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Deep learning with 3D-second order difference plot on respiratory sounds

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ABSTRACT

The second order difference plot (SODP) is a nonlinear signal analysis method that visualizes two consecutive data points for many types of biomedical signals. The proposed method is based on analysing quantization of 3D-space which is originated using three consecutive data points in signal. The obtained 3D-SODP space was segmented into 3–10 spaces using octants, spheres and cuboid polyhedrons of which centroids are at the origin. Lung sound is an indispensable tool for respiratory and cardiac diseases. The study is focused on classifying the lung sounds from at risk level and the interior level of chronic obstructive pulmonary disease (COPD). The COPD is one of the most deadliest and common respiratory diseases which come into existence as a consequence of smoking. The smokers for a few years are qualified as at risk level of COPD (COPD-0). The 12 channels of lung sounds from the RespiratoryDatabase@TR were utilized in the analysis of the proposed 3D-SODP quantization method. The lung sounds are auscultated synchronously from posterior and anterior sides of subjects using two digital stethoscopes by a pulmonologist clinician in Antakya State Hospital, Turkey. Deep Belief Networks (DBN) algorithm was preferred in the classification stage. It has a greedy layer-wise pre-training which is based on restricted Boltzmann machines and optimizes the pre-trained weights using supervised iterations. The proposed DBN model had 2 hidden layers with 270 and 580 neurons, respectively. The conjunction usage of 3D-SODP quantization features with the DBN separated the lung sounds from different levels of COPD with high classification performance rates of 95.84%, 93.34% and 93.65% for accuracy, sensitivity and specificity, respectively. The results indicate that the 3D-SODP quantization on respiratory sounds has ability to diagnose the levels of the COPD using the deep learning model. Especially, the octant-based quantization is effective on lung sounds with high generalization capability using a small number of feature set dimension.

1. Introduction

The emergence on the modern computer-assisted medical science results with new surfaced, capable and detailed information about the diseases. Meanwhile traditional medical science focused on the medicine, pharmaceutical industry and the treatment processes, modern medical science gives paths for diagnostic systems, disease prevention, and wearable health services in recent years. Patient-based variability, symptoms, and physical examination variations reveal the needs on healthcare systems with respiratory sound analysis methods and signal processing techniques for stable and detailed analysis of both short-term and long-term respiratory sounds. The computer-assisted techniques reduce the dependence on specialists in the field. Extracting new specific features of the diseases and analysis methods are in the development list of the researching groups to assess the perceived impact of healthcare systems. The biomedical signals such as electrocardiography (ECG) for cardiac diseases [1], electroencephalography(EEG) for neurological disorder [2,3], lung sounds for respiratory diseases [4,5] are the basis of the computer-assisted systems with the applicability capability of the digital signal analyzing algorithms and data acquisition using various sensors. Robust decision support functions, improvable modular quality, alerting physicians for abnormalities, detailed monitoring of the patients and detecting capability of the healthcare systems enable the diagnosis and the early diagnosis of the known diseases and the relationship for more diseases.

People have increasingly exposed to advanced new forms of known diseases with harmful aspects. The inability to upgrade treatment methods is an indication that the medicine science is

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not able to treat and prevent the reconditioned diseases as new forms. In the light of the World Health Organization reports in 2017, respiratory diseases are placed at the first rows on the most deadliest diseases list [6,7]. The most common respiratory diseases are asthma, chronic obstructive pulmonary disease (COPD) and lower respiratory infections. Respiratory diseases are caused by environmental factors such as pollutions, seasonal changes, infections, genetic factors, human-induced factors such as tobacco use, age and occupational factors. The respiratory diseases have curable and chronic levels for reaching healthy society, but the COPD has no cure to overcome the symptoms. It is a chronic process that can only be prevented and kept under control for avoiding interior severities. The early diagnosis of the COPD is a necessary and essential progress for providing healthy society, improvement of living conditions, and preventing respiratory-related deaths [8–10]. The most studies stand out relief by enabling the separation of COPD patients using clinical data including heart rate variability, blood pressure respiration spectra data, age, sex, hemoglobin, hematocrit, spirometric measurements, and disease history [11–18].

Respiratory sounds are the auscultated noninvasive characteristic sounds which are generated by the circulation of the breath through the airways and other respiratory system during the inspirium and exhalation. The respiratory sounds include adventitious forms and audible forms that are not easy to hear without medical tools. Even today, the respiratory sound auscultation is an invaluable clinical tool, is still most common, the most accurate and indispensable diagnostic tool for most of the pulmonologist clinicians. Auscultation of the lungs from various areas builds a foresight for diagnosis and deciding the level of the disorders. Regardless the simplicity of the auscultation, the thriving diagnosis of the chronic respiratory diseases needs expert skills and long-time experiences. Despite the limited number of researches on computerized diagnosis of the COPD using the auscultation sounds, there are many studies on detecting wheeze sounds that are adventitious pathological sounds heard from patients with the COPD and asthma [19,20]. The literature has focused on wheeze detection rather than diagnosis and analyzing of the COPD and the COPD stages. Naves et al. provided separating crackle and wheeze sounds which were recorded from 36 subjects using electronic stethoscope by utilizing combination of higher order statistics such as second-, third- and fourth-order cumulants and genetic algorithms [21]. Fernandez-Granero et al. proposed an early detecting model of COPD exacerbations using machine learning with an accuracy rate of 75.80% for exacerbation episode. They monitored 16 subjects using respiratory sounds for 6 months [22]. Oweis et al. allowed discrimination of different adventitious respiratory sounds that were recorded from 28 patients using electronic microphone over chest [23]. Kanwade and Bairagi focused on electromyographic signals during inhalation and exhalation process instead of respiratory sounds. They proposed a diagnosis COPD model using non-fiducial features from electromyographic signals and achieved classification performance rates of 85%, 88%, and 80% for accuracy, sensitivity, and specificity, respectively [24]. To the best of our knowledge, there is no significant study that has examined the evolution process of the diagnosis models on the COPD and the COPD severity classification using computerized lung sounds. Using computerized lung sounds in the diagnosis of the COPD and realizing the early management of the COPD at the risk level by classifying the subjects with incipient smokers (COPD-0) are the violent necessities for preventing the prevalence of the COPD complaints to reach such serious levels.

Spectrograms, harmonics, time-frequency distributions, time-domain waveforms, mel-frequency cepstral coefficients spectrograms and Hilbert spectral analysis are the most basic and common methods that generate visualization on time series. The second order difference plot (SODP) is an alternative data visualization method that is inspired by the Chaos Theory for many biomedical signals including EEG [3] and ECG [25,26]. The SOPD has an elliptical form distribution as seen in Fig. 2. The horizontal radius (*SD1*) and vertical radius (*SD2*) of the elliptical area were used as features and additional features in the researches [3,25,27]. The various methods evaluated shape base quantization by counting the number of data points within the geometric shapes such as central tendency method (CTM) which divides the SODP into circular regions with radius *r* [25], component CTM which divides the SODP into regions with radius *r* and features each of the divided quadrants [25], segmented plot analysis which divides the plot into square regions [28] and rectangle regions with logarithmically increasing metrics [26].

The aim of this study is proposing a novel method for feature extraction and data visualization on respiratory sound. The experiments were performed using various quantization on lung sounds for classification of COPD-0 stage (the incipient smokers who are at risk for COPD) and very severe COPD (COPD-4) stages. On the other hand, it has also the distinction of being a first-ever approach for separating the quite similar wheeze sounds from smokers and COPD patients. Incorporation of the COPD0 level into the analyzing processes and the determination of the differences between COPD0 and COPD4 have great importance for the definitive early diagnosis of the COPD in the developments of medicine. The COPD-0 is one of the most difficult-to diagnose stage in which patients have normal spirometric measurements and none of chronic symptoms. The lung sounds with the COPD have very similar auditory wheeze as the respiratory sounds of smokers. The common characteristics of the lung sounds give rise to wrong diagnosis for even experienced pulmonologist specialists during the auscultation assessment, if they do not use additional diagnostic tools. Diagnosing the COPD-0 stage has a great importance due to stopping the progress of the disability and has the possibility on facilitation of management for the probable patient at the COPD risk level. We proposed SODP-based auscultation sound visualization method and the various quantization methods on the SODP for significant characteristics on respiratory sounds. The proposed SODP method is a non-linear technique that evaluates the correlation between consecutive data points in three dimensional space using chaos theory.

The remaining of this paper is organized as follows; the auscultation sound database, preprocessing of the respiratory sounds, the SODP as a feature extraction method, quantization techniques on the SODP, the proposed three dimensional SODP (3D-SODP), and Deep Belief Networks (DBN) classifier are spelled out in Section 2. The experimental setup for the diagnosis model of the COPD stages, the empirical DBN iterations and the proposed DBN structure for classification of the respiratory sounds, and the achievements are expounded in Section 3. The efficiency of the quantization methods of the 3D-SODP on respiratory sounds, superior and limited aspects of the system is discussed in Section 4.

2. Materials and methods

In this section, auscultation sounds acquisition scenarios, preprocessing, indication of selected regions for auscultation and the characteristics of these regions, the proposed non-linear analysis 3D-SODP for feature extraction, and the DBN classifier algorithm are explained in detail.

2.1. Database

The respiratory lung sounds are non-stationary and stochastic signals which are still one of the cheapest diagnostics tools for respiratory and cardio-respiratory diseases. The lung sounds characterize specific and adventitious information,