

The Evaluation System for the Computer Simulation of the Crackles in Respirations

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Abstract—The computer synthesized crackles were simulated by 1) respiration signal in the approaching saw tooth wave; 2) modulation (amplitude modulation and frequency modulation); 3) adding noises and pulses of the crackle sources; 4) Butterworth filter; and 5) the output in wave, audio signal and spectrogram. The output of the computer simulations should be examined by the medical doctors. Therefore, an online questionnaire has been created for the evaluation of the computer simulations. The assessment of the computer synthesized crackles is the references to modify the parameters for the computer simulation. Therefore, the better quality of the computer simulation for the crackles will be expected as well as the human-like breaths will be successfully implemented.

Keywords— crackle, evaluation system, computer simulation, lung sound, respiration, amplitude modulation, frequency modulation.

I. INTRODUCTION

To understand the characteristics of the respiration sound, many research groups developed various analysis methods to process the lung sounds. Kandaswamy *et al.* employed the wavelet coefficients to classify lung sounds [1]. Sovijärvi *et al.* developed a new versatile PC-based lung sound analyzer with automatic crackle analysis (HeLSA); repeatability of spectral parameters and sound amplitude in healthy subjects [2]. Murphy *et al.* analysed the lung sounds by time-expanded wave-form to visualize the characteristics [3]. Chen *et al.* classified the abnormal lung sounds for diagnosis using k-nearest neighbour [4]. Chamberlain *et al.* employed the semi-supervised deep learning to study the lung sounds [5].

The designs of modern filters included adaptive filters [9-11], wavelet transform [12-15], artificial neuron network (ANN) [16-20], and so on. However, that the signal processes are all in the time domain presented the advantage of the adaptive filters. In the modern internet or mobile

communication, the operation systems handle the multi-task, and always open many programs for the conveniences of the users, and the necessary connected servers. Therefore, the adaptive filter is one of the better solutions for the noise cancellations of the sounds of sirens on the ambulances. Khan *et al.* [21] indicated that the reference signal represents the noise portion of the primary input; thus, the filter output is a signal that models the noise in the input, and the signal of interest is determined by subtracting the filter output from the primary input. Gnitecki *et al.* [22] pointed out that the linear adaptive filters have been reduced the heart sounds. Patel *et al.* [23] presented that the LMS algorithm of adaptive filtering has reduced approximately 15 dB of noise over the 100–600 Hz frequency range. The 3 aforementioned studies all remain the signals of interest, and the primary input contains both the noise to be removed by the adaptive filter. However, the sounds of auscultations on the ambulances mainly conclude the sounds of siren, and the respiration sounds. Therefore, the signal of interest can be selected by the design of adaptive filter. This is the characteristics of the implementation of system in this study.

The traditional analysis methods support the rich information and characteristics of the lung sounds. Therefore, Lu *et al.* [6] proposed the inverting processes of the analyses, i.e. computer synthesis of the lung sounds. The synthesized crackles which were based on communication theory included the following processes, 1) the flow source as a transmitter, 2) the frequency and amplitude-modulated (FM-AM) sounds, 3) the accompanying noise as a modulator, 4) the airway wall as a medium, and 5) the microphone as a receiver. The main contribution of this study is to explain 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 in the description of CORSA [7-8] by the different orders of Butterworth filters.

Based on Lu *et al.*'s model [6], this study inserted the element of the crackle to simulate the sounds. However, the qualities of the synthesized sounds need the assessments from the medical doctors. Therefore, this study proposed a questionnaire system which was built very rapidly to provide the medical doctors for their assessments.

II. METHOD

The crackle sound was simulated by the coding of MatLab. The processes were: 1) the simulation respiration signal using the approaching saw tooth wave; 2) modulation (amplitude modulation and frequency modulation); 3) adding noises and pulses of the crackle sources; 4) Butterworth filter; and 5) the output in wave, audio signal and spectrogram. The output of the computer simulation needs the examinations and evaluations by the medical doctors' auscultations. The cloud technology is mature now, therefore, we build an online questionnaire system for the evaluation of the crackle sounds which were the output of the computer simulation.

A. The simulation respiration signal using the approaching saw tooth wave

1) Saw Tooth Wave Approach: The respiration model employed the 5th order harmonics to approach a saw tooth wave. The mathematical expression presented as,

$$x_s(t) = \frac{1}{2} - \frac{1}{\pi} \sum_{k=1}^5 \frac{1}{k} \sin\left(\frac{k\pi t}{T}\right) \quad (1)$$

where x_s denoted for breath signal, k was the order of the harmonics of the x_s , T was the period of fundamental sine wave, and t denoted for time. The signal was synthesized by 44,100 Hz of sampling frequency in this study.

2) Pulse: The pulses were generated by the random numbers which was denoted as $r_p(t)$. The range of $r_p(t)$ were between 0 and 1. A pulse occurred under the conditions, i.e.

$$p(t) = 1 \quad \text{if } r_p(t) > th \quad (2)$$

$$p(t) = 0 \quad \text{if } r_p(t) \leq th \quad (3)$$

where $p(t)$ was the pulse train for the crackles. The threshold, $th=0.85$ in the period of expiration, but $th=0.75$ in that of inspiration.

3) The sound source of breath with crackle and noise: Based on the linear system, the original sound source of the breath with crackles and noises in the airway was presented as,

$$x_{cs}(t) = A_1 x_s(t) + A_2 p(t) + A_3 n_{cs}(t) \quad (4)$$

where $x_{cs}(t)$ denoted for the sound source of breath with crackle and noise, and A_1 was its amplitude. A_2

was the amplitude of the $p(t)$, i.e. the pulse train. A_3 was the amplitude of the noises in the airway ($n_{cs}(t)$).

B. Modulation

The lung sound synthesis has been firstly created by Lu *et al.* in 2011 [1]. The model was built by the combination of amplitude modulation (AM) and frequency modulation (FM). The simulation based on the electronic communication theory of the AM, and the FM.

Based on the theory of the combination of AM and FM, the $x_{cs}(t)$ has been modulated, and the modulated signal was denoted as $y(t)$.

C. Noise

The noises cause from the environment, electronic device, collisions of the airway, fraction of the tissues and so on. Therefore, the summation of the noises were denoted as $n_s(t)$. Therefore,

$$y_n(t) = y(t) + n_s(t) \quad (5)$$

where $y_n(t)$ was the modulated signal with noises.

D. Filter

The transfer function of Butterworth filter was generally presented as,

$$H(s) = \frac{1}{Q(s)} \quad (6)$$

where $s = j2\pi f$, s denoted for the parameter in the s domain, and $Q(s)$ was the specific polynomial for the Butterworth filters. In this study, the 4-th order Butterworth filter was employed. Therefore,

$$Q(s) = (s^2 + 0.7654s + 1)(s^2 + 1.8478s + 1) \quad (7)$$

In the frequency domain, the output of the filtering was described as,

$$Y(s) = Y_n(s)H(s) \quad (8)$$

where $Y_n(s)$ was the Fourier transform of $y_n(t)$. Furthermore, $Y(s)$ is the output of the simulation in the frequency domain.

E. Output

The inverse Fourier transform was employed to get the $Y(s)$ in the time domain. Therefore,

$$y(t) = \frac{1}{2\pi} F^{-1}\{Y(s)\} \quad (9)$$

F. Server

The synthesized crackles can be produced automatically. Because of the random pulses and noises, the results of the loops in the computer simulation were different. Therefore, the program was set 25 loops, then 25 synthesized crackles output. For the evaluation of the simulation, the 25 crackles were uploaded in the computer sever. The operating system of this server system was Window sever. The website was <http://140.129.117.168/EV2/EV2.htm>.

G. Questionnaire system

The 25 synthesized crackles were hyperlinked by the questionnaire system in the google cloud. The website was : https://docs.google.com/forms/d/e/1FAIpQLSfa3HnDMhAjxe_f8C1Qh4GntcdODJ2r3VAbvCBN_oknStkWMg/viewform?vc=0&c=0&w=1&usp=mail_form_link.

III. RESULTS

The results disclosed 2 of the 25 synthesized crackles in Fig. 1 and 2. They were produced by the different loops of the same program. In Fig. 1, the 2nd and 3rd cycles presented some crackles, and Fig. 2, the 2nd, 3rd, 6th, and 7th cycles presented some crackles

The 25 synthesized crackles have been uploaded to the online questionnaire system. The questionnaire system was shown in Fig. 3. The synthesized crackle list in the computer sever was presented by the hyperlink.

The medical doctors can visit the online questionnaire to give their comments and suggestions. Based on their valuable evaluations, the dominant parameters will be disclosed to improve the quality of the computer simulations.

Nowadays, some algorithms of the artificial intelligence are focused by many research groups. However, the real clinical crackles are not easy to collect, so the inverting processes, i.e., simulation first, and approaching to the real sound of the crackle, are intuitively realized a successful computer simulation.

The google form is a valuable resource for the research. Because of the cloud technology, the online questionnaire system was setup more rapidly than the schedule we imaged. Therefore, we strongly suggest that the readers employed the rich resources of the google form.

IV. DISCUSSIONS

The synthesized lung sound will be approved by the experienced medical doctors, and we will build a database which includes normal breath sounds, wheezes, fine crackles and coarse crackles. The medical doctors examine the sound by the list which presents an example in Table 1. Consequently, the parameters can be the input of the supervised learning.

In the near future, the technology of synthesized crackles will be developed much more maturely, because of the assessment and comments from the medical doctors from the questionnaire system. That some educational purpose application for the training of the medical college students will be feasible based on the model which this study proposed.

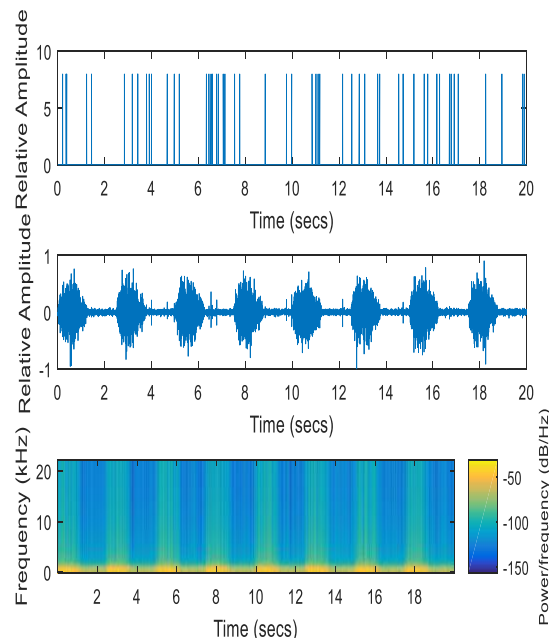


Fig. 1 Synthesized crackle I (Two of the 25 synthesized crackles)

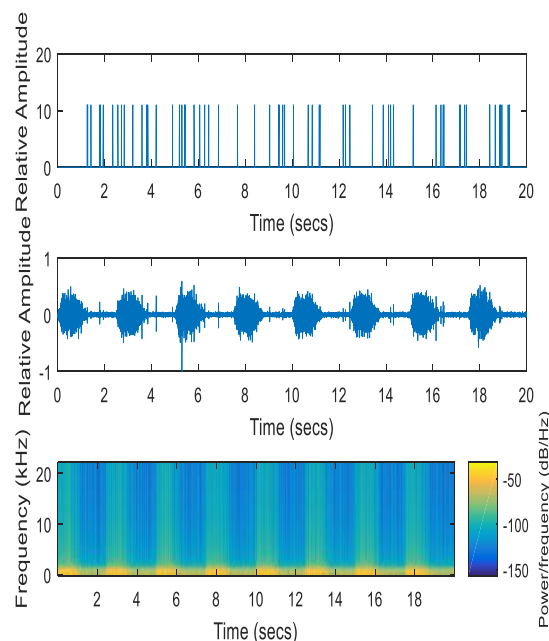


Fig. 2 Synthesized crackle II (Two of the 25 synthesized crackles)

This study proposed a segmentation method of the convolutional neuron network (CNN) to speed up the training time, and increase the accuracy. Actually, the respiration divides into 2 cycles. One is inspiration and the other is expiration. Therefore, the specific segmentations are very possible to be achieved under the advices from the experience medical doctors. A smart machine learning needs a knowledge base from the experienced medical doctors point out the significant features of the acoustic signals. The traditional machine learning methods include rule base, fuzzy logic, ANN and so on. We believe that the fundamental rule base combining with segmentation CNN will solve the balance of computing time and budgets. If the rule base aid the classification at first, the popular 28x28 pixels spectrogram image may be good enough for the fine tuning of the image classifications for the lung sound by checking the features of the rules which indicate the locality of the targets.

Fig. 3 The online questionnaire.

V. CONCLUSIONS

The computer synthesized crackles was developed by the theory of the communication systems. The output of the computer simulations should be examined by the medical doctors. Therefore, an online questionnaire has been created for the evaluation of the computer simulations. The assessment of the computer synthesized crackles as the references to modify the parameters for the computer simulation. Therefore, the better quality of the computer simulation for the crackles will be expected.

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Table 1 An example of the parameters and check

Filename	fc	amp_p	th1	th2	ryam1	ryfm1	rp1	ryam2	ryfm2	rp2	yy1rar1	yy1rbr1	bwhf	rf	crackle	points(1 to 5)
crackle2018Nov1673738091136.wav	63	8	0.86	0.83	1	0.128	2.643	0.02	0.1	11.608	8.648	0.114	0.0263	580		
crackle2018Nov1673738091152.wav	112	7	0.86	0.76	1	0.103	2.975	0.02	0.1	16.528	8.571	0.109	0.0286	631		
crackle2018Nov1673738091164.wav	177	11	0.93	0.77	1	0.113	2.223	0.02	0.1	10.718	9.315	0.119	0.0281	620		
crackle2018Nov1673738091177.wav	174	13	0.95	0.76	1	0.132	2.963	0.02	0.1	13.163	7.252	0.083	0.0221	487		
crackle2018Nov1673738091189.wav	64	12	0.9	0.77	1	0.124	2.117	0.02	0.1	11.342	8.581	0.115	0.0286	631		
crackle2018Nov1673738091202.wav	145	15	0.93	0.83	1	0.128	2.875	0.02	0.1	10.981	8.388	0.114	0.024	529		
crackle2018Nov1673738091213.wav	189	11	0.92	0.84	1	0.115	2.778	0.02	0.1	10.984	7.994	0.096	0.0269	593		
crackle2018Nov1673738091225.wav	164	12	0.86	0.77	1	0.128	2.432	0.02	0.1	10.019	7.544	0.093	0.0212	467		
crackle2018Nov1673738091237.wav	70	12	0.93	0.79	1	0.124	2.768	0.02	0.1	16.886	5.821	0.086	0.0228	503		
crackle2018Nov1673738091248.wav	135	13	0.86	0.76	1	0.124	2.43	0.02	0.1	16.275	6.334	0.088	0.0208	459		
Fc	The frequency of carrier															
amp_p	The amplitude of the pulses															
th1	The threshold for the pulse in expiration															
th2	The threshold for the pulse in inspiration															
ryam1	The intensity of the AM waves in expiration															
ryfm1	The intensity of the FM waves in expiration															
rp1	The intensity of the pulse waves in expiration															
ryam2	The intensity of the AM waves in inspiration															
ryfm2	The intensity of the FM waves in inspiration															
rp2	The intensity of the pulse waves in inspiration															
yy1rar1	Noise intensity in expiration															
yy1rbr1	Expemal noise intensity in expiration															
Bwhf	The -3 dB frequency of the normalized bandpass filter															
Rf	The real frequency of the bwhf															