# Qualitative Frequency Response Calibration of Sonocardiography System to Sense Wrist Pulse

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*Abstract* — **The frequency response of the microphone of the Yu and Wang sonocardiography system is qualitatively proven to cover the 0.5 to 10 Hz zone which is in the traditional Chinese medicine's interesting range of the wrist pulse data and is beyond the announced range of most commercial product. The calibration system employs a small speaker and a small capacity type microphone to construct a small air cell to service as an acoustic wave transfer zone where the speaker is employed to simulate the wrist pulse input. In order to simulate the small air column enclosed by the microphone's membrane cell and a patient's skin, the air cell bounded by the speaker and microphone has tiny and/or small leakage through the bounding interface. The air leakage is employed to simulate the patient's soft tissue around the measuring point. The data picked by the microphone is treated by a Fourier sine spectrum/spectrogram generator. Experimental results show that both cases with tine and small air leakages have apparent responses in the interested frequency range. Two test cases were included to demonstrate the system performance: one had the spleen disease and the other had heart problem. According to the Wang frequency resonance theory of arterial and vascular system, their spectrograms show that every corresponding harmonic mode havs unstable amplitude variation with respect to time. In other words, the data acquisition system together with time-frequency analysis accurately reflects the connection between the abnormal harmonic mode and corresponding organ.**

*Keywords* — **Frequency Response, Identification, microphone, wrist pulse, organ-meridians.**

## I. INTRODUCTION

The development of the technique in the traditional Chinese medicine has achieved a giant progress in recent decades. The study of the organ-meridians of human body has obtained more attention. Wang et. al. developed the resonance theory that each arterial bed in the vascular system is oscillated by the pressure waves at its own resonant frequency [1-3]. They came to two important conclusions. First, the organ spectra can be used as parameters to elucidate the physical status of the specific vascular beds. Specifically, the magnitude of a harmonic mode reflects the amount of blood spent by the corresponding organ. Second, as physical properties of a specific arterial bed change, the amplitude of the corresponding resonant mode changes more than that of the others. However, the corresponding resonant frequency will be approximately maintained by the heart rate control system to minimize the energy loss. Based on this theory, Yu and Wang developed an artery blood pressure pulse acquisition system to take the wrist arterial blood pulse pressure impulse data via a commercial microphone [4]. However, the interested frequency range of the wrist pulse data of the traditional Chinese medicine is lower than the announced range of most commercial microphone. The main concerning of this study is to qualitatively justify that the specific design of the Yu and Wang system [4] shift a microphone's frequency response to the range of human organ-meridians.

## II. THEORETICAL DEVELOPMENT AND EXPERIMENTAL SETUP

### A. Spectrum and Spectrogram Generator

Consider a data string, $y_0, y_1, ..., y_N$ . After applying the Gaussian smoothing, a smooth response is always available. It can be shown numerically that it is a diffusive smoothing in the interior point remote from the two ends [5,6]. If the remaining high frequency part is repeatedly smoothed $m$-steps, the difference between the original data string and final high frequency part is the desired smooth part. Note that this iterative filter is also diffusive in the interior points. Suppose that the original data sting involves sinusoidal and non-sinusoidal parts where the latter can be properly approximated by a polynomial with finite degree $M$ . In Ref.[7], it is further proven that, the non-sinusoidal part will be effectively removed from the high frequency part after applying the iterative Gaussian smoothing method $m$-steps provided that $m > M/2$. In a practical application, one can only provide a data string with finite length. The missing data beyond two ends will induced a result deviates from that without the missing data there. In Ref.[6], it was shown that, the significant error is about $\sigma/[1+0.8\log_{10}(m)]$ for that applying the iterative Gaussian smoothing method, where $\sigma$ is the Gaussian smoothing factor. It is recommended to remove these segments around the two ends.

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In Ref.[8,9], the above mentioned iterative filter is employed to remove the non-sinusoidal and low frequency parts. The Fourier sine spectrum of the remaining high frequency part will then have a small direct current error.

The time-frequency transform imposes a finite bandwidth window (centered on a given frequency) on the Fourier sine spectrum. The corresponding inverse Fourier transform of the band-pass limited spectrum is the real part of the spectrogram associated to the given frequency. Subsequently, the corresponding amplitude is obtained in terms of the Hilbert transform. After sweeping all the desired frequencies, the desired spectrogram is obtained.

### *B. Experimental Setup and Procedures*

In order to achieve stable sensitivity in response to the tiny wrist arterial pressure pulse data, a commercial capacity type microphone is employed, whose instructions are 20-20,000 Hz, 100mw, 32 Ω 105db sound pressure level sensitivity at 1kZ ±2 % and uses jack 3.5mm stereo plug for connection. The experimental facilities include a function generator (Iwatsu Inc. FG-350), two UNO speakers (10 mm and 21.85 mm diameters, 20-20,000Hz), a digital audio board (Onkyo Inc. SE-150PCI, SN ratio 100dB, 0.3-44KHz, sampling rate 32-192KHz).

Procedures of the experiment and data analytic involve the following steps. At first, a function generator sends a sine function with prescribed frequency (ranging form 0.5 to 10Hz) to the speaker to produce acoustic wave. After propagating through the confined air cell, the tiny pressure wave is then picked up by the microphone voltage output. The air cell is constructed by the speaker, microphone and a flat plate with a hole larger than the microphone membrane camber and smaller than the cone of speaker. The air leakage exists whenever the bonding plate was not sealed up firmly. The analogy signal is then converted to be a digital signal through a digital audio board. Finally, the digital data is saved in a personal computer via the Microsoft XP window system.

Note that, if the air cell is airtight, the microphone would not receive obvious signal because the speaker does not have enough energy to push the air cell in the frequency range less than 5Hz. In this study, a tiny and a small air leakages are examined for both speakers.

For the wrist pulse data measurement, the microphone is embedded into a belt so that the opening of the microphone membrane camber can be attached to a human skin around the wrist vessel without any air leakage. Note that air pressure variation is induced by the composite effect of the blood vessel expansion and contraction together with nearby soft tissue. As a consequence, it can not be properly picked up by most microphones except the capacity type with a small membrane camber. After a searching procedure via the finger, the measuring point is approximately located at the maximum response point among the three attach points of the classical feel pulse technique.

### *C. Data Analysis*

Since the capacity type microphone principally senses the pressure wave's derivative, all the raw data are integrated once to become the pressure data. The non-sinusoidal part of the digital data string is then removed by the iterative Gaussian smoothing method. In order to ensure the periodic condition, the following steps are employed: zero values of the sinusoidal part around the two ends were located by searching and interpolation; redistribute the data via a monotonic cubic interpolation; and perform the odd function with respect to an end. Subsequently, the Fourier sine spectrum of the remaining sinusoidal part is generated by the fast Fourier transform. Finally, the time-frequency plot is obtained by the Fourier sine spectrogram generator. In order to obtain a meaningful result, the experiment is repeated three times at every frequency input.

## III. RESULTS AND DISCUSSIONS

### *A. Frequency Response Identification*

At first, the arrangement employing the 10mm speaker with tiny air leakage is tested. Resulting spectrograms of the sinusoidal part for cases of 0.5 and 5 Hz are shown in Figs.1a and 1b, respectively. The 0.5Hz case has three dominate modes and many minor modes which have amplitude and frequency variations. These modes and variation of frequency and amplitude are caused by the tiny air leakage of the air cell and cannot be reflected from the spectrum. The spectrogram of the 5Hz case does not have significant variation of amplitude and frequency. This means that the air leakage does provide regular air stream almost in the inphase manner with respect to the speaker membrane. The frequency response of the case is shown in Fig.2. In the low frequency part, the captured amplitude increases up to 1.5Hz and then rapidly decreases after 2Hz. The fast attenuation reflects that the tiny air leakage is apt to become airtight in the high frequency part. It means that the speaker does not have enough energy to produce pressure fluctuation.

As to the small air leakage plus 10mm speaker arrangement, the resulting spectrograms are shown in Figs.3a and 3b which are corresponding to Figs.1a and 1b, respectively. A careful inspection upon these figures reveals that, in addition to the interested modes, many other modes exist too.

These extra-modes reflect the complicated flow field induced by the oscillatory air stream flowing through the air leakage. Nevertheless, both the 0.5Hz and 5Hz modes are captured as shown. Figure 4 shows the resulting frequency response where the test results obviously scatter one from another especially in the extreme low frequency zone. Again, this scattering is induced by the complicated flow field within the test air cell. Unlike that shown in Fig.2, in the high frequency part, the response amplitudes do not decay because the airtight is not a problem.

For the arrangement employing the 28.5 mm speaker, the corresponding frequency responses for the tiny and small air leakages are shown in Figs.5 and 6, respectively. Since a large speaker is more difficult to send energy to the microphone membrane chamber (in the central part of the speaker) than that of a small speaker, the amplitude responses in the extreme low frequency zone of these figures are smaller than that shown in Figs.2 and 4, respectively. In other words, their response curves shift to the right. Moreover, degrees of scattering of the 28.5mm speaker cases are larger than those of 10mm speaker.

Although there are some discrepancies, these tests show that the frequency response of the examined microphone is active in the range of 0.5-10Hz. This is quite different from the announced range of 20-20,000Hz. A reasonable explanation comes from the energy density reaching the microphone. In the open space, only a small amount of acoustic energy is received by the microphone. Therefore, if the frequency is lower than 20Hz, the acoustic pressure variation can not actuate the microphone. On the other hand, when the acoustic wave is confined within a small air-cell, most acoustic energy emitted from the speaker reaches the microphone. Therefore, the active frequency response range becomes 0.5-20,000Hz in such a special environment. As a consequence, the frequency response of the microphone of the Yu and Wang sonocardiography system covers the range of the wrist vessel pulse data whose fundamental frequency is corresponding to a human heart beating rate.

Finally, two tests are employed to demonstrate the performance of the whole data analysis system: one has the spleen disease and the other had heart problem. Figure 7 shows the resulting spectrogram of the wrist vessel pulse data of the former patient where the first seven modes are clearly shown. According to the Wang frequency resonance theory [1-3], the first 12 modes are the heart, liver, kidney, spleen, lung, stomach, Gall bladder, bladder, large intestine, sanjiao, small intestine, and pericardium meridians, respectively. The fourth mode shows abnormal amplitude variation which reflects the disease of the spleen. In Fig.8, the resulting spectrogram of the patient with heart problem shows that the first mode has an abnormal amplitude decrease in the interval of 4 to 6 seconds. It means that his heart has problem. These two tests obviously confirm that the sonocardiography data collecting system, Wang resonant theory and present data analysis system have the potential to help the traditional Chinese diagnosis of the wrist feel pulse technique.

(1a) (1b)

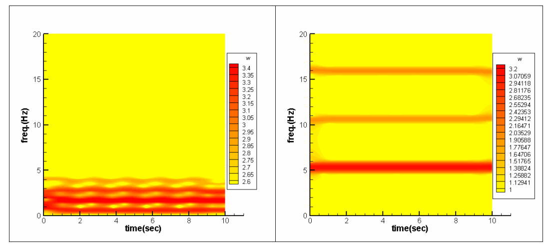


Fig.1 Spectrograms of the sinusoidal part of the 10mm speaker with tiny air leakage: (a) 0.5Hz case and (b) 5Hz case..

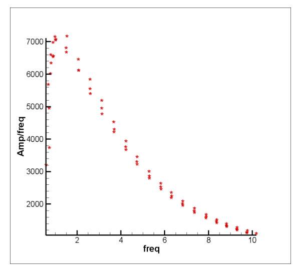


Fig.2 The overall frequency response plot of the 5Hz case of the 10mm speaker with tiny air leakage.

(3a) (3b)

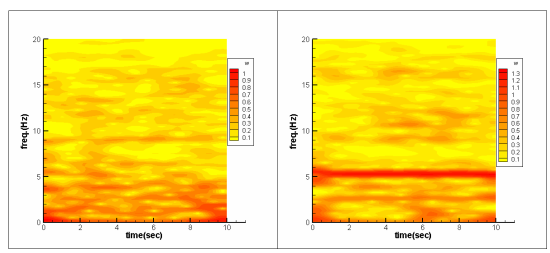


Fig.3 Spectrograms of the 10mm speaker with small air leakage: (a) 0.5Hz case and (b) 5 Hz case.

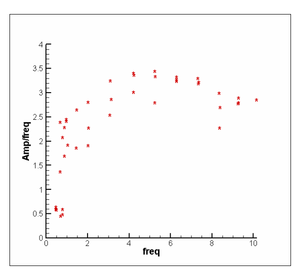


Fig.4 The overall frequency response plot of the 5Hz case of the 10mm speaker with small air leakage.

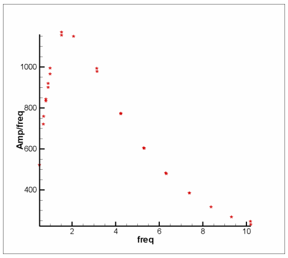


Fig.5 The overall frequency response plot of the 5Hz case of the 28.5mm speaker with tiny air leakage.

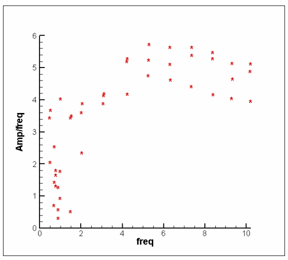


Fig.6 The overall frequency response plot of the 5Hz case of the 28.5mm speaker with small air leakage.

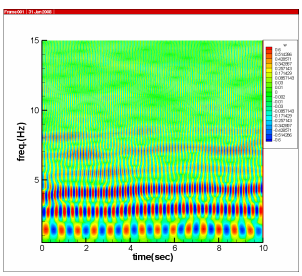


Fig.7 The real part spectrogram of the test case with spleen disease.

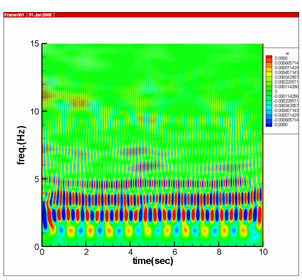


Fig.8 The real part spectrogram of the test case with heart disease.

## IV. Conclusions

An experimental set up was employed to simulate the operation conditions of a small commercial microphone to measure a human wrist vessel pulse data. Experimental results qualitatively show that the frequency response range of the microphone covers the range of 0.5-10Hz which is just the range of traditional Chinese wrist pulse diagnosis. Two tests cases confirm that the overall system has the potential to modernize the traditional Chinese wrist pulse diagnosis.

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