Spatial IIR – Thesis proposal

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Abstract

The analogy between spatially, linearly and uniformly distributed sensors (ULA - uniform linear array) processing (beam-forming) and a finite-impulse-response (FIR) filter [6] laid the grounds for the "spatial-processing" concept which enables the filtering (or nulling) of signals according to their direction-of-arrival (DOA). This analogy comes to mind when observing that for a given DOA, the time difference between the arrival of the signal between consecutive sensors is constant, similarly to a digital filter which samples its input at a constant rate in time. One can interpret this analogy as having a different filter for each DOA with the same coefficients but different sample rate in time. After observing the ULA-FIR analogy, one may ask what kind of receiver will be analogous to infinite-impulse-response (IIR) filter. Obviously, the motivation for a spatial IIR filter, as in the time-domain, is the ability to generate a "sharp" spatial filter response with minimal number of coefficients, i.e. minimal number of antennas, which will enable cost-efficient enhancement of specific DOAs and suppression of others. For this purpose, [8] presented "spatial-IIR" filter using shifted-sub-arrays to generate the delays in the auto-regressive part of the filter as can be seen in figure 1. The downside in this method is that it only enables

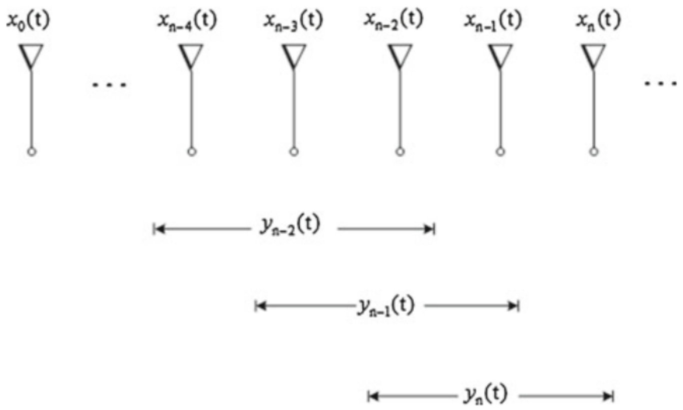

Figure 1: The sub-array solution for the spatial auto-regressive part of the filter

frame-by-frame processing and not an actual IIR which is influenced from all it's input's history. In other words, they still implement a time-domain IIR and not a spatial one. The inter-frame processing is not possible due to the fact that the user cannot know the time difference between consecutive frames for it depends on the DOA. Other papers ([3, 5, 4, 1, 7, 2]) are taking a different approach of 2D filtering, in both spatial and temporal domains simultaneously. All those methods suffer from the need of involving the time domain when the the processing should only be spatial. The plane-wave relation in 2D translates to a straight line in the spatio-time that should be enhanced by the filter. As in any filter-design scheme, the actual filter response differs from the ideal one and some trade-offs must be made. Our proposed approach is a source-sensor-cooperated-IIR-beam-former which assumes that the source can also transmit a synthetic signal which will be fed back in addition to its own signal, thus, as will be explained, enabling real IIR transfer function purely in the spatial domain.

Signal model

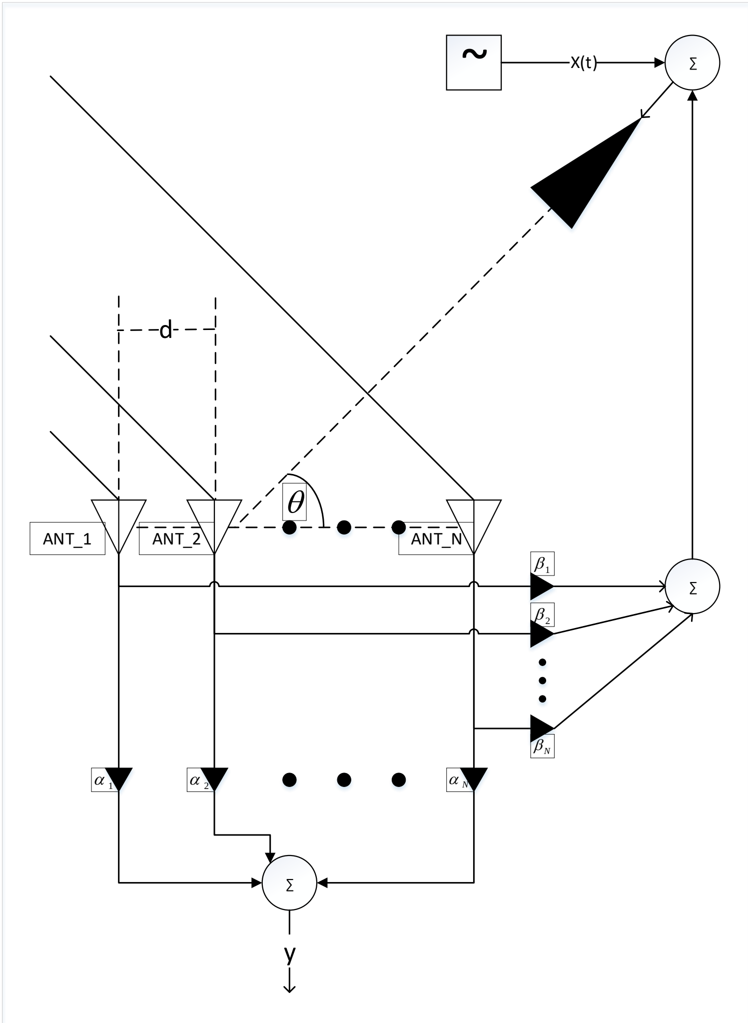

Figure 2: The proposed system : A source of far-field signal, which is received by a uniform-linear-array (ULA), also transmits a synthetic signal which is fed back to it.

By creating the set-up in figure 2, we hope to achieve the spatial-IIR which was previously discussed. Among it's applications, one can imagine a scenario of a multiple-speaker stage (figure 3), where in any given time, some of them should be heard and the others should be silenced. In a more heuristic manner, the stage will have a dynamic set of "hear-zone"s which can be actively controlled by merely selecting the $\boldsymbol{\alpha}, \boldsymbol{\beta}$ coefficients. Using the notation of regular letters (x) for scalars, bold letters for vectors ($\boldsymbol{x}$), capital letters (X) for matrices and defining $x(t)$ as the source signal, $x_n(t)$ as the n'th sensor received signal, N as the number of sensors in the ULA, r as the range of the source, c as the speed of signal propagation, $\tau_{pd} = \frac{r}{c}$ as the propagation delay, τ_{tx} as the feedback transmission delay, θ as the DOA of

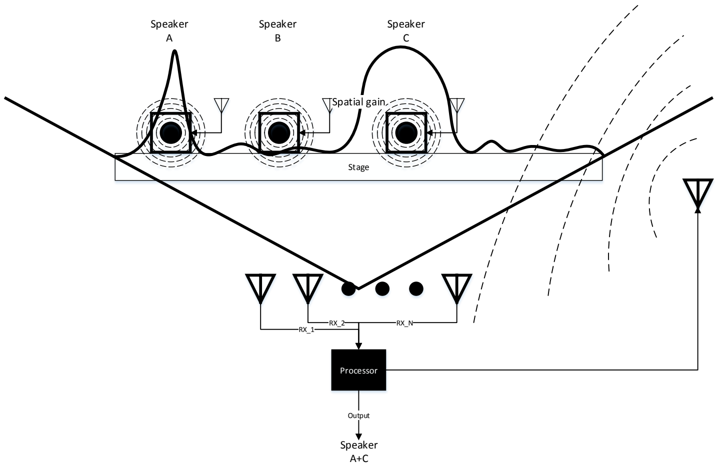

Figure 3: SpatialIIR - The multiple-speaker stage scenario.

the signal, and $\tau_\theta = \dfrac{d\cos(\theta)}{c}$ as the relative delay between the signal arrival to the sensors, one can extract the temporal relation which defines the overall system

$$x_n(t,\theta) = x(t - \tau_{pd} + n\tau_\theta) + \sum_{m=1}^{N} \beta_m x_m(t - \tau_{pd} - \tau_{tx} + m\tau_\theta) \tag{1}$$

and after some math, one gets the transfer function of the overall system

$$h(\omega, z) = \frac{\sum_{n=1}^{2N-2} \kappa_n z^{n-1}}{1 + e^{-j\omega(\tau_{pd}+\tau_{tx})} \sum_{m=1}^{N} \beta_m z^{m-1}} X(\omega) \tag{2}$$

where

$$\kappa_n = \begin{cases} e^{-j\omega\tau_{pd}}\alpha_n + e^{-j\omega(\tau_{pd}+\tau_{tx})} \displaystyle\sum_{m=1}^{n} \beta_m \alpha_{n+1-m} + \beta_{1+\frac{n}{2}} \sum_{r=1}^{N} \alpha_r, & \text{if } (n \bmod 2) = 0 \\ e^{-j\omega\tau_{pd}}\alpha_n + e^{-j\omega(\tau_{pd}+\tau_{tx})} \displaystyle\sum_{m=1}^{n} \beta_m \alpha_{n+1-m}, & \text{otherwise} \end{cases}$$

and the purpose of our thesis proposal is to investigate and develop methods of choosing the coefficients $\boldsymbol{\alpha}_{opt}$ and $\boldsymbol{\beta}_{opt}$ when a goal beam-pattern, $H_{wanted}(\omega, z)$, is presented to achieve

$$h(\omega, z, \boldsymbol{\alpha}_{opt}, \boldsymbol{\beta}_{opt}) \approx h_{wanted}(\omega, z)$$

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