Cough Sound Discrimination in Noisy Environments using Microphone Array

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Abstract— **Cough sound discriminator algorithms are capable of distinguishing between dry and wet cough types. The performance of such algorithms, however, is affected by noise and reverberation in the environment. The effect of reverberation on the performance of cough sound discriminators was previously studied in [1]. In this paper, the effect of noise on the performance of cough sound discriminator is studied and quantitatively measured using previously defined Linear Separation Score (LSS) [1]. Experiments revealed a significant decrease in the performance of cough sound discriminator in the presence of white noise using a single microphone for cough sound acquisition. A microphone array structure containing a maximum of 7 microphones along with delay-and-sum beamforming algorithm was used to improve the performance of the cough sound discriminator. Experimental results showed improvement in the performance of the cough sound discriminator in the presence of white noise using microphone arrays.**

Keywords-component; microphone array; beamforming; cough sound discrimination;

I. Introduction

The use of microphone arrays has gained popularity in systems where additional environmental features are needed from the acquired sound. The information obtained from microphone arrays could be used for sound source localization [2], reverberation and echo removal [3], noise reduction [4] and much more.

Microphone arrays are also used in various patient-monitoring applications in order to acquire biological sounds from patients [5]. Cough is a commonly acquired biological sound due to its presence in most respiratory diseases [6]. Chatrzarrin et al. [7] previously designed a cough sound discrimination algorithm, which extracted two features from cough sounds in order to discriminate between dry and wet cough types. The first feature (Feature 1) distinguished between dry and wet cough sounds based on the number of peaks of the energy envelope of the cough signal. The second feature (Feature 2), on the other hand, used the power ratio of two frequency bands of the cough signal in order to discriminate between dry and wet cough signals [7].

As mentioned in [1], the previously designed cough sound discriminator algorithm in [7] did not take into account distortion sources such as noise and reverberation within the environment. As a result, the effect of such sources of distortion remained unknown.

The effect of reverberation on the performance of cough sound discriminator was examined in [1]. In this study, cough sounds were acquired in a reverberant environment and the performance of the cough sound discriminator was evaluated using numerous microphone-to-speaker distances. The study concluded that a significant decrease in the performance of cough sound discriminator occurred as the distance between the cough sound source and microphone increased. In order to improve the performance of the cough sound discriminator, a microphone array structure was used. The authors examined the performance of cough sound discriminator as the number of microphones within the array increased. In addition, the effect of microphone-to-microphone distance and microphone-to-speaker distance on the performance of the cough sound discriminator was thoroughly studied. The performance of the cough sound discriminator was measured using Linear Separation Score (LSS). Linear Separation Score is a numeric value between 0 and 1 (0 and 100%), which measures the linear separability of cough sounds. An LSS of 1 (or 100%) indicates 100% separation between the dry and wet cough signals.

In this paper, the performance of cough sound discriminator in the presence of noise using a single microphone for cough sound acquisition is studied. Previously developed performance score (i.e. LSS [1]) is used in this paper to measure the performance of the cough sound discriminator. Furthermore, a microphone array structure similar to [1] along with delay-and-sum beamforming algorithm is used to improve the performance of cough sound discriminator.

II. Experimental Setup

Cough sound acquisition was performed in a room of size 11m x 10m x 4m. The room was the same as that of [1] in order to maintain consistency between the experimental results. The room contained various objects such as tables, chairs, whiteboards and other office equipment. In addition, the room contained both walls and windows.

The equipment used to conduct the cough sound acquisition experiment along with a description of their functionality is listed in Table 1. The KOSS M85 Plus speaker was used to play both cough sound signals, in addition to providing a source of white noise. Figure 1 depicts the experimental setup used to study the effect of white noise on the cough sound discriminator algorithm using a single microphone for cough sound acquisition. A similar setup as that of Figure 1 was used to study the effect of microphone array on improving the performance of cough sound discriminator in the presence of

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white noise. In the single microphone experiment, only one microphone as depicted in Figure 1 was used. For multi-microphone sound acquisition, the microphones were incrementally added to the structure at various equidistant microphone-to-microphone distances.

The white noise was placed 100cm at an angle of roughly 60° from the center of the microphone array structure. The volume of the white noise was tuned to be roughly equal to the loudest cough sound volume and played at -15dB using Adobe Audition.

Table 1 Cough Sound Acquisition Experimental Setup

Component	Description
MOTU 896HD	Cough playback and capture
Audio-Technica AT803B	Microphone
KOSS M85 Plus	Speaker

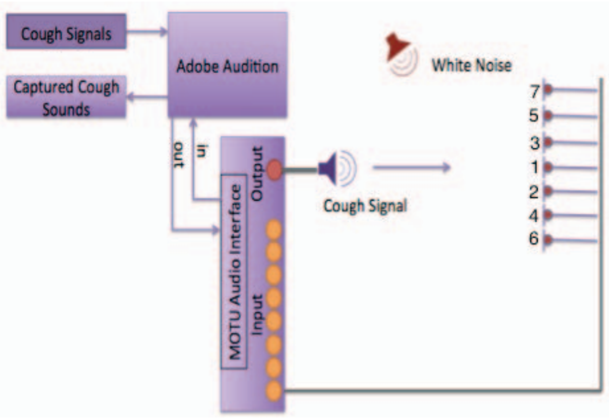

Figure 1: Microphone Array Cough Sound Acquisition Setup

III. COUGH SOUND ACQUISITION USING A SINGLE MICROPHONE IN THE PRESENCE OF WHITE NOISE

This section is divided into two sets of experiments. The first experiment investigates the effect of white noise on the performance of the cough sound discriminator at different microphone-to-speaker distances. The second experiment investigates the effect of white noise on the performance of the cough sound discriminator at different volume levels of the played cough sounds.

A. Microphone to Speaker Distance

A total of two experiments were performed where the distance between the speaker and microphone was varied while keeping the volume and distance of the white noise emitter constant. The experiments were performed at microphone-to-speaker distances of 50cm and 200cm.

Figure 2 and Figure 3 depict the result of cough sound acquisition with a single microphone and added white noise. As it could be seen, the performance of the cough sound discriminator decreases significantly when white noise is added to the system. Furthermore, at the distance of 200cm, the discriminator fails to discriminate between the two cough types. Table 2 summarizes these results and compares them with the results obtained in [1].

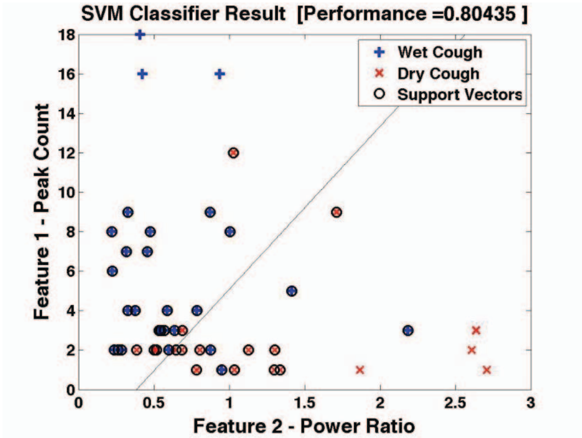

Figure 2: LSS of single-mic and white noise ($D_{mic\text{-}speaker}$ = 50cm)

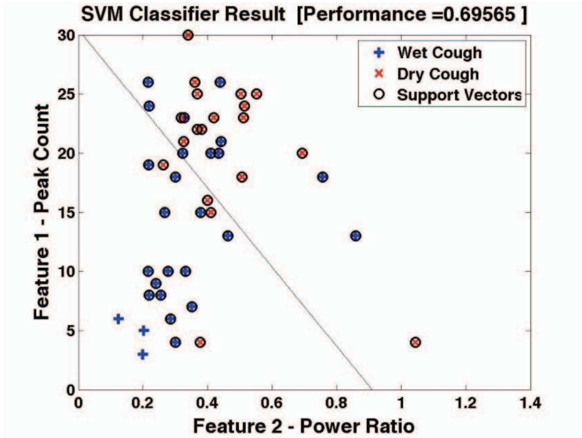

Figure 3: LSS of single-mic and white noise ($D_{mic\text{-}speaker}$ = 200cm)

Table 2: LSS of single microphone cough sound acquisition with and without white noise

Mic-Speaker Distance	No White Noise	White Noise
50 cm	1	0.80
200 cm	0.84	0.68

B. Cough Sound Volume Level

In order to analyze the relationship between the injected white noise and the volume of the played cough sounds, the described experiment was repeated with different cough sound volume levels.

The experimental setup in this section was similar to that depicted in Figure 1. The volume level of the played cough sounds was modified using Adobe Audition software. The distance between the speaker and microphone was set to 200cm. Figure 4 and Table 3 summarize the obtained results. As it could be observed, the performance improves as the volume of the cough sounds increase. However, the performance decreases at very high volume levels due to system saturation.

Table 3: LSS of single microphone cough sound acquisition with white noise and variable cough sound volume

	Adobe Audition Volume Level (dB)						
LSS	-20	-10	-5	0	3	5	8
	0.61	0.69	0.69	0.71	0.71	0.73	0.69

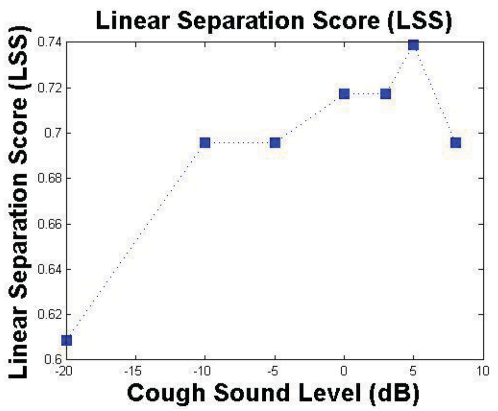

Figure 4: LSS of variable cough volume with single microphone

IV. Cough Sound Acquisition Using Microphone Array in the Presence of White Noise

In the previous section, the effect of white noise on the performance of the cough sound discriminator was analysed using a single microphone for cough sound acquisition. The results indicated that the cough sound discriminator is not capable of distinguishing between dry and wet cough sounds in the presence of white noise. The decrease in the performance of the discriminator was more evident as the distance between the speaker and microphone increased.

In this section microphone array is used in the cough sound acquisition stage of the experiment in order to improve the LSS of the cough sound discriminator in the presence of white noise. A delay-and-sum (DAS) beamforming algorithm similar to [1] was used for processing the acquired signals. Similar to the previous section, two sets of experiments were performed.

In the first experiment, the distance between the speaker and microphone array structure was varied at different microphone-to-microphone distances, while keeping the distance between the white noise source and the microphone array constant. In the second experiment, the volume of cough sounds was varied between -20dB and 8dB at the microphone-to-speaker distance of 200cm and microphone-to-microphone distance of 15cm.

A. Microphone to Speaker Distance

Table 4 and Table 5 summarize the LSS obtained when using microphone arrays in the presence of white noise. Similarly, Figure 5 and Figure 6 graphically depict the results obtained in this section. As it could be seen from the tables and figures, adding more microphones significantly improved the LSS of the discriminator.

Table 4: Microphone array LSS ($D_{Mic\text{-}Speaker}$ = 50 cm)

Num of Mics	Microphone-to-Microphone Distance (cm)			
	5	10	15	20
1	0.81	0.83	0.81	0.81
2	0.91	0.89	0.89	0.82
3	0.93	0.95	0.91	0.82
5	0.93	0.95	0.91	0.85
7	0.95	0.95	0.93	0.89

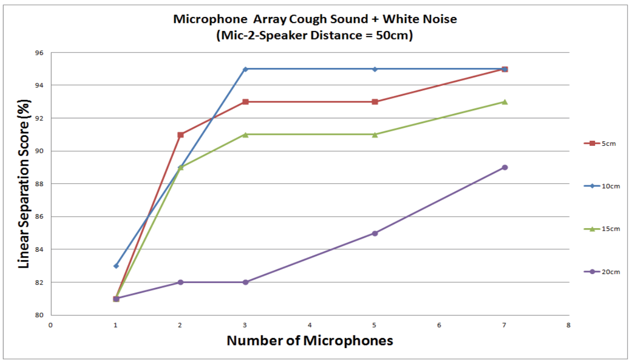

Figure 5: Microphone array LSS ($D_{Mic\text{-}Speaker}$ = 50 cm)

Table 5: Microphone array LSS ($D_{Mic\text{-}Speaker}$ = 200 cm)

Num of Mics	Microphone-to-Microphone Distance (cm)			
	5	10	15	20
1	0.69	0.71	0.73	0.69
2	0.73	0.75	0.77	0.81
3	0.77	0.81	0.85	0.81
5	0.79	0.85	0.89	0.81
7	0.81	0.81	0.78	0.73

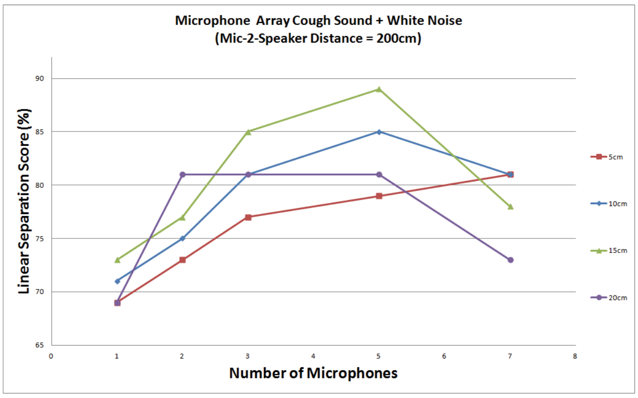

Figure 6: Microphone array LSS ($D_{Mic\text{-}Speaker}$ = 200 cm)

B. Cough Sound Volume Level

Figure 7 and Table 6 depict the results obtained from varying the cough sound volume in the presence of white noise. The experimental setup was similar to that of single-microphone cough sound acquisition.

Table 6: Microphone array LSS with cough sound volume

Num of Mics	Adobe Audition Volume (dB)						
	-20	-10	-5	0	3	5	8
1	0.60	0.73	0.69	0.71	0.71	0.73	0.71
2	0.60	0.77	0.79	0.81	0.81	0.85	0.81
3	0.63	0.85	0.87	0.89	0.89	0.91	0.85
5	0.65	0.89	0.89	0.91	0.89	0.91	0.85
7	0.58	0.78	0.78	0.85	0.85	0.85	0.83

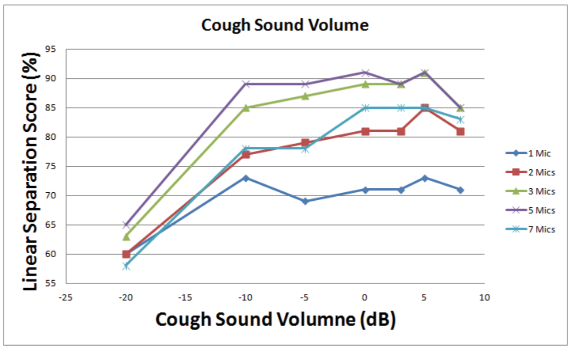

Figure 7: Microphone array LSS with cough sound volume

In the final part of this paper, the volume of the cough sounds were varied in order to determine the effect of cough sound volume on the performance of the cough sound discriminator in the presence of white noise. From the result depicted in Figure 7, it could be seen that increasing the volume of the cough sounds improved the LSS, which is due to an increase in signal-to-noise ratio (SNR). Furthermore, adding more microphones to the microphone array also improved the performance of the cough sound discriminator. The increase in volume at very high levels however, decreased the performance due to the fact that at high volumes, the various components of the system saturated and started injecting noise into the system.

V. DISCUSSIONS

In this paper, microphone array and beamforming techniques were used in order to improve the performance of cough sound discriminator in noisy environments. From the single-microphone cough sound acquisition, it was observed that the performance of the cough sound discriminator decreased significantly in the presence of white noise. In order to improve the performance, microphone array was used for cough sound acquisition. From Figure 5 and Figure 6, it could be seen that a significant improvement was observed when using a microphone array as opposed to a single microphone. For microphone-to-speaker distance of 50cm, a maximum LSS of 0.95 was obtained as opposed to 0.81 in single-microphone experiment. For the microphone-to-speaker distance of 200cm, a maximum LSS of 0.89 was obtained as opposed to 0.69. This significant improvement was due to the fact that microphone array and delay-and-sum beamforming algorithm provides the ability to cancel unwanted noise while amplifying desired signals. For the 50cm microphone-to-speaker distance, 5cm and 10cm microphone-to-microphone distance resulted in the maximum LSS. For the 200cm microphone-to-speaker distance, however, the 15cm microphone-to-microphone distance resulted in the best performance. These findings could be explained by the beampattern formed by each of the configurations and also by the number and location of side-lobes, which exist in each configuration. Figure 6 also reveals another interesting finding. At microphone-to-microphone distances of 15cm and 20cm, it was observed that the LSS significantly decreased when using 7 microphones. Although this observation initially seemed non-intuitive, it could be explained by taking a closer look at the experimental setup. From Figure 1, it could be observed that microphone number 7 is the closest microphone to the white noise source. As the distance between the microphone increase, microphone number 7 gets closer to the white noise source. At microphone-to-microphone distances of 15cm and 20cm, microphone number 7 is so close to the white noise source that two events occur. First, the microphone is picking up only white noise and barely any of the actual desired signals. Second, being so close to the white noise source causes the microphone to saturate and hence not capture the desired signals appropriately.

VI. CONCLUSION AND FUTURE WORK

In this paper, the performance of the cough sound discriminator was studied in noisy environments using a single microphone for cough sound acquisition. Furthermore, a microphone array was used to improve the performance of the cough sound discriminator in such environments. The effect of microphone arrays on the performance of the cough sound discriminator was fully analysed under various microphone-to-speaker and microphone-to-microphone distances and by varying the number of microphones and volume of the cough sounds. Future work in this area should focus on exploring other types of beamforming algorithms, developing new feature extraction algorithms capable of discriminating between dry and wet cough sounds under noisy and reverberant environment and finally developing a cough sound classifier.

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