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An improved simplicity-based approach for heart sound analysis

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ABSTRACT

Segmentation is the preliminary step towards computer-aided automatic heart disorder diagnosis. In the literature, most heart sound segmentation algorithms depend on energy or time-frequency characterization of the signal. However, the property of varying amplitudes and frequency characteristics from one cycle to another makes it difficult to detect major heart sound components.Recently a new measure, simplicity, which is robust against amplitude variation, has been proposed for heart sound analysis. In this paper, we investigate the influence of the parameter values such as window length and embedding dimension on the simplicity profile by using sinusoids and white noise as analyzed signals. Then we conclude suitable parameter values and proper amount of zero-mean white noise added to the PCG for improving simplicity-based heart sound analysis. As shown by experiments, we conclude that for 8000Hz sampled and amplitude normalized PCG signal, window length with 40~50 samples and embedding dimension with 8~10, noise addition weight factor with 0.01~0.03 would be reasonable choice for better simplicity-based heart sound analysis.

1. INTRODUCTION

Segmentation of a phonocardiogram (PCG) by detecting its major components S1 and S2 is generally the first step in the heart sound analysis for automated diagnosis of heart disorders. Many algorithms for heart sound segmentation have been reported so far, but most of them are based on the energy or time-frequency characterization of the signal [1-4], the performance of which are largely affected by the non-stationary property of heart sounds. Recently, under the assumption that the human heart acts like a hidden dynamic system that undergoes state transitions to generate various heart sounds, a new measure, namely, simplicity, showing large amplitude in the regions where the major components of the PCG occur, has been proposed [5,6]. The advantage of the simplicity measure is that it is robust to amplitude variation of the heart sound. So it seems very promising to detect S1 and S2 components of the heart sound. But we observed that the simplicity measure does not give satisfactory results when either filtering or wavelet transform is applied to the PCG for further processing. That's because the complexity of the background noise decreases due to kind of lowpass filtering to make the simplicity floor very high. To discriminate background noise regions from S1 and S2 regions with simplicity, it is necessary to add some amount of zero mean white noise to the PCG to lower the simplicity of the background noise regions in the PCG. This kind of problem has been stated in [5] but has not been addressed in detail anywhere.

The simplicity is also influenced by the size of window length and embedding dimension for a given signal. In this paper, we have investigated the influence of the parameter values used in the simplicity analysis such as window length and embedding dimension with sinusoids and white noise. Then we suggest appropriate amount of zero mean white noise addition to the PCG for improved simplicity-based heart sound analysis. Experimental results are presented with our discussions.

This paper is organized as follows. In section 2, we will give a brief explanation about how to get the simplicity of a given signal. Then various simplicity results for sinusoids and white noise will be shown with discussions. Finally, we conclude in section 4.

2. COMPUTATION OF SIMPLICITY

The simplicity is calculated on the frame basis. First get the N data samples as an analysis frame. It is called a window length here. Then construct a subframe whose length is m over the frame. Here m is called an embedding dimension. We can construct $p=(N-m+1)$ subframes by shifting sample-by-sample. These subframes construct a data matrix X to compute the simplicity. The procedure to compute the simplicity can be summarized as follows [3].

① Construct a data matrix X for a given PCG

② Generate a covariance matrix C with eq.(1), where X^T represents the transpose of X and p is for normalization.

$$C = X^T X / p \tag{1}$$

③ Obtain a diagonal matrix D whose elements are eigenvalues of C sorted in descending order. Then get the normalized eigenvalue $\hat{\lambda}_j$ with eq.(2).

$$D = diag(\lambda_1, \lambda_2, ..., \lambda_m)\ ,\ \lambda_1 \geq \lambda_2 ... \geq \lambda_m$$

$$\hat{\lambda}_j = \frac{\lambda_j}{\sum_{k=1}^{m} \hat{\lambda}_k}\ ,\ j = 1, 2, ..., m \qquad (2)$$

④ Calculate the entropy measure and complexity with eq.(3) and eq.(4).

$$H = -\sum_{k=1}^{m} \hat{\lambda}_k \log_2 \hat{\lambda}_k \qquad (3)$$

$$\Omega = 2^H \qquad (4)$$

⑤ The simplicity is defined by eq.(5).

$$\text{simplicity} = \frac{1}{\Omega} \qquad (5)$$

⑥ Shift the analysing window by one sample and repeat ①~ ⑤ steps for the given data.

3. EXPERIMENTS

We have investigated the effect of parameters, i.e., window length N and embedding dimension m, on the simplicity of a sinusoidal signal and zero mean white noise. Considering moderate frequency components of S1 and S2 sounds to high frequency murmurs of the PCG, we choose the frequency of a sinusoid from 100Hz to 500Hz with 100Hz increment. For given values of N and m, the sampling frequency of a signal also affects the simplicity value, but we set the sampling frequency to 8000Hz as used in [5].

3.1 Simplicity values depending upon (N, m)

Using the procedure given in section 2, we calculated maximum, minimum and mean values of the simplicity of a sinusoid with unit amplitude and zero mean white noise with unit variance depending upon (N, m). Fig. 1 shows the variation of max/min/mean simplicity of the 100Hz sinusoidal signal and white noise with varying m for fixed window length. The window length was set to three cases; greater, equal, and less than the period of the signal, i.e., 120, 80, and 40 samples, respectively. It is shown that the simplicity of the white noise decreases sharply regardless of the window length while that of the sinusoid decreases gradually as the window length gets shorter. The mean simplicity of the white noise becomes about less than 0.1 when embedding dimension m is greater than 10. As N becomes smaller than the period of the signal, the simplicity becomes high and deviation between maximum and minimum simplicity becomes wider with increase of m / N.

Fig. 2 and Fig. 3 show the variation of max/min/mean simplicity of 200Hz and 500Hz sinusoids, respectively, with white noise for $N = 40$. It can be observed that as the frequency of the sinusoid increases, in other words, when the window length gets longer than the period of the signal, the simplicity value with small m decreases sharply and converges to 0.5 as m increases. When the embedding dimension is very small, it sees only small part of the signal to calculate the simplicity. So the simplicity may have high value even though the window length is smaller than the period of the signal. But as the embedding dimension increases, since the analysis frame includes more than one period of the signal, variation of the signal is reflected in the simplicity to increase the complexity, and the simplicity become about 0.5.

Fig 4 shows the variation of max/min/mean simplicity of the 100Hz sinusoid and white noise with varying N for fixed embedding dimension m =10, 6, 2. It is shown that though we can get high simplicity of a sinusoid by decreasing m, mean simplicity of the white noise also increases. Considering Fig.1 ~ Fig.4, N = 40 ~ 50 and m = 8 ~ 10 seems to be suitable choice for the simplicity analysis of the PCG with sampling frequency of 8000Hz.

3.2 Effect of adding noise on the simplicity

Fig. 5 shows the variation of max/min simplicity of the sinusoids depending upon the amount of white noise addition, where α denotes the weight of the white noise with unit variance. We set the (N, m) to (50, 10). We can see that the simplicity value decreases when the frequency of the sinusoid increases as expected. It is shown that if the additive noise increases the maximum simplicity decreases gradually while minimum simplicity value decreases rapidly to converge to be less than 0.2. We found that when α is smaller than about 0.03 it only attenuates less than 1% of the original maximum simplicity. The 300Hz and 400Hz sinusoids have shown similar results to that of 500Hz.

3.3 Results with real PCG data

The PCG signal was first normalized with its absolute maximum value, and then zero mean Gaussian white noise was added as given in eq.(6).

$$x(n) = s(n) + \alpha w(n) \qquad (6)$$

Where $s(n)$ denotes a normalized PCG, $x(n)$ is a noise added PCG, and $w(n)$ is zero mean white Gaussian noise, α is a weight factor. Fig. 6 shows examples of simplicity profile of the noise added heart sound signals when α = 0.001, 0.01, 0.02, 0.05, respectively. We can observe that discrimination with simplicity between major components of the heart sound and the background noise of the PCG is improved greatly by adding appropriate amount of noise to the PCG. Since the beginning and end portions of the S1, S2 components have relatively small amplitude, addition of noise affects much more to them and make the simplicity value low. But it only reduces the interval of time gating of the S1 and S2 components slightly. Considering that too little addition of noise does not lower the simplicity floor enough as shown in the figure as well as addition of too much noise lowers the overall simplicity value, α = 0.01 ~ 0.03 seems suitable choice for simplicity-based heart sound analysis.

4. CONCLUSION & DISCUSSION

Simplicity-based heart sound segmentation algorithm has proved to be superior to energy and time-frequency-based methods by virture of its independence of absolute amplitudes and frequency variations of heart sounds. However, the issure on how the two important factors, namely, parameter values of analysis window and embedding dimension, play their individual role on the shape of simplicity profile remains un-addressed. In this paper, we firstly investigate the influence of above two factors on the simplicity curve by using sinusoids and white noise as analyzed signals under various cases to try to provide quantitatively constructive suggestions on the reasonable options of these factor values. Furthermore, taking into account that a certain amount of white noise addition to PCG can suppress significantly the simplicity floor of background noise, we also perform comparative experiments according to different options of the added white noise weight factor value. By combination, we conclude that for an amplitude normalized PCG signal sampled at 8KHz, window length with 40~50 samples and embedding dimension with 8~10, noise addition weight factor with 0.01~0.03 would be reasonable choice for improving simplicity-based heart sound analysis.

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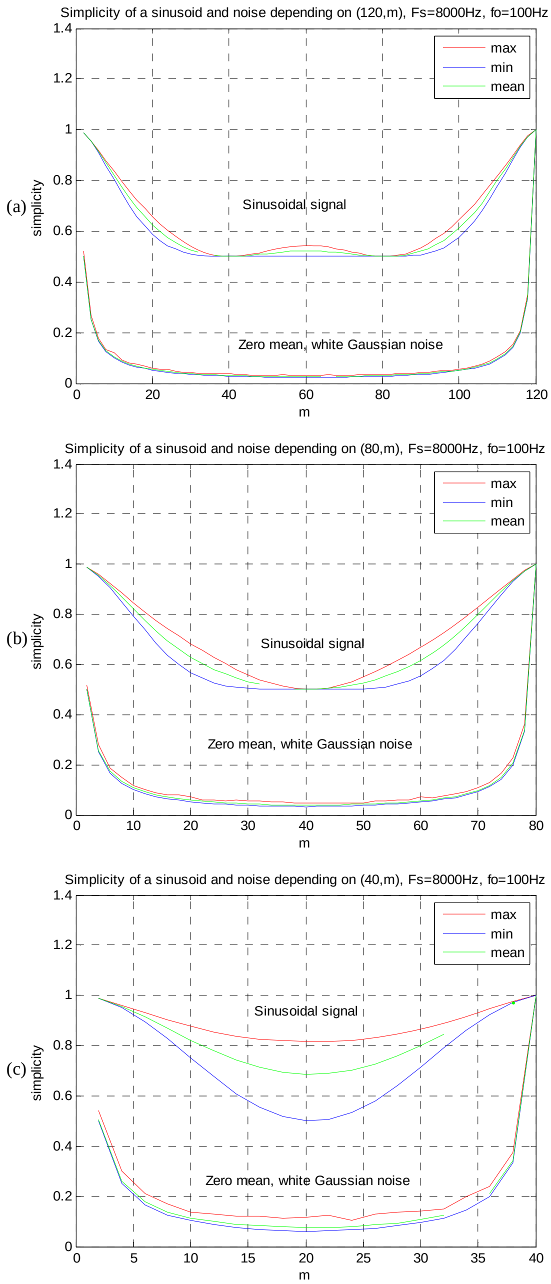

Figure 1. Simplicity of a 100Hz sinusoid and zero mean white noise depending upon m (a) N =120, (b) N =80, (c) N =40

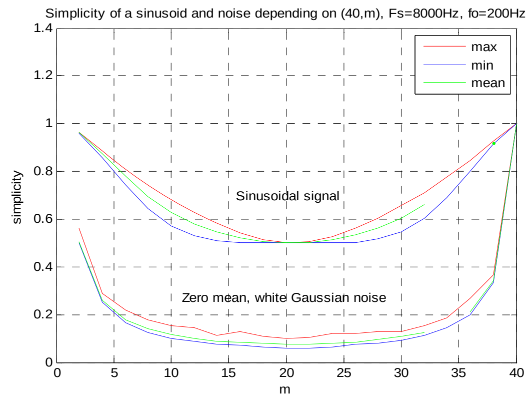

Figure 2. Simplicity of a 200Hz sinusoid and zero mean white noise depending upon m

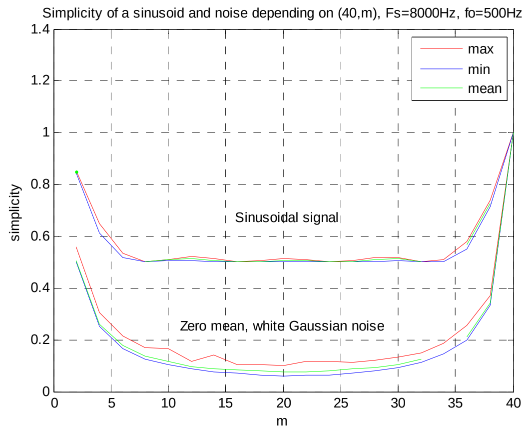

Figure 3. Simplicity of a 500Hz sinusoid and zero mean white noise depending upon m

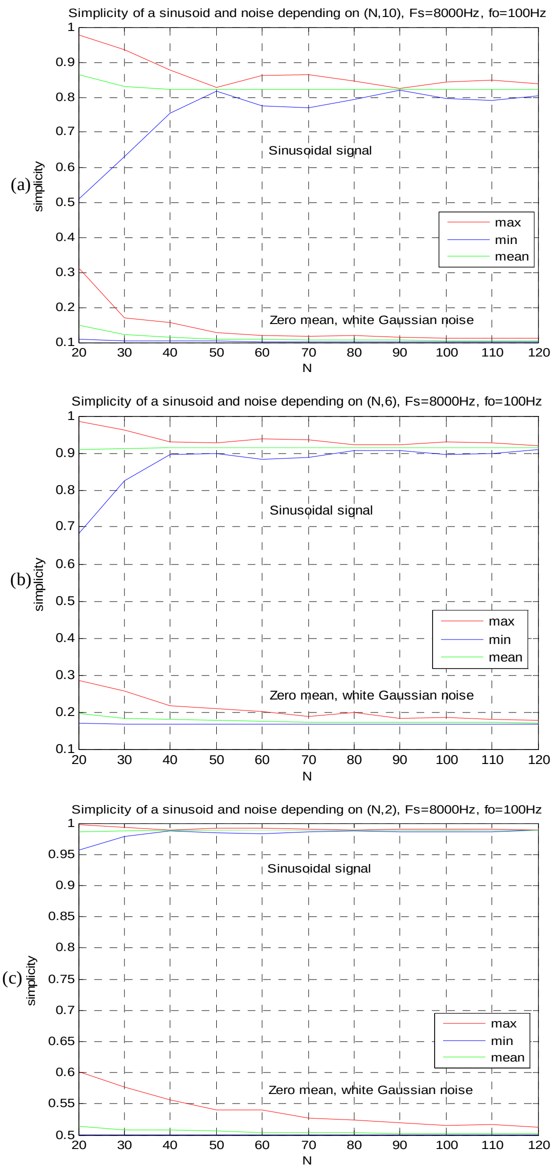

Figure 4. Simplicity of a 100Hz sinusoid and zero mean white noise depending upon N (a) m =10, (b) m =6, (c) m =2

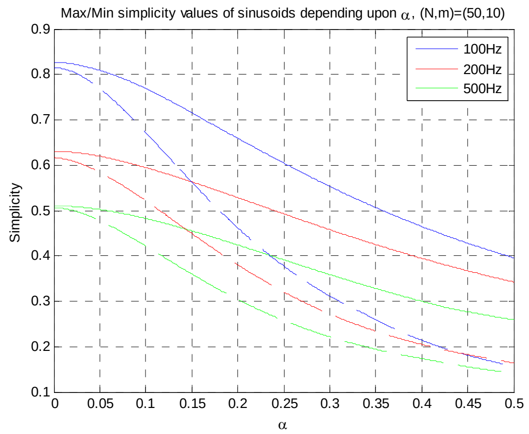

Figure 5. Maximum and minimum simplicity of sinusoids depending upon α

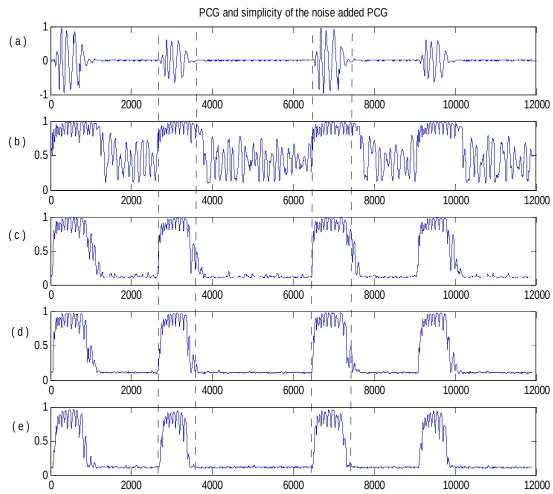

Figure 6. PCG and simplicity profile of the noise added PCG (a) Normal PCG, (b) simplicity with α =0.001, (c) α =0.01, (d) α =0.02, (e) α =0.05