עיצוב אלומה מרחבי מבוסס משוב עם ~~אפליקציות~~ לעיבוד אותות אקוסטיים
Feedback Based Spatial Beamforming With Applications ~~of~~ Acoustic Signal Processing

Yehezkel Karo Itay

Supervisor: Prof. Cohen Israel
External supervisor: Dr. Dvorkind Tsvi

2017/11/02

Introduction

~~The analogy between~~ uniform linear array (ULA) processing in the spatial domain ~~and the~~ finite-impulse-response (FIR) filtering in the time domain ~~is well known~~ (e.g. [1]). The ~~equivalence~~ arises because the temporal FIR's input is composed of equally time-spaced samples ~~where is~~ the ULA's input is obtained by equally spatially-spaced samples of the impinging wavefront. Both temporal FIR filtering and array based spatial filtering assign weights to each sample in order to achieve a desired temporal/spatial response. From time domain filter design theory, it is well known that infinite impulse response (IIR) filters attain certain advantages over FIR filtering. A natural question to consider is "what is the array structure in spatial domain which is analogous to IIR filtering in the time domain"? The motivation for finding ~~the~~ IIR equivalent in the spatial domain is obvious:

- Increased degrees of freedom over conventional array processing to control the array response.
- Substantially lower number of taps (smaller number of array elements and reduced array aperture) is required for obtaining a desired response in comparison to FIR based design. This, naturally, results in cost-efficient array.

In his PhD thesis [2], Wen presented the same question. The suggested approach in that work for achieving "spatial-IIR" fitlering was to use shifted-sub-arrays, in order to approximate the the auto-regressive part of the filter. As also mentioned in [2], this method only enables frame-by-frame processing and is not a full IIR implementation. Additional works [3, 4, 5, 6, 7, 8] ~~are taking~~ a different approach of 2D spatio-temporal filtering. In particular, the wavefront is viewed as a two dimensional signal, and the processing is done by performing IIR filtering in the time domain, but only FIR filtering (using ~~the~~ finite number of sensors) is performed in the spatial domain. These methods suffer from the need of incorporating the time domain while the processing should be purely spatial. Furthermore, restricting the IIR processing to the time domain misses the main goal of achieving a purely spatial IIR design.
In this ~~thesis~~ we propose ~~a genuine~~ spatial-IIR filtering. As time-domain filter design relies on feeding back the filter's input with a combination of it's taps, our approach relies on spatial feedback of received array signals back to the transmitter. In the context of acoustic ~~signals~~ processing, a cooperative speaker will hold an electronic or acoustic transponder. Thus, the received signals at a microphone array will consist of the direct speech signal of the speaker, and a feedback signal which was recorded by the array at a previous time epoch (see Fig 1). Naturally, this suggested approach requires a cooperative speaker/source but, as will be explained, genuine spatial-IIR filtering will be achieved by this scheme. It can be shown that with this approach one gets the transfer function of the overall system

$$y_\theta^{\mathcal{F}}(\omega) = \frac{\boldsymbol{\alpha}^T \boldsymbol{d}_\theta e^{-j\omega\tau_{pd}}}{1 - \boldsymbol{\beta}^T \boldsymbol{d}_\theta e^{-j\omega(\tau_{pd}+\tau_{tx})}} x^{\mathcal{F}}(\omega)$$

where x is the source signal, y is the beamformer output, θ is the direction-of-arrival (DOA) angle of the received signal, $\boldsymbol{\alpha}, \boldsymbol{\beta}$ are user-controlled coefficient vectors, $\boldsymbol{d}_\theta$ is the steering vector, τ_{pd} and τ_{tx} are the propagation delay from the source to the reference sensor and the feedback transmission delay

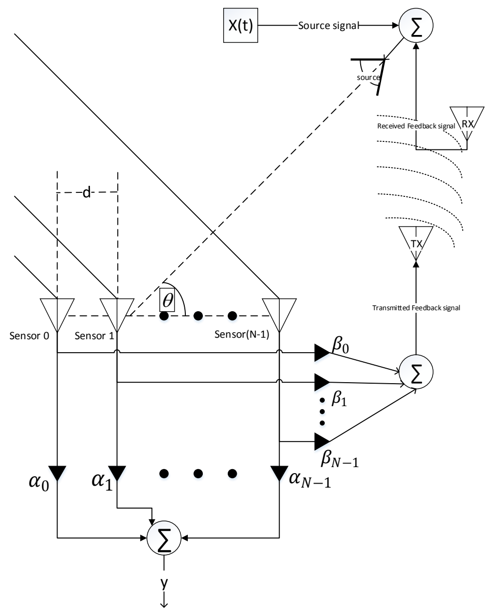

Figure 1: ~~The~~ proposed system: A far field source is received by an array. The received signal is also retransmitted back to the source. The latter has a transponder which feeds the signal back to the array.

respectively. ^{T} stands for the transpose operator and the super-script $^{\mathcal{F}}$ represents the Fourier transform. The existence of θ dependent denominator in the transfer function implies that the spatial filtering is indeed IIR-like for cooperative speakers.

Research goals

In this ~~thesis proposal~~ we will investigate and develop methods of choosing the coefficients $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ when a desired beam-pattern, $H_{\cancel{wanted}}(\theta)$, is to be approximated. We will examine the outcome of partial knowledge of the propagation delays τ_{pd}, τ_{tx} and their influence on the stability of the filter. Another possible direction of research is to consider a more realistic reverberant channels which are common in acoustical environments, rather than the simple one-tap channel presented here. Simulations of dynamic spatial filtering of multi-speakers will be presented and compared to other conventional methods such as the classical delay and sum beamformer. ~~If time permits~~, we ~~may also~~ implement the above suggested system.

References

[1] Barry D Van Veen and Kevin M Buckley. Beamforming: A versatile approach to spatial filtering. *IEEE assp magazine*, 5(2):4–24, 1988.

[2] Fuxi Wen. *Array signal processing using spatial domain infinite impulse response structure and volterra model.* PhD thesis, 2013.

[3] H. L P Arjuna Madanayake, Leonard Thomas Bruton, and Sean V. Hum. A Systolic Array 2-D IIR Broadband RF Beamformer. *IEEE Transactions on Circuits and Systems II: Express Briefs*, 55(12):1244–1248, 2008.

[4] H. L.P.Arjuna Madanayake and Leonard T. Bruton. Systolic array processors for 2D IIR spatio-temporal beamforming wave-digital filters (WDFs). *IEEE Pacific RIM Conference on Communications, Computers, and Signal Processing - Proceedings*, (1):47–52, 2009.

[5] H L P Arjuna Madanayake, Student Member, and Len T Bruton. A Systolic-Array Architecture for First-Order 3-D IIR Frequency-Planar Filters. 55(6):1546–1559, 2008.

[6] L. T. Bruton. Three-dimensional cone filter banks. *IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications*, 50(2):208–216, 2003.

[7] C. Ward, P. Hargrave, and J. McWhirter. A novel algorithm and architecture for adaptive digital beamforming. *IEEE Transactions on Antennas and Propagation*, 34(3):338–346, 1986.

[8] Rimesh M. Joshi, Arjuna Madanayake, Jithra Adikari, and Len T. Bruton. Synthesis and array processor realization of a 2-D IIR beam filter for wireless applications. *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, 20(12):2241–2254, 2012.