Smart noise reduction based on reliability of direction-of-arrival estimate

Mitsunori Mizumachi
Kyushu Institute of technology, Japan, Email: mizumach@ecs.kyutech.ac.jp

Introduction

Noise reduction plays an important role to achieve acoustic signal processing in the real world, because acoustic signals are quite fragile in the presence of interferences such as competing sound sources, background noises, and room reverberation. Until now, to solve this problem, various kinds of noise reduction methods have been proposed. Spectral subtraction [1] is the most well-known approach with a single channel observation, and microphone array is employed in spatial filtering to reduce directional acoustic noises [2]. In general, each method assumes some constraints in a target sound source and an acoustic environment. In other words, each approach has both advantages and drawbacks when it is used in the real world.

In this paper, smart noise reduction is proposed by suitably choosing spectral subtraction or beamforming based on acoustic and spatial information extracted from multi-channel observations. Direction-of-arrival (DOA) is the important feature in spatial signal processing. The author has proposed a noise-robust DOA finder with both source dynamics and environmental noise models [3]. The DOA finder also conducts noise reduction to update noise model in each time step, and works well in stationary noise environments. It is, however, difficult for the DOA finder to deal with non-stationary noises. To solve the problem, the author has considered to measure reliabilities of DOA estimates [4]. In this paper, suitable noise reduction method is adaptively employed depending on DOA reliability to deal with non-stationary noises.

Relationship Between Noise Reduction and DOA Estimation

Model-based DOA estimation

The DOA finder, which is previously proposed by the author [3], employs both the model of the dynamics of a target sound source and environmental noise model. It is important for obtaining accurate DOA estimates to consider the source dynamics, because sound sources such as human speakers usually move continuously and smoothly. On the other hands, the environmental noise model contributes to improve noise robustness for DOA estimation. There is a dominant frequency, which can be selected out by comparing a spectrum of a noisy observation with the noise spectrum estimated in the previous time. DOA estimation is carried out using band-limited observed signals in the dominant frequency. An accurate DOA estimate gives a good noise estimate by beamforming, and an accurate noise estimate yields more accurate DOA estimates. Synergic integration of DOA estimation with noise reduction has been achieved throughout accurate noise estimation, which is an another side of noise reduction.

Robust noise reduction for DOA estimation

Assuming that the temporal change of an environmental noise signal is less dynamic than that of a target speech signal, we can model the spectral characteristic of the acoustic environment by subtracting the noise estimate from the noisy observation in the deterministic manner of spectral subtraction [3]. However, acoustic environments are time-invariant and difficult to exactly predict the characteristics under non-stationary noise scenes.

In this paper, to deal with non-stationary noises, noise model is adaptively updated using some acoustic and spatial information only when model update is required. In other words, smart noise reduction is required to achieve robust DOA estimation, and robust DOA estimation achieve noise reduction with high accuracy.

Smart Noise Reduction

Smart noise reduction can be achieved by understanding acoustic scene correctly, because we can select out the proper approach depending on acoustic scene. Time-varying acoustic scene is difficult to describe the whole characteristics, but it can be modeled with some parameters. In this paper, we focus on reliability of a DOA estimate to understand the complexity of acoustic scene. DOA estimation is carried out through state estimation of spatial features, which is cross-correlation between 2-ch observations [5]. The state estimation can be done by particle filtering [6] considering a target source model [7]. It is found that effective sample size [8] is good estimator to DOA reliability [4].

Noise model is adaptively updated based on both existence probability of a target signal and DOA reliability given by effective sample size as shown in Table 1. Here, estimating noise model corresponds to noise reduction. In the view point of noise reduction, either spectral subtraction or beamforming is properly employed based on DOA reliability as shown in Table 2.

Performance Evaluation

The proposed noise reduction method is incorporated into DOA estimation. As the performance of the smart noise reduction, DOA estimate is indirectly given in

Signal	DOA reliability	**Noise model**
no	-	Update using observation
yes	low	Nothing to do
yes	high	Update by beamforming

Table 1: Adaptive scheme for updating noise model based on both signal existance probability and reliability of DOA estimate.

Signal	DOA reliability	**Noise reduction**
no	-	Nothing to do
yes	low	Spectral subtraction
yes	high	Beamforming

Table 2: Adaptive noise reduction which is also used for updating noise model.

Figure 1. Noise scenarios is prepared as stationary factory noise [9] with some sudden white noises around 150th-250th and 450th-550th frames. When true DOA trajectory of a target speech signal [10] is set as shown in a black line, DOA estimates with the proposed adaptive noise model, which is updated as described in Table 1, and a static noise model, which is prepared in advance as well as spectral subtraction, are given in each time by blue and red lines, respectively.

It is obvious that the proposed adaptive noise estimation, that is, smart noise reduction, contributes to improve noise robustness in DOA estimation.

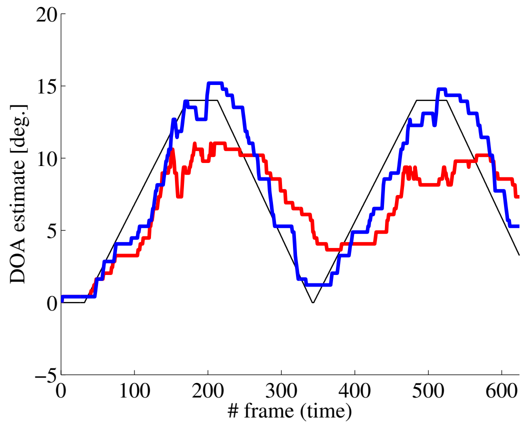

Figure 1: DOA estimates with the proposed adaptive noise model in Table 1 and a static noise model are plotted in each time by blue and red lines, respectively. Black line shows a true DOA trajectory.

Conclusions

This paper proposed smart noise reduction by understanding acoustic scene. Noise reduction is incorporated into DOA estimation, and updates a noise model, which aims at improving noise robustness in DOA estimation. Based on acoustic and spatial information extracted from multiple observations, either spectral subtraction or beamforming is carried out based on both a reliability of each DOA estimate and target signal detection. As a result of performance evaluation, the proposed adaptive noise method has a significant advantage in DOA estimation under non-stationary noise conditions over a static noise model.

Acknowledgment

This study was partially supported by Industrial Technology Research Grant Program in 2008 from New Energy and Industrial Technology Development Organization (NEDO) of Japan, and the Grant-in-Aid for Young Scientists (B) from the Ministry of Education, Science, Sports and Culture of Japan.

References

[1] S. F. Boll, “ Suppression of acoustic noise in speech using spectral subtraction, ”IEEE Trans. Acoust., Speech, and Signal Process., vol. 27, no. 2, pp. 113-120, 1979.

[2] M. S. Brandstein and D. B.Ward (eds.), *Microphone Arrays: Signal Processing Techniques and Applications*, Springer-Verlag, 2001.

[3] M. Mizumachi and K. Niyada,“ Synergic integration of noise reduction and DOA estimation with stochastic target sound source and deterministic noise models, ”Proc. Intl. Congress of Acoustics (ICA2007), CD-ROM, 2007.

[4] M. Mizumachi and K. Niyada, ”Robust direction-of-arrival estimation by particle filtering with confidence measure based on effective sample size under noisy environments,” Proc. Joint 4th Intl. Conf. on Soft Computing and Intelligent Systems and 9th Intl. Sympo. on advanced Intelligent Systems (SCIS&ISIS 2008), CD-ROM, 2008.

[5] C. H. Knapp and G. C. Carter, ”The generalized correlation method for estimation of time delay, ” IEEE Trans. Acoust., Speech, Signal Process., Vol. 24, pp. 320–327, 1976.

[6] A. Doucet, J. F. G. de Freitas, and N. J. Gordon, *Sequential Monte Carlo Methods in Practice*, Springer-Verlag, New York, 2001.

[7] M. Mizumachi and K. Niyada, ”DOA estimation using cross-correlation with particle filter,” Proc. Joint Workshop on Hands-Free Speech Communication and Microphone Arrays (HSCMA2005), CD-ROM, 2005.

[8] J. S. Liu and R. Chen, “ Blind deconvolution via sequential imputations, ”J. Amer. Stat. Assoc., vol. 90, pp. 567-576, 1995.

[9] A. Varga, H.J.M. Steeneken, “ Assessment for automatic speech recognition: II. NOISEX-92: A database and an experiment to study the effect of additive noise on speech recognition systems, ” Speech Comm., vol. 12, no. 3, pp. 247-252, 1993.

[10] R. G. Leonard,“ A database for speaker independent digit recognition, ”Proc. Intl. Conf. on Acoust., Speech, and Signal Process. (ICASSP ’84), vol. 9, pp. 328-331, 1984.