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A Novel Method for Achieving Spatial Infinite Impulse Response Processing

Feedback based spatial beamforming, with applications of acoustic signal processing.

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Research goal

goal

~~The main research goal in this thesis proposal is to find a spatial analogous to the temporal IIR filter architecture, develop methods of shaping the spatial response of such system and investigate its stability in partial environmental parameters knowledge.~~

~~Abstract~~ 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 time-domain From filter design theory, it is well known that infinite impulse response (IIR) filters attain certain advantages over FIR filtering.

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. A natural question to consider is "what is the array structure in spatial domain which is analogous to ~~infinite-impulse-response~~ (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 true 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.

As time-domain IIR filter design relies on feedback from the filter taps and its output back to the filters' input, our...

In this thesis we propose a true spatial-IIR filtering. ~~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. Naturally, this suggested approach requires a cooperative speaker/source but, as will be explained, a pure spatial-IIR filtering will be achieved by this scheme. It can be shown that with this approach one gets the transfer function of the

See fig. ...

overall system

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

direction of arrival

beamformer angle

where x is the source signal, y is the ~~receiver~~ output, θ is the DOA of the received signal, $\boldsymbol{\alpha}, \boldsymbol{\beta}$ are user-controlled coefficient vectors, $\boldsymbol{d}_{\theta}$ is the steering vector ~~with n'th element $e^{-j\omega\tau_{n,\theta}}$~~, τ_{pd} is the propagation delay from the source to the reference sensor and τ_{tx} is the feedback transmission delay. ^{T} stands for the transpose operator and the super-script $^{\mathcal{F}}$ represents the Fourier transform. The shape ~~of~~ the transfer function implies that the spatial filtering is indeed IIR-like for cooperative speakers. ~~thus achieving the main part of our research goal.~~

לציין.
τ_{tx}, τ_{pd}

We note that the current form of spatial filter requires knowledge of the prop. delay.

existance of the denominator in

Research goals

להוציא את
המסקנה
הזהירה
בהבדלה הזו
כרגע.

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.