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Analysis of Lung and Heart Sound using Smartphone Stethoscope

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Abstract:

Korea and the world population are suffering from heart and lung disease due to aging. There are only few objective data regarding to bronchial or lung sounds. Therefore, it is necessary to normalize the data for breathing sounds objectively. In this paper, we analyze lung data using algorithm PCA(Principal Component Analysis) and AVRLCR(Average Level Crossing Rate) and then present an objective data about asthma and pneumonia. The peak frequency of the spectrum indicates the type of disease, and the AVRLCR value represents an indicator for determining the type of disease. And based on the period of the waveform, the waveform is displayed by autocorrelation and the pulse rate is displayed in real time.

Keywords: *Heart and lung disease, PCA(Principal Component Analysis), AVRLCR(Average Level Crossing Rate), Autocorrelation, Pulse rate*

I. INTRODUCTION

There are many subjective opinions of doctors in diagnosing heart and pulmonary disease with a stethoscope. However, the smart stethoscope proposed here displays heart and pulmonary disease as waveforms and spectrograms to provide objective diagnosis.

The use of auscultation in pulmonary medicine is not accurate, but the quantitative analysis of respiratory sound is needed. [1,2] At the same time, lung sound has sonant to differ according to circumstance in despite of same patients. This paper is to classify normal conditions and abnormal (pneumonia, etc.) symptoms. Diagnosis was made using the smart stethoscope and characteristics of diseases was confirmed by PCA and AVRLCR algorithm.

II. Principal Component Analysis & AVRLCR

Analysis and algorithm

In lung sound processing, PCA has been widely used for signal processing such as dimensionality reduction, data compression, and feature extraction. PCA is very important for extracting the optimal linear method as a figure of merit.

Kernel PCA equations are by Schőlkopf[3] [4][5].

Given a set of M, $x_i \in R$ (i=1, 2, . . . , M).

We consider a nonlinear mapping, Φ, to feature space F.

$$\Phi : R \rightarrow F, x \rightarrow \Phi(x) \qquad (1)$$

In dot products of the form($\Phi(x_i) \cdot \Phi(x_j)$), we define kernel function K,

$$K(x_i, x_j) = \Phi(x_i) \cdot \Phi(x_j) \quad (2)$$

For compute the value of the dot product in F without having to carry out the map Φ.

Defining an M x M matrix K by $K_{ij} = K(x_i, x_j)$, we need to diagonalize K to obtain eigenvalue, λ, and eigenvector, α, in F.

$$M\lambda\alpha = K\alpha \quad (3)$$

$\lambda_1 \leq \lambda_2 \leq \cdots \leq \lambda_M$denote eigenvalues, and α^n the corresponding complete set of eigenvectors which have elements of $\alpha_1^n, \alpha_1^n, \cdots, \alpha_{M1}^n$. We normalize α^n as

$$I = \lambda_k(\alpha^n \cdot \alpha^n) \text{ for all k=1, ..., M} \quad (4)$$

Let x represent a test point, n-th kernel principal components are

$$\alpha_i^n \cdot K(x_i, x_j) \quad (5)$$

Kernel function is often used as follows:

1. Polynomial kernel

$$K(x_i, x_j) = (x_i \cdot x_i + r)^d \quad (6)$$

2. Gaussian kernel

$$K(x_i, x_j) = \exp[-c\, |x_i - x_j|^2] \quad (7)$$

Here, d, r, and c are parameters [6].

Next, LCR and AVRLCR are explained in detail. The LCR algorithm has been used widely to check the spectral correlation of the lung sound. In particular, it has been used as a very useful parameter for the processing of lung sound.

One pitch period of the thoracic waveform is used as a unit of speech synthesis. A convenient and simple algorithm for analysis of one pitch period of a waveform is the level crossing rate. And one pitch period of the thoracic sound waveform is signaled and stored in the table of a digital distance sequence of the LCR. Therefore, level crossing rate is as follows.

$$L_n = \sum_{m=0}^{N-1} |sgn[x(n-m) - L_{th}] - sgn[x(n-m-1) - L_{th}]| \quad (8)$$

And AVRLCR is

$$AVRLCR = \sum_{m=0}^{N-1} [L(n)/\, length] \quad (9)$$

It needs elements to represent the transitional parts for length. The transition element for the signal is constituted by a major combination of the first and second formants. On average, the major elements of the first and second formants can be marked as LCR. The interval of the sequence is quantized to 12 bit digital.

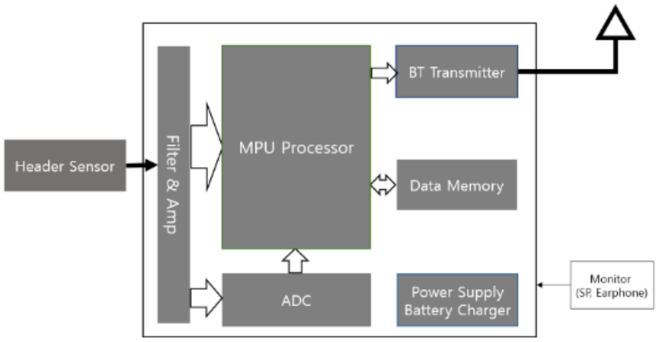

Fig. 1. Block-diagram of Pneumonia Data Extraction System

A block diagram of the pneumonia data extraction system is shown in Fig.1. The sounds of the chest are obtained by air-coupled microphones (Header sensor). The signal input to the sensor is sent to the preamplifier and the high gain amplifier, and is then sent to a low pass filter (third order 1000Hz) and extractor circuit to extract the characteristics of the pneumonia. Pneumonia feature consists of limited op amplifier, relative detector circuit and S/H amplifier. Peak value of pneumonia means the maximum amplitude value of sample period. The peak value of amplitude is sent in sample and holder, where the peak value is set to zero. The digital clock generates the clock so that the control signals required for the sequence are made smoothly. Data is collected through a smart phone with a data collection board(SMT_5000). This board has an analog input that can sample resolution 12bit. In addition, there is an I/O ports for inputting and outputting data. And this port controls clock frequency and the gain of the amplifiers. The digitized signal is transferred to memory through the I2C port and finally stored on the hard disk [7,8,9,10,11].

In order to calculate the energy due to the level crossing rate, the following method was used. First,

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an audio analyzer was used to calibrate the header sensor independently of the system. The average sensitivity of the header sensor(microphone) is 12 mV/Pa. The cutoff frequency is set from 20 to 1500Hz. Input sinusoidal signal of header sensor was input as 1mV and gain level value of each system is converted to A/D to save and calibrate the value. By linear feedback of these values, the transfer function is estimated. The microphone sensitivity and input feedback constants are stored in memory. Lung sound data coming into the sequence is calculated with the average LCR computed from the constants of its inputs.

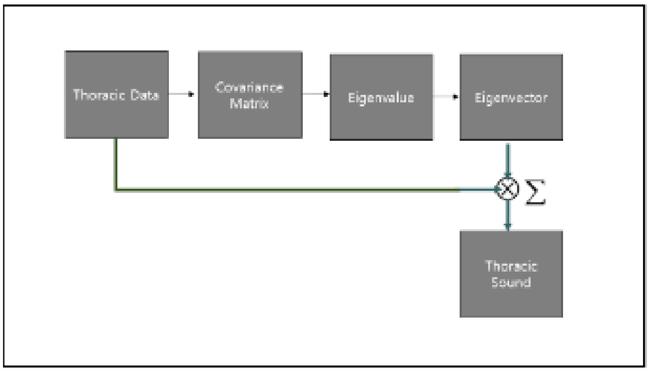

Fig. 2. Flowchart of PCA algorithm

Results and Discussion

Thoracic sound data has been collected to use analysis software by making visual C++. The process puts a Hamming window on the chest data(thoracic sounds) and applies the LCR algorithm to it to extract the data. The data was used in the following sequence.

Fig. 7 shows the data extraction process diagram.

10 records were taken for each disease with 1 minute acquisition time at 5 positions (left, right, center of lung and left and right below the back) and a sampling rate of 2KHz per input at Jesus Hospital in Jeonju city. In this paper, the number of numerical data samples of a lung sounds are 34000 and training set per disease is 10. And block diagram of PCA algorithm is shown in Fig.2.

Fig.3 shows normalization data of 10 thoracic sound sets by each asthma patient. Row axis is sampling number and column axis is the amplitude of sampling. At the same time, Fig.4 shows original data of 5 thoracic sound sets by each asthma patient. First picture includes the most common element of each thoracic trouble data in Fig.4. And the 10th data preserved the smallest common element in Fig.4. For the same principal, first picture includes the most common element of each disease.

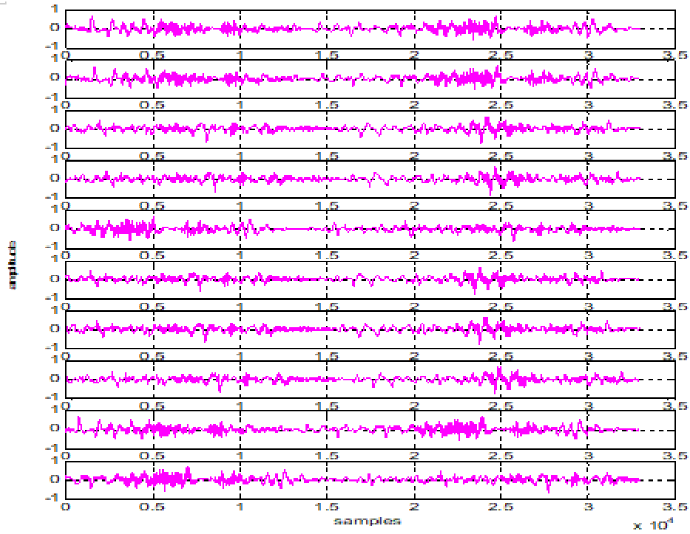

Fig. 3. Thoracic Sound Sets of Asthma Patient

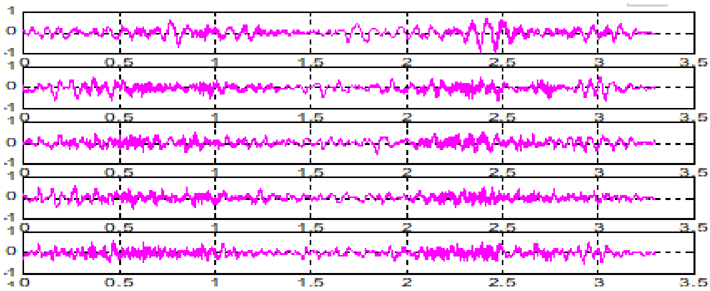

Fig. 4. Original Thoracic Sound of Asthma Patient

To obtain first vector value of PCA, we applied a simulation through software program. As a result, the original thoracic sound vector values are shown in Table 1.

Table 1. Implemented Code of Blood Pressure

	Asthma	Pneumonia	Bronchitis
Thoracic Sound Space Vector Values	-0.0787	-0.0654	0.0937
	-0.0355	0.1639	0.0570
	0.5239	0.1310	0.0298
	-0.3830	-0.5752	0.0240
	0.0023	-0.0257	-0.4490
	-0.4130	-0.2570	-0.1525
	0.4845	-0.0469	-0.1973

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	0.3854	-0.5677	-0.5966
	-0.0582	-0.5431	-0.6011
	0.1194	0.0020	0.0449

Fig.5 shows comparison of LCR and AVRLCR for each disease. Furthermore, Fig.6 shows obvious difference in AVRLCR for detecting each disease.

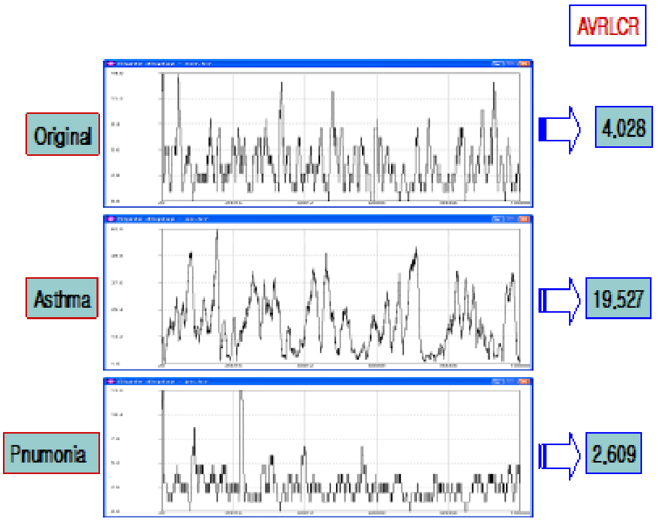

Fig. 5. Comparison of LCR and AVRLCR for each disease

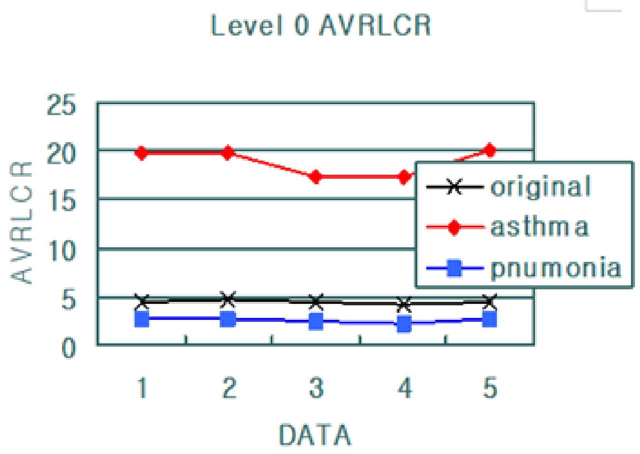

Fig. 6. Comparison of AVRLCR for each disease

Fig. 7. Data Extraction Process

Display and Pulse rate

The autocorrelation function (10) was used to calculate and display the waveforms and pulse rates of the stethoscope sounds (such as heart sounds and thoracic sounds). And a firmware program was applied to accurately display the waveform on the time domain. The autocorrelation function (1) was used to calculate the absolute value which is the positive value. The program accurately displays the period of the waveform in the time domain and calculates the heart rate by calculating the period. Fig. 8 shows the pulse rate (Heart rate) and waveform in real time.

$$R_{ff}(\tau) \triangleq \int_{t_0}^{t_0+T} f(t+\tau)\overline{f(t)}dt \qquad (10)$$

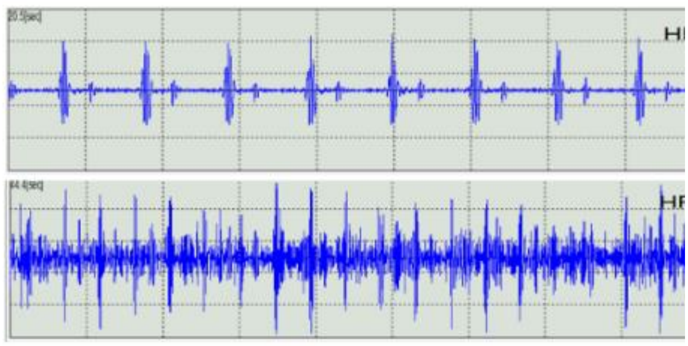

Fig. 8. Heart rate(HR) and waveform

Results

In the experiment for lung sounds, the structure of hardware system and design through programming are introduced. In this paper, we propose characteristic lung sounds using PCA and AVRLCR for objective data of lung sounds.

Fig.5 and Fig.6 are shown various data for each disease which are detected as the useful lung sound data in diagnosis.

Respiratory physicians evaluated the detected lung sound data and we have attained results of a feature that can determine the disease.

Given the above results, it is necessary to study for more accurate software algorithm of lung sound.

Also, in order to solve a reliable lung sound algorithm, a reference DB must be built and hardware must be reinforced. We are trying to analyze the constraints of the hardware and various distortions.

In addition, we have introduced a system that can easily diagnose person’s heart and lung disease anytime, anywhere, using a smartphone stethoscope without limitation of place and time.

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