The cancellation of human sounds using synthesized soundwaves

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Abstract. The principle of destructive interference is applied to reduce or eliminate the spoken sound in order to increase speech privacy. This research is divided into two parts: the synthesis of sound from formula, using both analytical linguistics and physical approaches, and the actual cancellation of simple to complex sounds in the real world setting. The results suggested that in a real-world setting, up to 60% intensity reduction could be repeatedly detected. When the complexity of the sound is increased, difference in interference pattern could be detected between sounds in frequency range within the human hearing spectrum. Furthermore, it is found that the generation of negative sound using the four formants is not comprehensive enough to interfere effectively with actual sound, therefore the spectral slice is needed to synthesize more complex sounds. After testing various variations, it is found that using 11 most intense frequency components adjusted in proportion according to each original amplitude best cancel the widest range of human sound samples. This method was used to test the effectiveness of actual human sound cancellation. Though effective cancellation was detected in the high frequencies range of the sound spectrum, other frequency ranges were barely affected. The difference between cancellation patterns of each frequency range might need investigating before the cancellation of human sound can be effectively applied in real life.

1. Introduction
Nowadays, there are two main sound management methods, however, these still have weaknesses which can be further developed. The sound masking system that is widely used in open-plan offices, which uses white noise to reduce the Signal-to-Noise Ratio (SNI) to reduce the semanticity (ability to recognize meaning) of sound, must be installed in a wide area because this solution does not solve the problem at the sound source directly, but focuses on the hearer [1]. In addition, research shows that such white noise can decreases working efficiency and increase annoyance, compared to unmitigated human sounds [2].

The Active Noise Control (ANC) system, which is another popular system, and uses the same principle of destructive interference as this study, focuses on reducing the intensity of low frequency and constant sounds, such as the sound generated by engine and unwanted background noise entering headphones [3]. ANC technology uses sound interference method to cancel out incoming noise by generating specifically designed sound wave to make destructive interference. Yet, this technology is currently not able to reduce the human voice according to the complicated properties and variability of it, so this paper aims to study the possibility to use the interference method to reduce the volume of human sound in the vicinity of speaker.
2. Experimental apparatus

2.1. Part I: The cancellation of soundwaves in practical setting
Error microphone and speakers are firstly calibrated using function generator. We also studied the effects of damp rate of sound waves in air in our experiment to reveal the amplitude reduction due to air resistance.

2.1.1. Select the experimental setup, the distance of speaker and the distance of the error microphone.
Error microphones and speakers are calibrated using function generator to ensure the stability of frequency and intensity of sound waves. Two speakers were used to create sinusoidal sound waves at a frequency of 500 Hz. Experiments were conducted in 3 setups: in a closed pipe, in open area with speakers facing each other and in open area with speakers facing the same way. The remaining sound was recorded with the error microphone at every 1 cm in delimitation of the experiment.

2.1.2. Find the damp rate of sound wave in the real world setting. Air resistance will decrease the energy of sound waves, decreasing the amplitude, which can be modelled as a damped harmonics. This experiment is to study the effect of damp rate on the difference in amplitudes within 30 cm, the vicinity of experimental setup. After calibration sinusoidal waves with the frequency of 500 Hz were generated. The intensity of sound was measured at every 1 cm to the distance of 30 cm away from the speaker.

2.1.3. Test the cancellation of sound waves. Test to prove that the sound can cancel each other by using a sound with two frequencies, 700 and 1500 Hz, which are in the dominant frequency range for the phoneme /a/ being studied (freeware Audacity used for sound generation) A sound of 700 Hz, 1500 Hz and the inverse waveform of each were fed to the speaker in turn to interfere with the sound with both frequencies, and the resulting spectrograms were analysed using the program Praat. Repeat with a 4 frequencies combination selected from the average frequencies with highest intensity peaks of the samples.

2.1.4. The cancellation of human sound. Human sound samples of the phoneme /a/ were collected, and inverted using Audacity, then were made to interfere with each other in the experimental setting specified in 2.1.3.

2.2. Part II: Generating the synthesized sound wave
Compare human sound with synthesized sound (e.g. Siri, Google Translate, and sounds synthesized in this study) by analysing their spectrograms and spectral slices. Samples of sounds synthesized using various numbers of highest intensity peaks and adjusted for amplitude in multiple ways were collected and tested against human sound samples, the residual sounds after interference were then recorded and analysed.

3. Results and discussion

3.1. Part I: The cancellation of soundwaves in practical setting

3.1.1. The interference between single frequency. From the results of the experiment, it was found that sound interference can be observed in a real life setting, as seen in figure 1, but not to the extent indicated in theory, possibly due to the air resistance and the limitations of the experimental devices.
3.1.2. *The interference between 2 frequencies and 1 frequency.* From experimental results it was found that when the waves are more complex, comprising of multiple frequencies, the differences of interfering have more errors. In table 1, significant differences in frequency resulting from both constructive and destructive interference were observed. Inverted wave of a frequency can cancel out the component with the same frequency in a composite sound without interfering with the other frequency components in a practical setting.

| Incident frequency (Hz) | Targeting frequencies (Hz) | Standard Ratio | Experimental Ratio | General Observations | T-test Result (alpha = 0.05) |
|------------------------|---------------------------|----------------|-------------------|----------------------|----------------------------|
| 1500                   | 700+1500                  | 1.04           | 1.19              | Constructive         | Significantly Different     |
| 1500 (inverted)        | 700+1500                  | 1.16           | 1.08              | Destructive          | Significantly Different     |
| 700                    | 700+1500                  | 0.44           | 0.56              | Constructive         | Significantly Different     |
| 700 (inverted)         | 700+1500                  | 0.53           | 0.49              | Destructive          | Significantly Different     |

3.1.3. *The interference between 4 frequencies and 1 frequency.* Further experiments with composite sounds of 4 frequencies are shown in table 2. It is found that observable differences in frequency resulting from both constructive and destructive interference can only be found at some frequency range, while at others the effect is not significant enough for conclusions at alpha = 0.05.

| Incident frequency (Hz) | Targeting frequencies (Hz) | Standard Ratio | Experimental Ratio | General Observations | T-test Result (alpha = 0.05) |
|------------------------|---------------------------|----------------|-------------------|----------------------|----------------------------|
| 933                    | All                       | 0.20           | 0.28              | Constructive         | Significantly Different     |
| 933 (inverted)         | All                       | 0.20           | 0.24              | inconclusive         | Insignificantly Different   |
| 1635                   | All                       | 0.25           | 0.28              | Constructive         | Significantly Different     |
| 1635 (inverted)        | All                       | 0.25           | 0.15              | Destructive          | Significantly Different     |
| 3314                   | All                       | 0.30           | 0.32              | Constructive         | Significantly Different     |
| 3314 (inverted)        | All                       | 0.28           | 0.30              | inconclusive         | Insignificantly Different   |
| 4724                   | All                       | 0.22           | 0.20              | inconclusive         | Insignificantly Different   |

3.1.4. *The study significant of “damp rate” in air.* From the experiment, found that the air resistance causes the soundwaves amplitude is decreased average 2.5 decibels within 30 cm as shown in figure 2, which is the scope of this project. Conclude that the decreasing amplitude is not significant to the results.

3.2. *Part II: Cancellation of human sound and synthesis of soundwaves*

3.2.1. *The synthesis of soundwaves.* From the synthesis of the human sound with formant, which classifies sound in linguistics, found that it is not accurate enough to simulate the human sound for interfering because it consists of only 4 main frequencies.

Analyzing spectral slices of human voice samples and simulating various sound patterns, it was found that the synthesized sound from the selection of 11 most prominent frequencies and the adjustment of
according to the proportion found in sample of the human voice results in the best match to the most samples. Therefore, this method was chosen to synthesize the sound.

3.2.2. The cancellation of human sound. The intensity of human sound decreases significantly only in the high frequency range, but not in lower frequency range as seen in figure 3. This unusual effect may come from the great variability of human sound quality. Further study may be required to eliminate this effect in order to apply human sound cancellation in real life.

![Figure 1](image1.png)  
**Figure 1.** 500 Hz sine waveform after interference occurs. (a) shows 500 Hz wave from single speaker (without interference. (b) shows interfering waves.

![Figure 2](image2.png)  
**Figure 2.** The graph shows the decrease in amplitude of the wave in the air within 30 cm.

![Figure 3](image3.png)  
**Figure 3.** The comparison between the intensity of uninterfered and interfered human samples by negative wave of the sample at 5 highest intensity frequencies.

![Figure 4](image4.png)  
**Figure 4.** Comparison of wave form (upper) and spectrogram (lower) of sound synthesized based on four highest intensity frequencies (a) and human sound sample (b).
Figure 6. Comparison of spectral slices between original human sound sample (a) and the result of interference between human sound and 11-frequencies adjusted synthesized sound (b).

4. Conclusion
The open space layout with speakers facing each other was selected for the experiment setup because there is no standing wave and the sound intensity is higher. In actual conditions, the air resistance does not have a significant effect on the amplitude reduction within 30 cm, the scope of this project. From the experiment, with the sine wave and single frequency, the interference of soundwaves can actually interfere, and the intensity of sound decreases by approximately 60%. When the waves are more complex, we find differences in the intensity changes between sound waves in different frequencies within the limits that humans hear.

In the second part, the synthesis of the soundwave, it was found that four main formant frequencies were not accurate enough to simulate human voice as shown in figure 4. So the synthesis using the average peak frequencies was employed instead with eleven dominant frequencies as shown in figure 5. The resulting sound is intelligible because of the difference in sound quality. However, the waveform of the sound is sufficiently similar and can interfere with human voice in the medium frequency range as shown in figure 6. In the low frequency range, a decrease in intensity was found but still not significant enough to effectively interfere with the noise. In order to develop the interference of human sound to apply in real life, it may be necessary to study the reasons that cause the difference.

At present, Wave Form Synthesis (WFS) technology can limit the area of listening allows us to determine the specific audible area, such as the voice of car navigation system that only the driver could
hear [4]. Therefore, it could be made possible to determine the area of our speech by applying this technology with the results from this study. This device would not only increase speech privacy in a society where privacy is decreasing but may also result in confidence and better mental conditions.

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References
[1] Liebl A, Assfalg A and Schlittmeier S J 2016 Appl. Acoust. 110 170–5
[2] Marks P 2014 Beams of sound immerse you in music others can't hear New Scientist Online:https://www.newscientist.com/article/mg22129544-100-beams-of-sound-immers-you-in-music-others-cant-hear/
[3] Qiu X, Li X, Ai Y and Hansen C H 2002 Appl. Acoust. 63 467–79
[4] MPS LLC 2019 Sound Masking vs. Noise Cancellation Online:https://mpsllc.com/sound-masking-vs-cancellation/