Filtering Performance of Reducing the Sampling Rate of Sound Card: Perspectives on Different Signal-to-Noise Ratios

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***Abstract*— This study presented a theoretical analysis to prove that there exists an optimal sampling frequency to reduce the noise in the signal to reduce the processes of acoustic digital signal processing. The respiration sounds have been recorded by 2 to 44.1 KHz or higher sampling rates, however, the optimal frequency might be decided by the noise from environment. This study solves the problem from the point of theoretical view. The findings were interesting because the noise in a pure sine wave can be reduced by lower sampling rates. The sampling frequency of lung sound recording can be reduced in the range of 2 to 5 KHz. In addition, the results supported to enhance signal-to-noise ratio in the receivers of frequency modulation, under-water acoustics, and other communication applications.**

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I. Introduction

THE linear interpolation technology for recovery of the signal is a common method, but the precision of the interpolation is not clear. In lung sound recording, the suggestive sampling rates are 44.1, 22.05, 11.025, 5.5125, and 2.75625 KHz which are based on the sampling rate of traditional recorders. The sampling is the basic process of the signal processing. The modern lung sound and heart sound recorders, biomedical sensors, digital image systems, storage devices, digital communication systems get the acquisition of raw data from the humans by sampling [1,2]. The computing speeds of the micro-processors are enhanced by the semiconductor manufacturing technology which allowed the were 10 MHz 30 years ago, but that of the advanced communication signal converters are several GHz now [16].

The Computerized Respiratory Sound Analysis (CORSA) [3] pointed out the survey of respiratory sounds research, and very high speed internal clock to control the units of the processors. Therefore, the sampling rate of the electronic devices has been accelerated in the past decades. For example, the limitation of sampling rate of analog-to-digital converters the sampling rate was listed as a parameter of the method of digitalization [4]. The word lengths, and sampling rates were considered to record the lung sound perfectly by using the sound blaster cards or commercial multi-channel signal acquisition cards. The simplest process of the acquired raw data is moving average as a low pass filter to reduce the noise. The algorithm of adaptive filters acquired the environment noise to cancel the noise in the signals [5]. Furthermore, in the computation of the spectrogram, the overlapped data decided its resolution [6]. Therefore, the total error in a specific duration of lung sound can be a dominant factor of precision.

The adjustable sampling rate has been employed to reduce the volume in data storage and communication. Some literatures presented the adjustable sampling rate can enhance the signal-to-noise ratio [7,8]. In some cases, the weak signal with lower sampling rate, and the strong signal with higher sampling rate are the rules to reduce the data volume, and enhance the SNR. Therefore, the experimental results can be discussed by the theoretical analysis. The following proof proposed a direct solution to the optimal sampling rate for reducing the noise.

II. METHOD

If the signal x(t) with noise n(t), and the sampling rate is $\omega_s = \frac{2\pi}{T}$, where *T* is the period. The sampling pulse train is denoted as *p(t)*. Therefore, the sampled signal is:

$$y_p(t) = \left(x(t) + n(t)\right) \cdot p(t) \tag{1}$$

where $p(t) = \sum_{n=-\infty}^{\infty} \delta(t - nT)$

In this study, the proof gives a solution to reduce noise by taking an optimal sampling frequency.

Taking the Fourier transform [9], we have:

$$Y_p(j\omega) = \left(X(j\omega) + N(j\omega)\right) \cdot P(j\omega) \tag{2}$$

Generally, a low-pass filter with the transfer function of $H(j\omega)$ is always designed as be a pre-processing device to cancel the noise. Therefore, the noise can be optimal reduced by some specific sampling rate in the condition of

$$\frac{d}{d\omega_s}\left(Y(j\omega) - X(j\omega)P(j\omega)H(j\omega)\right) = 0 \tag{3}$$

That is:

$$\frac{d}{d\omega_s}\left(\frac{1}{T}\sum_{k=-\infty}^{\infty} N\left(j(\omega - k\omega_s)\right)\right) = 0 \tag{4}$$

Then

$$\frac{-jk}{T}\sum_{k=-\infty}^{\infty} N'\left(j(\omega - k\omega_s)\right) = 0 \tag{5}$$

The optimal ω_s depends on the solution of the differential of $\sum_{k=-\infty}^{\infty} N'\left(j(\omega - k\omega_s)\right) = 0$. It exists the solution of ω_s to reduce the noise.

To verify the proof, we design a computer simulation to show the statistical view of the reduction of noise. Ideally, the respiration can be simplified as a sine wave whose half cycle for inspiration, and the other for expiration. The noise was the additive white Gaussian noise (AWGN) which is the common noise in the communication system [14]. The parameters of computer simulation were listed in Table 1.

The average absolute errors of the sampling points were computed to evaluate the performance of the method of reducing the sampling rate. The sampling rates were formulized as:

$$f_{si} = \frac{44.1}{2^{i-1}} KHz \tag{6}$$

where i=1 to 5, are also the group indexes, i.e. the sampling frequency of group 1 was 44.1 KHz, and that of group 2 was 22.05 KHz.

The pure signal in group 1 was denoted as $x_1[n]$, and the noised signal was $y_1[n]$ whose numbers of points are N. We reduce the sampling rate by dividing 2^{i-1} where i>1. The numbers of samples were also reduced to be $N/2^{i-1}$. However, the number of the samples can be recovered by well-known linear interpolation technology. Therefore,

$$me_i = \frac{\sum_{k=1}^{k=N} \left|\hat{y}_i - x_1\right|}{N} \tag{7}$$

where $\hat{y}_i$ was the reduced noised signal and recovered by linear interpolation. Consequently, the percentage of error reduction (ξ) can be described as:

$$\xi(\%) = \frac{me_i}{me_1} \cdot 100\% \tag{8}$$

III. RESULTS

The ideally pure sine wave and that with the AWGN and random noise (RN) of signal to noise ratio (SNR) =40 dB were shown in Fig. 1 (a) and (b). The sampling rate was 44.1 KHz. The root-mean-square (RMS) error was computed by different sampling rates of 44.1(Group 1), 22.05(Group 2), 11.025(Group 3), 5.5125(Group 4), and 2.76125(Group 5) KHz, respectively. We run 100 times of computer simulations by the same parameters in Table 1 to compute the mean absolute errors (MAE). The box plots were presented in Fig. 2.

TABLE I THE PARAMETERS of the SIMULATED RESPIRATION SIGNAL.

Variables	Value
Shape	Sine wave
Period	3 sec.
Signal to noise ratio (SNR) of AWGN	20, 30, 40, and 50 dB
Sampling rate	44.1(Group 1), 22.05(Group 2), 11.025(Group 3), 5.5125(Group 4), and 2.76125(Group5) KHz

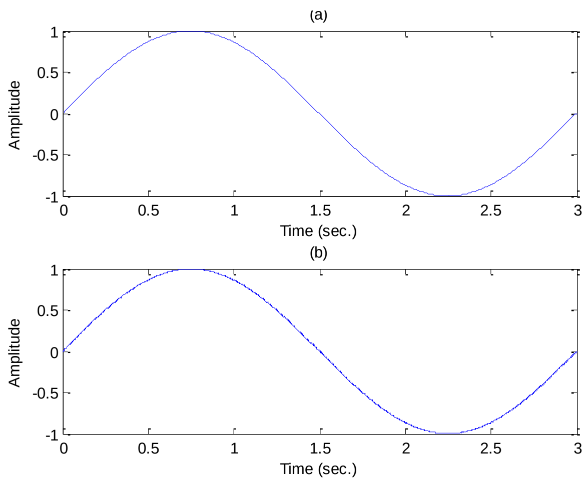

Fig. 1. Computer simulation: (a) the ideally pure sine wave and (b) that with AWGN.

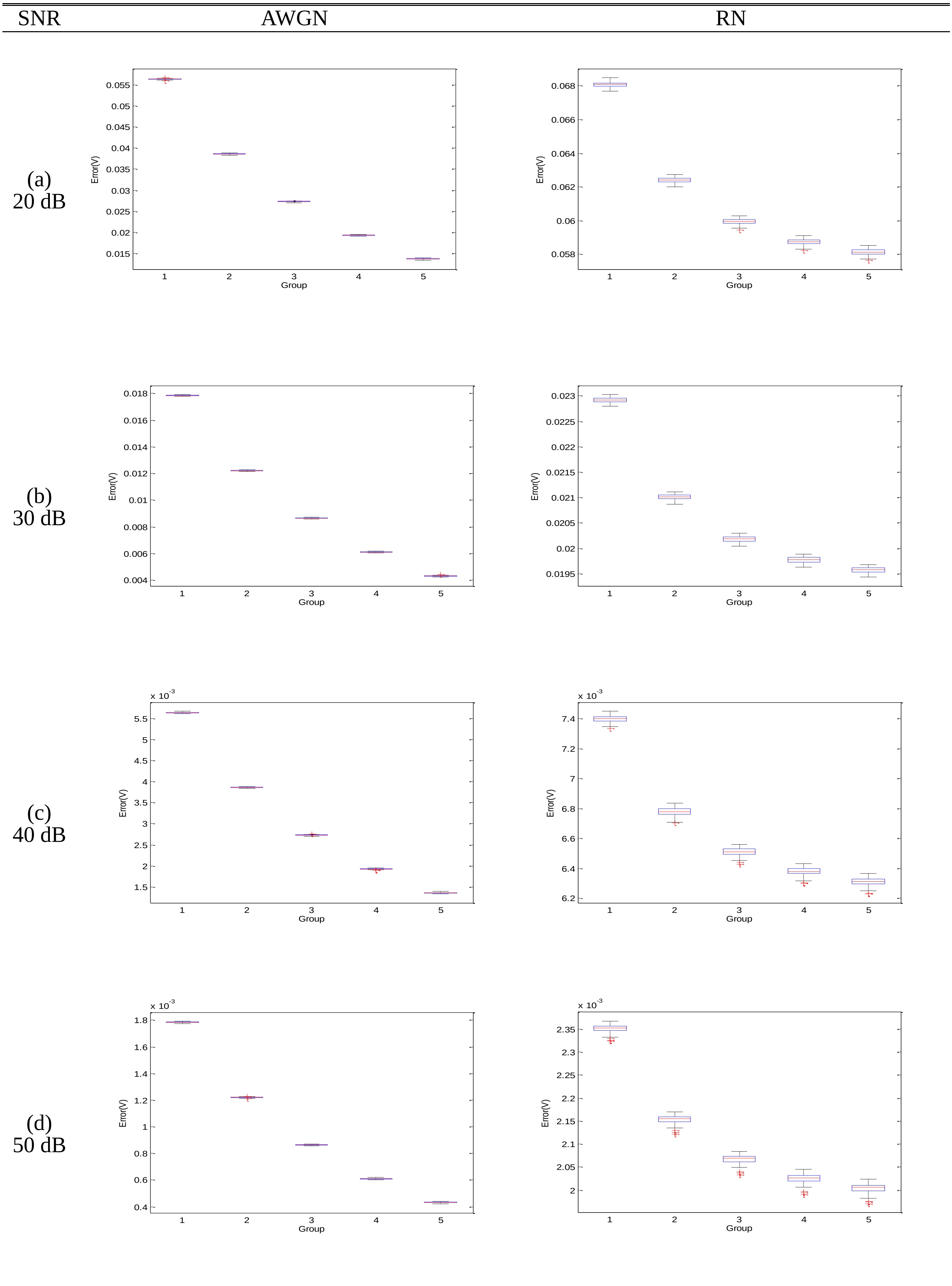

Fig. 2. The box plots of the MAE of Groups 1, 2, 3, 4, and 5 of 100 times. The AWGN level were (a) SNR=20, (b) SNR=30, (c) SNR=40, and (d) SNR=50. (The sampling rates: 44.1(Group 1), 22.05(Group 2), 11.025(Group 3), 5.5125(Group 4), and 2.76125(Group 5) KHz)

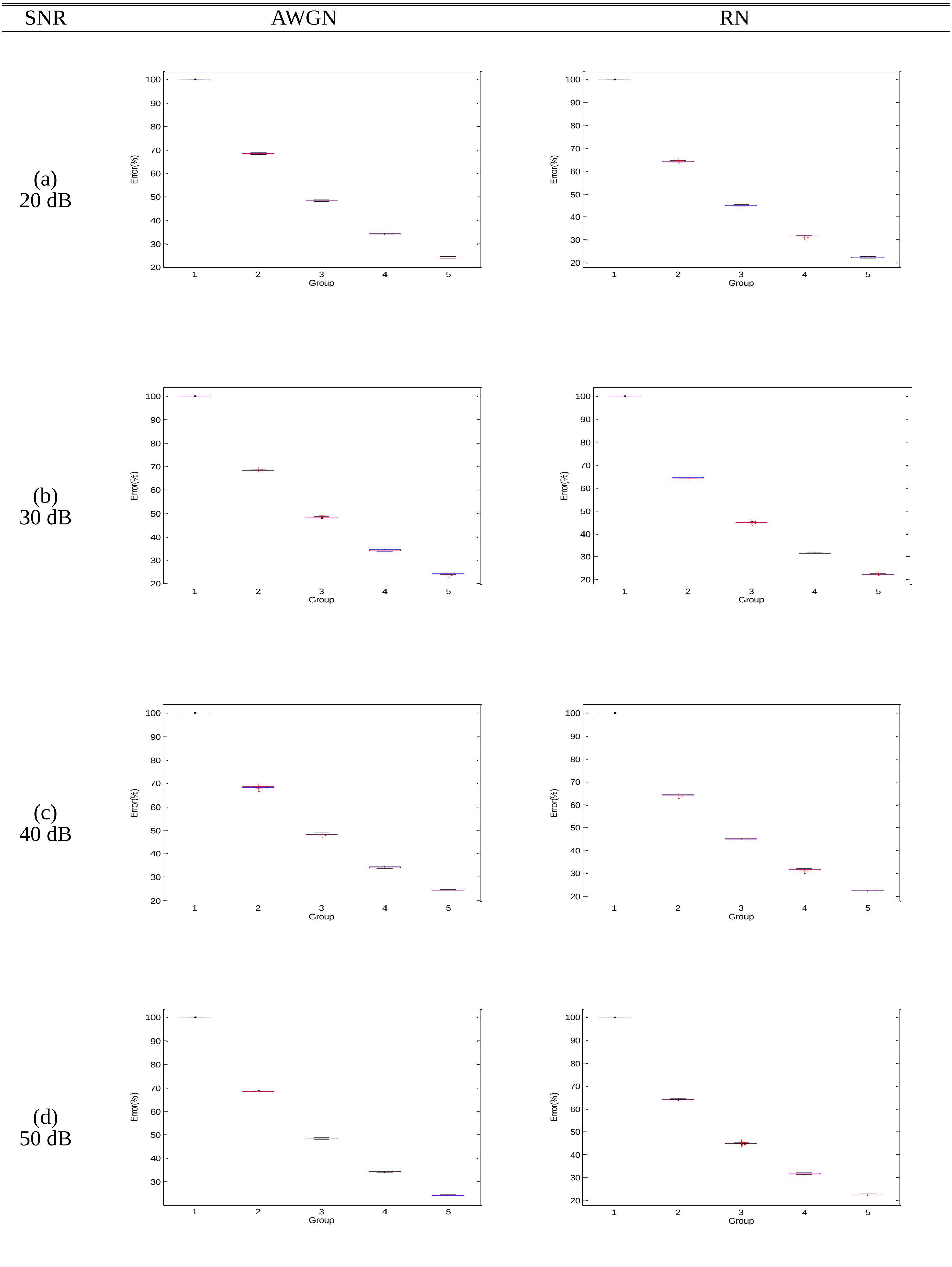

Fig. 3. The box plots of the percentage of error reduction (ξ) of Groups 1, 2, 3, 4, and 5 of 100 times. The AWGN level were (a) SNR=20, (b) SNR=30, (c) SNR=40, and (d) SNR=50. (The sampling rates: 44.1(Group 1), 22.05(Group 2), 11.025(Group 3), 5.5125(Group 4), and 2.76125(Group 5) KHz)B

Figure 2 presented the statistical results. Each box contained 100 trials of MAE. In (a), the SNR of AWGN is 20 dB. The box plots displayed that Group 5 (sampling rate =2.76125 KHz) has gotten the minimum MAE errors. Compared with the original signal (Group 1), the operation of reducing sampling rate cancelled about 1/5 MAE errors from the point of statistical view. In (b), (c), and (d), the SNRs were 30, 40, and 50 dB. All results show that the smallest sampling rate (Group 5) gets the smallest RMS errors. Based on the proof, there exists a optimal sampling rate to reduce the noise. From the box plots, we find that the lower sampling rate got the lower MAE errors by statistical analysis.

The percentage of error reduction by decreasing the sampling rate was obviously. Figure 3 presented the performance of the reducing sampling frequency. All plots displayed that group 5 achieved the best effect of noise cancellation for both AWGN and RN. The ξ s were in the range of 15 to 25%. Therefore, the filtering performance of the easy method for pure sine waves was excellent.

From the observation of Figs. 2, and 3, the lower sampling rate did reduce both AWGN and RN. The lower frequency signal can be filtered the noises by the lower sampling rate of sound card.

IV. Discussion

The pure sine waves usually play as the carrier in the communication systems [17]. In the detection systems, the reflections of the transmitting pure sine waves are widely employed in sonar, RADAR, and other systems. The sampling rate of receiver can be reduced based on the results of our study, especially in the real-time computing system. Fourier series described that a periodic signal is the linear combination of the fundamental signal and its harmonics. Therefore, the simulated ideally pure sine wave is significant, because of the theory of the linear time invariant (LTI) system [1]. The box plots can be expanded to explain the geniality of the operation of the reducing sampling rate. Chang and Lai [11] have studied on the performance evaluation and enhancement of lung sound recognition system in two real noisy environments. The results presented that the frequencies of noises were higher than that the main episodes in the spectrogram. Therefore, if the sampling rate of the experiment reduced to a specific frequency and processed the raw data with moving average, most of the environmental noise can be much cancelled. However, the experienced medical staff usually records the lung in silent environments whose noises compose with the sounds from air conditioners, fans, computer systems and so on. Based on the sampling theory, the energy of noise would be reduced by the lower sampling rate that shows the possibility of the optimal sampling rate can be found in some specific environments. Furthermore, the processing of the digital data can be accelerated by decreasing the data. The benefits of selecting a better sampling rate can achieve the better performance of signal processing. CORSA indicated that the wheeze was contained in the domain frequency at 400 Hz, but a number of investigators have suggested that the range is actually between 80–1,600 Hz and 350–950 Hz by filter theory [12,13]. Lu et al [14] have synthesized the normal breath and wheezing sounds whose main components were under 2 KHz. All the papers provided that the evidence of the sampling rate can be reduced to cancel the noise. However, the crackle includes the higher frequency components, the optimal sampling rate can be higher than normal breath and wheezing sounds. This is the limitation of using the lower sampling rate for lung sound recording. Furthermore, the standardized sampling rates applied in many industry standard sound facilities are 44.1, 22.05, 11.025 or 5.5125 KHz as standards. Most modern research groups selected 44.1 or 22.05 KHz to record the lung sound. The filtering performances of AWGN and RN were close. Therefore, the filtering method can be employed in the receivers of digital systems to cancel the noises caused from different reasons.

Some electronic stethoscope use the lower frequency of sampling rate [18]. It supports the examination of this study. We give the better choice of sampling rates to the researchers of respiration sounds.

V. Conclusion

The theoretical analysis of reducing sampling rate filter was solved in this study. The proof can be employed to simplify the filter design, if we get the smallest error from the simulated signal by the optimal sampling frequency. In addition the reasons of noises in physiologic signals are usually band-limited, therefore, the optimal sampling frequency can be used to simplify the system design. In the detection systems, the reflections of the transmitting pure sine waves are widely employed in sonar, RADAR, and other systems. The sampling rate of receiver can be reduced based on the results of our study, especially in the real-time computing system.

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