Digital Personalized Health and Medicine
L.B. Pape-Haugaard et al. (Eds.)

Distinguishing Septal Heart Defects from the Valvular Regurgitation Using Intelligent Phonocardiography

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Abstract

This paper presents an original machine learning method for extracting diagnostic medical information from heart sound recordings. The method is proposed to be integrated with an intelligent phonocardiography in order to enhance diagnostic value of this technology. The method is tailored to diagnose children with heart septal defects, the pathological condition which can bring irreversible and sometimes fatal consequences to the children. The study includes 115 children referrals to an university hospital, consisting of 6 groups of the individuals: atrial septal defects (10), healthy children with innocent murmur (25), healthy children without any murmur (25), mitral regurgitation (15), tricuspid regurgitation (15), and ventricular septal defect (25). The method is trained to detect the atrial or ventricular septal defects versus the rest of the groups. Accuracy/sensitivity and the structural risk of the method is estimated to be 91.6%/88.4% and 9.89%, using the repeated random sub sampling and the A-Test method, respectively.

Keywords. Time growing neural network, Intelligent phonocardiography, A-Test method, septal heart defects, heart sound signal

1. Introduction

Since the last few decades when extracting medical information from heart sound has become a topic of study, several machine learning methods have been proposed for learning details of the heart sound signals for the classification purposes [1][2][3]. Although deep learning methods initiated a considerable change in the processing methods sophisticated for medical signals including heart sound signal [4][5], several research questions should be answered in terms of both the theoretical and the applicative contents. PhonoCardioGram (PCG) is a device for recording of mechanical activity of heart, as reflected by the heart sound. The term Intelligent PhonoCardioGraphy that has recently appeared in this contexts, implies on a computerised PCG supported by the intelligent machine learning

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methods to extract medical information from the signal [6][7][8]. Time Growing Neural Network (TGNN) has been introduced as a powerful learning method either for classifying cyclic time series [4], or for extracting medical information from the non-cyclic stochastic time series [5], in parallel to the hybrid methods [9][10][11]. Effectiveness of TGNN has been investigated for symptom detection of PCG signals, and also for screening a certain heart abnormality among other possible pathologies [11][12][5]. An important applicative aspect of IPCG is its potential in patient prioritisation in terms of the disease severity. For example, a valvular regurgitation in children is managed differently from septal leakage, as the former might not effect growth of the children, whereas the later which can effect growth of the patient.

This paper presents a method for diagnosing a group of paediatric patients with septal defect from the other group of valvular leakage, the two pathological conditions manifested by systolic murmur. Similarity of the disease manifestations in auscultation make the diagnosis a complicated task, which neccessiates expensive investigations even for those with mild defects. It is important to note that timely detection of septal defects can prevent further complications including pulmonary artery defect, ventricular hypertrophy and dilatation, pulmonary hypertension, and heart failure, each can put negative impact on the growth of the children suffering from, which is sometimes irreversible. The presented method employs TGNN for extracting medical information from a heart sound recording regarding the heart septal defects, showing an important application of medical informatics. The resulting technology can be easily incorporated into an IPCG to help practitioners or nurses at primary healthcare centres to detect and prioritise the patients for further investigation. The resulting IPCG can provide valuable medical information even for a paediatric cardiologist to be oriented in the echocardiographic investigation [13].

2. Material and Methods

2.1. Data Collection

Heart sound signals of 10 second duration were recorded from the children referrals to Tehran University of Medical Sciences, using a WelchAllyn Meditron Analyzer in conjunction with a portable computer with 44100 Hz of sampling frequency and 16 bit resolution. All the referrals or their legal guardians gave the informed consent for participation in the study, which was conducted according the Good Clinical Practice, and complied with the World Medical Association and Helsinki Declaration. The referrals were investigated by a paediatrician as well as paediatric cardiologist who used echocardiography as the gold standard along with complementary tests like chest X-Ray, in accordance to the guideline of Tehran University of Medical Sciences. Six groups of paediatric individuals were included in the study: healthy children with no audible murmur (NM), and with audible innocent murmur (IM), as well as abnormal children with Ventricular Septal Defect (VSD), Atrial Septal Defect (ASD), Mitral Regurgitation (MR) and Tricuspid Regurgitation (TR). The patient population is listed in Table 1.

Table 1. Study population.

Heart condition	Number of Patients	Age Range (years)	Average age ± SD (years)
ASD	10	5 − 15	9.3 ± 3.2
IM	25	2−14	6.7 ± 3.7
NM	25	4 − 15	8.6 ± 3.4
MR	15	4 − 18	11.8 ± 4.1
TR	15	6 − 18	12.6 ± 4.4
VSD	25	1 − 9	3.9 − 2.4

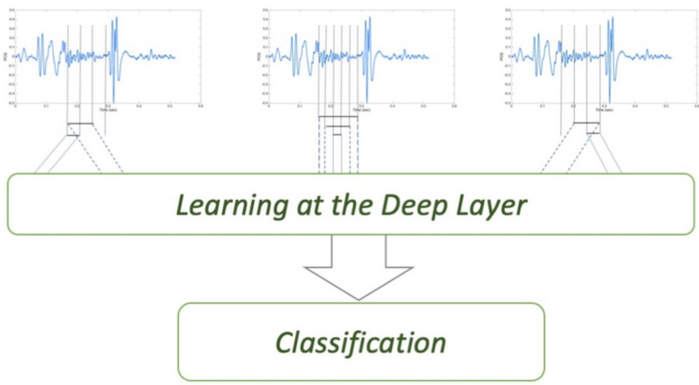

Figure 1. The flowchart of the learning method.

2.2. The processing algorithm

The signals are first down-sampled to 2 KHz using the antialiasing low-pass filter and then normalised. The processing method is based on our deep learning method, in which spectral contents of heart sound signal is calculated using three fashions of growing windows. In this technique, the systolic part of PCG signals are characterised by its spectral contents calculated over three different schemes of temporal windows: the forward, the backward and the mid-growing windows. Details of the growing method can be found in [4]. The number of the growing windows for each scheme is selected to be 3 based on the medical considerations. Figure 1 illustrates the growing time schemes. We used Fisher criteria for finding the most discriminative frequency bands for spectral calculation. This is performed at the deep learning layer in which the most discriminative frequency band is found for each temporal window, and the spectral energies are used by a three layer perceptron neural network with a hidden/output layer of 10/1 neurone for the ultimate learning process. The neural network is trained using back propagation error method in which the output layer performs the binary classification of septal defect against the rest of the classes .

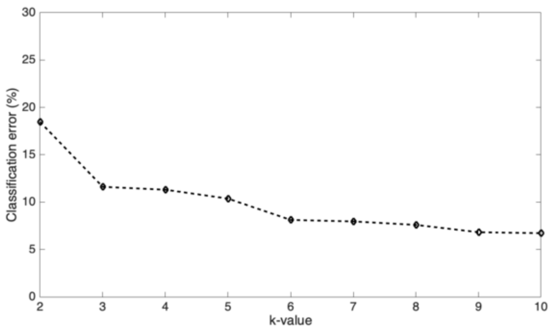

Figure 2. Results of the A-Test method for different index of *k*-value.

2.3. *The validation method*

The method is validated by using repeated random sub-sampling method as well as the A-Test for the structural risk evaluation. In the repeated random sub-sampling, 30% of data is randomly selected for testing and the rest for training the method, and the two performance measures, accuracy and sensitivity, are calculated, where the former is defined the percentage of the correctly classified samples whereas the later which is defined as the percentage of the correctly classified samples from the patient group (those patients with septal defect). This procedure is repeated several times and the statistical descriptive of the performance measures are found. The A-Test method is based on using K-fold validation method with different values of K, spanning from 2 to half of the minimum group size [4].

3. Results

The repeated random sub-sampling with 100 iterations was applied to validate performance of the method. Average of the accuracy and the sensitivity is estimated to be 88.4 and 91.6 with and standard deviation of ± 3.9 and ± 5.7, respectively. In order to evaluate structural risk of the method, the A-Test method is employed. The average classification error is estimated to be 9.89% using the A-Test method. Figure 2 shows results of the A-Test method, exhibiting a decreasing trend for the classification error, which implies on a good capacity of enhancement with larger training data. As can be seen, the method performance is by far better than a paediatric cardiologist who relies on the conventional auscultation, as the studies show the average screening accuracy is less than 80% [3].

4. Discussion

This study suggested a method for distinguishing two important cardiac abnormalities, the septal defects and valvular regurgitation. Ventricular septal defects must be diagnosed at the early ages, and the diagnosed patients should undergo appropriate disease managements, in contrast with the valvular regurgitation which are found at the later ages of the childhood. An important aspect of this study is the use of sophisticated time growing neural network for characterising heart sound signal, and hence extracting important medical information from the signals. This innovative method allows the IPCG to provide a more comprehensive information to practitioners or family doctors at primary healthcare centres, resulting in a more efficient patient prioritisation. This avails access to paediatric cardiologists to those of rather urgent need sooner than those of need to a regular supervision, and also improves automatic extraction of medical information from IPCG.

Acknowledgement

The authors would like to thank Prof. A. Kocharian for his valuable cooperation in data collection. This study was supported by the CAPIS Inc., Mons, Belgium, and also by the KKS financed research profile in embedded sensor systems for health at Mälardalen University, Västerås, Sweden.

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