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Wideband Laguerre adaptive array with pre-steering constraints

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Abstract: Replacing TDL filters with Laguerre filters in the popular wideband Frost space-time array has resulted in a far better performance, lower computational load and faster convergence rate. Compared with IIR-based arrays, the Laguerre design also offers guaranteed convergence, much simpler design with lower computational complexity and better SINR. However, one limiting factor in all these three broadband space-time beamformers is the quantisation error in the front-end pre-steering delays which are used to compensate for the effect of misalignment between the array geometry and the look direction. To make the Laguerre beamformer robust against the quantisation error, a set of frequency domain constraints is introduced in its linearly constrained minimum variance formulation to replace the pre-steering delays. These constraints are also very flexible in incorporating different requirements such as creating multiple desired beams, placing nulls in interference directions, null broadening and pattern synthesis considerations while all these features can be handled in an adaptive manner. The comprehensive set of simulation results not only shows that the proposed algorithm outperforms the existing TDL or IIR based beamformers but it also demonstrates its great flexibility in achieving the desired pattern.

1 Introduction

There has been an increasing interest in developing wideband beamforming methods in various areas ranging from microphone arrays to wireless communication systems [1–4]. Owing to its prominent features and its simple adaptive procedure, the pioneering design of the Frost space-time beamformer, shown in Fig. 1*a*, and its associated linearly constrained minimum variance (LCMV) algorithm have been the centre of attention in many wideband beamforming design methods [1–6]. In the Frost beamformer, pre-steering delays are followed by tapped delay line (TDL) filters in each branch of the array as it is shown in Fig. 1*b*. Pre-steering delays are used to align the desired wideband signal impinging on the sensors while TDL filters are employed to create a frequency independent pattern for them [6].

To increase the performance of the Frost beamformer, replacing TDL filters with IIR filters has been proposed by some authors [7–9]. However, since poles of the IIR filters are calculated adaptively, using such beamformers increases the risk of instability and convergence to a non-optimal solution.

In [10] we proposed replacing TDL filters with Laguerre filters in the Frost beamformer as it is shown in Fig. 1*c*. Since the Laguerre filter has only one pole, which is optimally determined through an off-line procedure, it obviates the instability problem. Furthermore, because of the orthogonality feature of the Laguerre functions, the Laguerre beamformer design greatly reduces the number of weights and the computational load while it is still demonstrating a great performance [10].

As it is shown in Fig. 1*a*, in most space-time beamforming structures, regardless of which method is used for time domain filtering, pre-steering blocks are used at the front-end. As mentioned previously, these blocks are basically used to steer the pattern towards the desired signal [5, 6]. However, using pre-steering delays is not a favorite approach because of its practical hurdles [11–15]. We not only need to adaptively change these pre-steering delays, if we wish to track the desired signal at different directions, but we should also tune these delays precisely otherwise the desired signal may be considered as an interference and suppressed accordingly. This is particularly important with the presence of error in the positions of sensors, lack of accuracy in the estimation of the desired direction or quantisation error in setting the pre-steering values [12, 15, 16].

Although using interpolation techniques or invoking fractional delay filters have been considered to mitigate the effect of quantisation errors in pre-steering delays [17–19], elimination of pre-steering delays and incorporating their effects in the constraint matrix of the LCMV formulation has been the more favorite approach [13, 20–22]. Based on the same notion, we have recently proposed a set of frequency domain constraints which considers both the distortion-less response and the steering requirement in a much simpler and more effective manner in a TDL-based beamformer [15]. The goal of the current article is to extend these frequency domain constraints to the specific case of the Laguerre wideband beamformer.

In our earlier work [10] we showed in details that our proposed Laguerre beamformer outperforms both TDL and IIR-based beamformers when ideal pre-steering delays are assumed for all methods. However, just like the other two methods the Laguerre beamformer suffers performance degradation with quantisation error in the pre-steering blocks. Therefore our goal in the current article is to eliminate the pre-steering blocks in the Laguerre beamformer but incorporate their effects into the constraint matrix of the LCMV algorithm. This not only resolves the quantisation error while preserving all the prominent features of the Laguerre design but it will also allow us to steer the beam in real-time through the adaptive procedure of the Laguerre LCMV formulation. Besides, we show that by using this method, pattern synthesis requirements can be incorporated into the adaptive LCMV formulation of the beamformer, reconciling these two rather different design strategies. Specifically, we can enforce different attenuation levels to different interference sources, consider multiple desired beams, apply null broadening techniques to make the beamformer robust against directional errors, or consider other desired requirements. Since all these requirements are incorporated into the constraint matrix of the