisation and diagnostic aid, additional to the historical and physical examination findings, can help physicians to make difference between innocent and pathological murmurs.

Although there exist many papers in which different methods have been investigated to develop a PCG-based interface for cardiac ausculatation interpretation, for example the recent one [2], however this technique (PCG-based interface) is not practical in the auscultation context of a large number of patients, for example: for school children and/or waiting lists for the Echocardiographic analysis of the Cardiology Services. Also it requires that primary care physicians must be highly educated in signal processing techniques in order for them to read and interpret Phonocardiograms. The development of an automated algorithm can then serve as a rapid and low cost device to screen numericaly **objective criteria** for every single heart sound picked up from the ausculation areas corresponding to the four cardiac valves. The objective criteria values can serve as indictors for detection and classification of possible heart murmurs.

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In the previous work reported in Reference [1], three automated algorithms that show significant potential promising in their use as an alternative diagnostic tool for the classification of heart sounds into normal/innocent and pathological classes were developed. These are based on three different methods: The Direct Ratio which is applied to a single heart beat signal represented in time domain, Wavelet processing applied to the equivalent frequency domain representation of the signal and Artificial Knowledge Based Neural Networks. The later method (AKBNN) was adopted to overcome the common limitations of the two previous methods, which are:

1- The only systolic murmurs identification, because of the problem of locating the position of the second heart sound S2 for some pathological cases, and then the diastolic timing of the cardiac cycle is excluded for classification.

2- The amplitude of the first heart sound S1 (S2 in case of diastolic murmur identification) which is liable to the indicators of pathology (objective criteria) is not constant for every heart sound recording. This can lead to wrong classification.

3- At least 4 objective criteria (algorithm's outputs) are needed for screening only systolic events, which may be not desirable for the auscultation of a large number of patients.

The AKBNN method operates on some periods of the cardiac cycle to analyse a given individual heart sound recording, which makes it able to detect murmurs of both classes (systolic and diastolic) and all possible types. The obtained results in the context of the common limited Database (only congenital murmurs captured from children) indicated that AKBNN produced the best performance as an automated murmurs classifier with an optimum sensitivity and specificity of 92.9% and 92 % respectively, with respect to the two evaluated previous methods. But its Hardware implementation requires a very large memory space because of its training DATA-set which must represent all possible types of murmurs which exist within both systolic and diastolic timing classes. However, capturing all possible different murmurs types for both classes is not guaranteed during DATA collection. This is because pathological murmurs are not only congenital which can be captured from a certain age limit (childhood), but there exist also other types which can affect patients at the adult's age because of some bacteria (acquired pathology), and they may be captured only if there are sufficiently associated adult patients who accept to voluntarily participate in DATA collection.

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The performance of an implemented automated algorithm based on such method remains strongly dependent to the answers of the two following questions:

1- What is the correlation between a specific murmurs type recorded from different patients for the same conditions (gender, age, weight, height, position during auscultation,..,ect)?; and

2- How many different murmurs types are there, that must be represented in training DATA-set for a network to have a sensitivity and specificity of 100% for all possible heart sound recordings?

This means, an under-representation of all possible murmurs types in the training DATA-set can result in misclassification of some of them. Only very large clinical observations of different categories of patients (children, young adults and adults) with the collaboration of clinicians and cardiologists can help for answers to the two above questions. In the next section, a proposed approach that overcomes the main limitations of the three previous methods will be described.

2. Novel approach description

In this approach, the measurement technique of the normalized time dependent sound energy decaying used in room acoustics for characterization [2] can be applied for heart sounds analysis. Given a single heart beat signal which can be extracted by an automated algorithm from a clean individual auscultation recording (filtering system output), and after separating the systolic and diastolic timing segments of the signal, normalized time dependent energy decaying for both segments can be calculated by a discrete version of the following formula:

$$E(t) = \frac{\int_{t}^{+\infty} h^2(t)dt}{\int_{0}^{+\infty} h^2(t)dt},$$

where $h(t)$ represents the time dependent signal (systolic/diastolic timing segment), and $E(t)$ its normalized time dependent energy decaying.

If this technique is applied to a systolic timing signal for example (similarly to diastolic segment), it allows overcoming the problem of the first heart sound S1 (S2) where its variable amplitude is used as reference for all the indicators of pathology in the two previous methods (the Direct Ratio and Wavelet Processing). Furthermore, a new indicator of pathology independent of S1/S2 is proposed, that is, the Early Time Decay measured once the energy decaying $E(t)$ reaches certain threshold in dB. In the proposed approach an Early Time Decay value above certain threshold represents an indication of pathology. The threshold value which corresponds to healthy heart will be determined after extensive clinical observation and trial for different categories of patients.

Finally, to screen the objective criteria for pathology indication, only one output per timing segment is needed in the novel approach rather than at least four outputs each in the two previous methods. Although, this novel approach doesn't require all types of pathology in the Database for study and analysis, as it is the case for the AKBNN method. Because any timing segment associated to a heart sound with murmur, regardless its type and grade must have a total energy higher than that associated to a heart sound with no murmur (first hypothesis formulated in the previous work). Then in the first case (pathology), the energy decaying can be later than that of the second case (normal). In the Table 1 below advantages and disadvantages of the three previous methods are recapitulated and compared against that of the proposed approach.

3. Results

The novel approach was applied to a restricted Database of heart sounds recorded as wave files (duration: 6 seconds, resolution: 16 bits and sampling frequency: 11025 Hz) which correspond only to 10 different adults patients [3]. Only 3 examples of analysis results of three patients are displayed in this section. Two examples correspond to patients with different types of pathology (Aortic Stenosis and Mitral Stenosis) and one corresponds to patient with normal heart. In Figure 1 and 2, we can see an example of clean pathological signal as compared to a normal signal, both extracted by an automated algorithm. After extracting one signal period (one single heart beat) of the cardiac cycle and separating the systolic and diastolic segments of every individual recorded heart sound (supposed clean), normalized energy decaying for both segments was calculated in order to measure corresponding Early Times Decay which represent the indicators of pathology within the systole and/or diastole. Figure 3 and 4 show corresponding curves, where we can see a late energy decaying in the systole and diastole of the two pathology types with respect to an early energy decaying of the normal case. In the Table 2 corresponding Early Times Decay T20 in ms for the three cases were calculated for an arbitrary value of 20 dB of energy decaying. A great value of T20 as compared to that of the normal case can be considered as indication of pathology for the associated valves, which are in the two cases: Aortic and Mitral valves.

4. Conclusions

In this paper, a novel approach for an automated algorithm design for cardiac murmurs detection and classification has been developed. This approach as compared to the previous methods overcomes their main limitations which formulate the problematic topic of the future project, particularly those recapitulated in the Table 1. Although, the initial algorithm stage for extracting one signal period of the cardiac cycle and separating the systolic and diastolic segments was easily designed for some signals (10), associated to the pathology types, where all have the amplitudes of the first and the second heart sounds S1/S2 higher than that of the associated murmurs in the cardiac cycle (clinical grade lower than 5). However, more DATA collection is needed for visualisation and observation in order to make the algorithm applicable even for murmurs with high clinical grade. But, murmurs with grade 5 and 6 may be excluded from the Database, since they can be easily audible even with the edge of the stethoscope on or off the chest wall of the patient.

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Table 1: Advantages and disadvantages recapitulation for the previous methods as compared to that of the proposed approach

	Murmurs Identification			
Methods	**Systolic**	**Diastolic**	**Murmurs Types Representation in Database**	**Outputs Screening**
The Direct Ratio	Possible but dependent of S1	Possible but dependent of S2	Murmurs of all types not required	At least 4 Systolic outputs + 4 Diastolic outputs
Wavelet processing	Possible but dependent of S1	Possible but dependent of S2	Murmurs of all types not required	At least 4 Systolic outputs + 4 Diastolic outputs
AKBNN	Possible	Possible	Murmurs of all types required	Only 1 Logical output 1 or 0
Novel Approach	Possible not dependent of S1	Possible not dependent of S2	Murmurs of all types not required	Only 1 Systolic output + 1 Diastolic output

Table 2: Early Time Decay T20 for the 3 cases

T20 (ms)	**Systolic**	**Diastolic**
Normal Heart	92	83
Aortic Stenosis	340	111
Mitral Stenosis	108	568

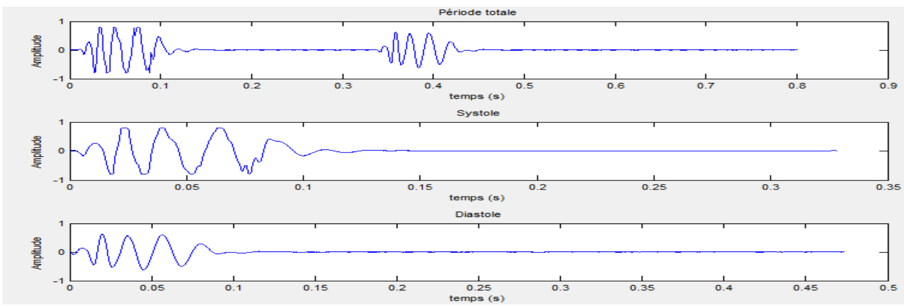

Figure 1: One signal period of the cardiac cycle corresponding to a normal heart

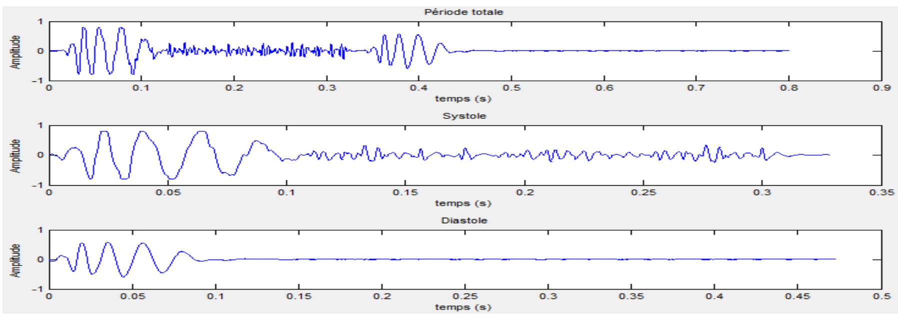

Figure 2: One signal period of the cardiac cycle corresponding to a pathological heart

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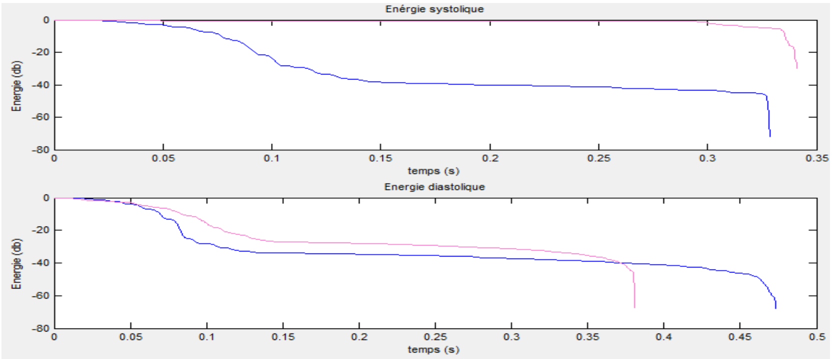

Figure 3: Normalized energy decaying curve for systole (up) and diastole (down) – Pathology Type: Aortic Stenosis (Red) as compared to Normal Heart (Blue)

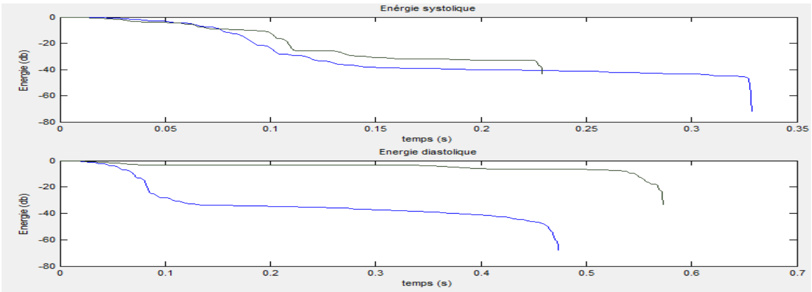

Figure 4: Normalized energy decaying curve for systole (up) and diastole (down) – Pathology Type: Mitral Stenosis (Green) as compared to Normal Heart (Blue)

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