A Machine Learning Method for Screening Children with Patent Ductus Arteriosus Using Intelligent Phonocardiography

Arash Gharehbaghi, Ankica Babic, and Amir A. Sepehri

1 Introduction

Intelligent phonocardiography as a non-invasive and inexpensive approach has been recently sounded for screening cardiac disease [1, 2]. Recent studies revealed that application of the intelligent phonocardiography is not limited only to screening pediatric heart disease, as it steps toward associating diagnostic value with the approach [3–5]. Importance of this approach is better realized when considering that a large number of the pediatric referrals to the hospital have normal hearts, while shortage of pediatric cardiologists causes long waiting time for the families which brings stress and costs to the healthcare system. On the other hand, there are still a considerable number of pediatric patients in the primary healthcare centers which are negatively misdiagnosed due to the complexities in cardiac auscultation as it is still employed for the screening purpose [6]. Patent ductus arteriosus (PDA) is a congenital disease caused by an abnormal blood flow between the two major arteries exiting the heart. Aortic and pulmonary artery are connected through a vessel, named ductus arteriosus before birth. Although ductus arteriosus plays an important role in fetal blood circulation, it should be naturally ceased within a few hours after the birth when the lung performs a normal respiration. Those children whose ductus arteriosus remains opened long after the birth are considered as suffering

A. Gharehbaghi (✉)
Department of Innovation, Design and Technology, Mälardalen University, Västerås, Sweden
e-mail: arash.ghareh.baghi@mdh.se

A. Babic
Department of Biomedical Engineering, Linköping University, Linköping, Sweden

Department of Information Science and Media Studies, University of Bergen, Bergen, Norway

A. A. Sepehri
CAPIS Biomedical Research and Development Centre, Mons, Belgium

P. R. M. Inácio et al. (eds.), *5th EAI International Conference on IoT Technologies for HealthCare*, EAI/Springer Innovations in Communication and Computing,
https://doi.org/10.1007/978-3-030-30335-8_7

from PDA. A child with untreated PDA can develop complications like pulmonary hypertension which may require heart or lung transplant in the long term. It is therefore of critical importance to screen children with PDA soon before developing serious complications when the disease progress can be controlled by an appropriate management. One of the manifestations of PDA is a continuous heart murmur heard in both the systole and the diastole. Auscultation of the murmur initiated by a PDA is a complicated task, especially for the unexperienced practitioners and nurses of primary healthcare centers. Studies on the intelligent phonocardiography toward murmur classification in children have been profoundly reported over decades [7–10]. However, this is not true for developing a sophisticated processing method for screening children with PDA from the heart sound signal. This paper presents a novel method for processing heart sound signals to detect PDA murmur. The method adjusts our internationally patented method (PCT/EP2009/051410), which we called the Arash-Band, in a way to include temporal characteristics of the signal. Results showed an acceptable performance for the classification comparing to the one for a practitioner which had been reported to be below 70%. The method exhibits low complexities in testing, offering the possibility to be used either as a decision support in the primary healthcare centers or as a distributed screening system on the web technology [11].

2 Materials and Methods

2.1 The Data Preparation

Heart sound signal and electrocardiogram (ECG) were recorded from 50 children, who referred to Children Medical Centre of Tehran University, Iran, using an electronic stethoscope of Meditron Analyzer in conjunction with a DELL laptop equipped with 16-bit sound card. The sampling rate was 44,100 Hz to have good recording/play back signal. Each recording had 10 s duration. All the referrals gave the informed consent for participating in the study. The study was conducted according to the Good Clinical Practice, and complied with World Medical Association and Declaration of Helsinki, and approved by the institutional committee of ethics. All the referrals were examined by a pediatric cardiologist who used echocardiography as the gold standard in companion with the ECG, chest X-ray, and other complementary tests. The patient population is listed in Table 1.

2.2 The Processing Method

The heart sound signals were downsampled using an anti-aliasing filter and segmented through which the first and the second heart sounds were carefully annotated

Table 1 The patient characteristics of the participating population

Total number of patients	50
Number of healthy individuals with no murmur	15
Number of healthy individuals with innocent murmur	15
Age range of the healthy individuals	4–15 years
Number of patients with patent ductus arteriosus	20
Age range of the patients with patent ductus arteriosus	0–5 years

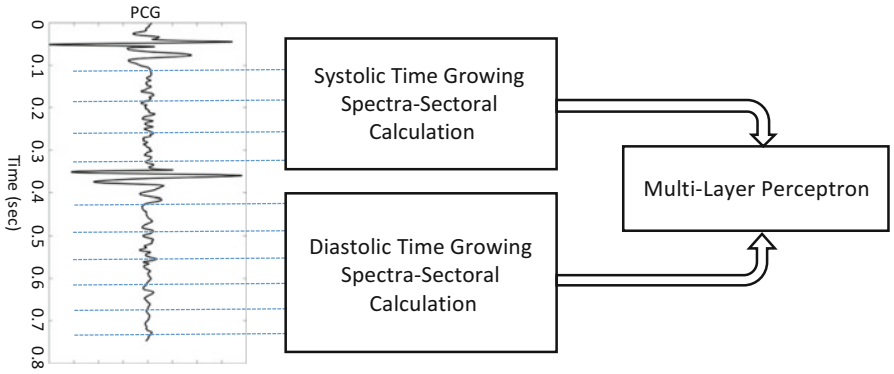

Fig. 1 An illustration of the innovative processing method. Details of the calculations can be found in [12]

according to the concurrence with the ECG peaks. The processing method is based on our original method, named Short Time Arash-Band, which relies on spectral calculation over two sets of the short sectors of the signal, one set for processing the systolic and the other set for the diastolic parts, independently. Then, the spectra-sectoral contents of the signal are calculated for the purpose of feature selection. Details of the spectra-sectoral calculations are found in [12]. Figure 1 illustrates the sectoral processing. A backward growing with three sectors and a forward growing with five sectors are empirically selected to analyze the systolic and diastolic parts of the signal, respectively. The spectral contents of the sectors are calculated using the priodogram. For each sector, a discriminative frequency band is found based on the Arash-Band method [12]. The calculated spectra-sectoral energies are employed by a multilayer perceptron neural network for the classification.

2.3 The Evaluation

Performance of the method is evaluated by using leave-one-out method. In this method, one single data is used for testing the method and the rest for training.

This procedure is repeated 50 times with each single recording used only once for testing. Then, the accuracy of the method is calculated as:

$$P_{ac} = 100\frac{N_{TP} + N_{TN}}{N_{TP} + N_{TN} + N_{FP} + N_{FN}} \quad (1)$$

where N_{TN} and N_{TP} are the number of the correctly classified individuals from the healthy and the PDA groups, respectively. The N_{FP} and N_{FN} are the number of the incorrectly classified individuals from the PDA and the healthy groups, respectively. The leave-one-out method is suitable when the data size is small, as is the case for this study.

3 Results

Figure 2 demonstrates samples of the healthy and PDA group. The healthy subject shows an innocent murmur, whereas for the PDA the murmur is of continuous one. The murmur intensity of the healthy subject is heard even higher than the PDA patient. This makes the differentiation problematic using both the conventional auscultation and the artificial intelligent-based methods.

Figure 3 demonstrates result of the leave-one-out method, applied to the 50 signals of our database.

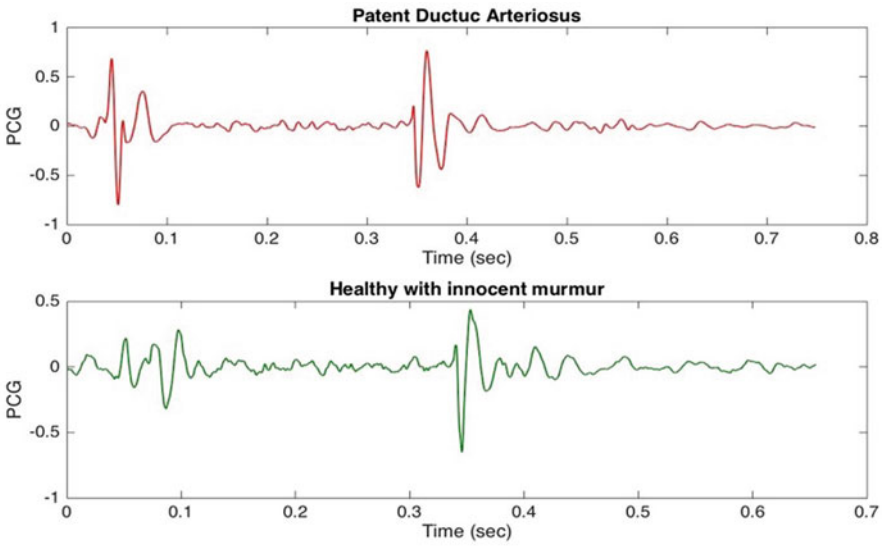

Fig. 2 A sample of the healthy subject (with innocent murmur) against another one with PDA, from our database

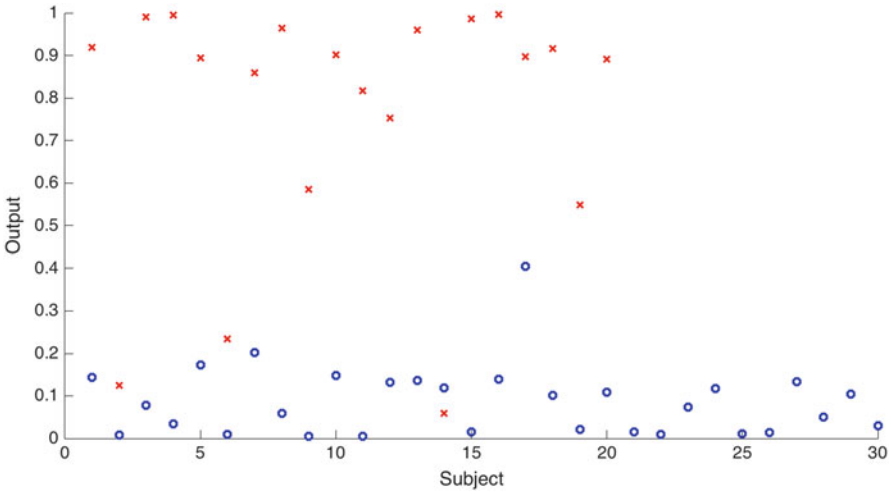

Fig. 3 Output of the method for the healthy children (blue **O**) and the children with patent ductus arteriosus (red **X**)

As can be seen, the two groups are acceptably segregated using the proposed method. However, there are three children with PDA which are misdiagnosed by the method, offering a sensitivity of 85%. All the three false negative patients are subjects of silent PDA, which can be considered as healthy individuals. Referring to the database, all the three patients have small PDA. On the other hand, there are four cases of healthy children which are classified as abnormal, because of the high intensity innocent murmur. These individuals mostly undergo echocardiography. The accuracy of the method is estimated to be 86% with a specificity of 87%.

4 Discussion

This paper suggested the intelligent phonocardiography as an automated approach for improving screening accuracy of the children with congenital heart disease in primary healthcare centers. The approach is easy-to-use, inexpensive, non-invasive, and quick that allows the practitioners and nurses to candidate proper patients to undergo echocardiography. The processing method proposed in this paper is based on the advanced deep learning method [12], but with an empirical modification toward more simplification for a quick learning. Although the advanced deep learning method shows minimal structural risk compared to a hybrid method [13], complexity of the presented method in this paper also is minimal in the both training and testing phase. The suggested method takes both the temporal and spectral contents of the heart sound into consideration such that an optimal classification is obtained. Application of artificial neural networks had been reported in a large

number of the studies on heart sound signal analysis, in which murmur classification was an objective [14–19]. However, development of a sophisticated deep learning method, with minimal complexities in detecting PDA children was not previously reported. One of the important characteristics of the presented method is the low structural risk and robustness against the test data [12]. Nevertheless, it is necessary for the method to be trained with a broader dataset by which overfitting is avoided and a better performance can be observed.

5 Conclusions

This paper presented an original machine learning method for detecting pathological heart murmurs resulted from patent ductus arteriosus (PDA) in children. The purposed method is a simplified extension of our deep learning method for classifying cyclic time series, with a considerably less complexities in the training phase. Results of the leave-one-out validation method exhibited an acceptable performance, outperforming a typical pediatrician who employs conventional auscultation. The method can be easily integrated with a portable computer to be used as an efficient decision support system in primary healthcare centers.

Acknowledgments 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.

Conflict of Interest The authors declare that they have no conflict of interest.

References

1. Gharehbaghi, A., Ekman, I., Ask, P., Nylander, E., Janerot-Sjöberg, B.: Assessment of aortic valve stenosis using intelligent phonocardiography. Int. J. Cardiol. **198**, 58–60 (2015)
2. Gharehbaghi, A., Dutoit, T., Sepehri, A.A., Kocharian, A., Lindén, M.: A novel method for screening children with isolated bicuspid aortic valve. Cardiovasc. Eng. Technol. **6**(4), 546–556 (2015)
3. Gharehbaghi, A., Ask, P., Nylander, E., Janerot-Sjöberg, B., Ekman, I., Lindén, M., Babic, A.: A hybrid model for diagnosing sever aortic stenosis in asymptomatic patients using phonocardiogram. In: World Congress on Medical Physics and Biomedical Engineering, Toronto, Canada, pp. 1006–1009. Springer, Cham (2015)
4. Gharehbaghi, A., Sepehri, A.A., Kocharian, A., Lindén, M.: An intelligent method for discrimination between aortic and pulmonary stenosis using phonocardiogram. In: World Congress on Medical Physics and Biomedical Engineering, Toronto, Canada, pp. 1010–1013. Springer, Cham (2015)
5. Gharehbaghi, A., Sepehri, A.A., Lindén, M., Babic, A.: Intelligent phonocardiography for screening ventricular septal defect using time growing neural network. In: Mantas, J., Hasman, G., Gallos, G. (eds.) Informatics Empowers Healthcare Transformation, pp. 108–111. IOS Press, Amsterdam (2017)

6. Watrous, R.L., Thompson, W.R., Ackerma, S.J.: The impact of computer-assisted auscultation on physician referrals of asymptomatic patients with heart murmurs. Clin. Cardiol. **31**(2), 79–83 (2008)
7. Akay, Y.M., Akay, M., Welkowitz, W., Semmlow, J.L., Kostis, J.B.: Noninvasive acoustical detection of coronary artery disease: a comparative study of signal processing methods. IEEE Trans. Biomed. Eng. **40**(6), 571–578 (1993)
8. Gharehbaghi, A., Sepehri, A.A., Lindén, M., Babic, A.: A hybrid machine learning method for detecting cardiac ejection murmurs. In: EMBEC & NBC 2017, pp. 787–790. Springer, Singapore (2017)
9. Gharehbaghi, A., Lindén, M., Babic, A.: A decision support system for cardiac disease diagnosis based on machine learning methods. In: Informatics for Health: Connected Citizen-Led Wellness and Population Health, pp. 235–238. IOS Press, Amsterdam (2017)
10. Welkowitz, W., Akay, M., Wang, J.Z., Semmlow, J., Kotis, J.: A model for distributed coronary artery flow with phonocardiography verification. Card. Electrophys. Circ. Transp. **121**, 261–272 (1991)
11. Gharehbaghi, A., Lindén, M.: An internet-based tool for pediatric cardiac disease diagnosis using intelligent phonocardiography. In: Internet of Things. IoT Infrastructures: Second International Summit, IoT 360°, Rome, Italy, pp. 443–447. Springer, Cham (2015)
12. Gharehbaghi, A., Lindén, M.: A deep machine learning method for classifying cyclic time series of biological signals using time-growing neural network. IEEE Trans. Neural Netw. Learn. Syst. **29**(9), 4102–4115 (2018)
13. Gharehbaghi, A., Babic, A.: Structural risk evaluation of a deep neural network and a Markov Model in extracting medical information from phonocardiography. Stud. Health Technol. Inform. **251**, 157–160 (2018)
14. DeGroff, C.G., et al.: Artificial neural network-based method of screening heart murmurs in children. Circulation. **103**, 2711–2716 (2001)
15. Sinha, R.K., et al.: Backpropagation artificial neural network classifier to detect changes in heart sound due to mitral valve regurgitation. J. Med. Syst. **31**, 205–209 (2007)
16. Ari, S., et al.: In search of an optimization technique for artificial neural network to classify abnormal heart sounds. Appl. Soft Comput. **9**, 330–340 (2009)
17. Dokure, Z., et al.: Heart sound classification using wavelet transform and incremental self-organizing map. Digit. Signal Process. **18**, 951–959 (2008)
18. Gharehbaghi, A., Babic, A., Sepehri, A.A.: Extraction of diagnostic information from phonocardiographic signal using time-growing neural network. In: World Congress on Medical Physics and Biomedical Engineering, pp. 849–853. Springer, Singapore (2019)
19. Sepehri, A.A., Kocharian, A., Janani, A., Gharehbaghi, A.: An intelligent phonocardiography for automated screening of pediatric heart diseases. J. Med. Syst. **40**, 16 (2016)