Super-Resolution DF for Passive Bistatic Radar

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Introduction

Bistatic radar is radar which has separate transmission and reception sites. Bistatic radar has the advantage of keeping the receiver site covert [1], and mitigating the covertness of many stealth targets [2] (which are typically optimised for monostatic radars). However, there are several challenges that the bistatic configuration introduces to the radar. One of these is the way in which direction finding (DF) is handled.

In most monostatic radars, a bream is merely steered in a particular direction either physically or electronically. In bistatic radar, this method is highly inefficient, due to the small detection region as illustrated in Figure 1, and the long integration times required for passive radar in particular.

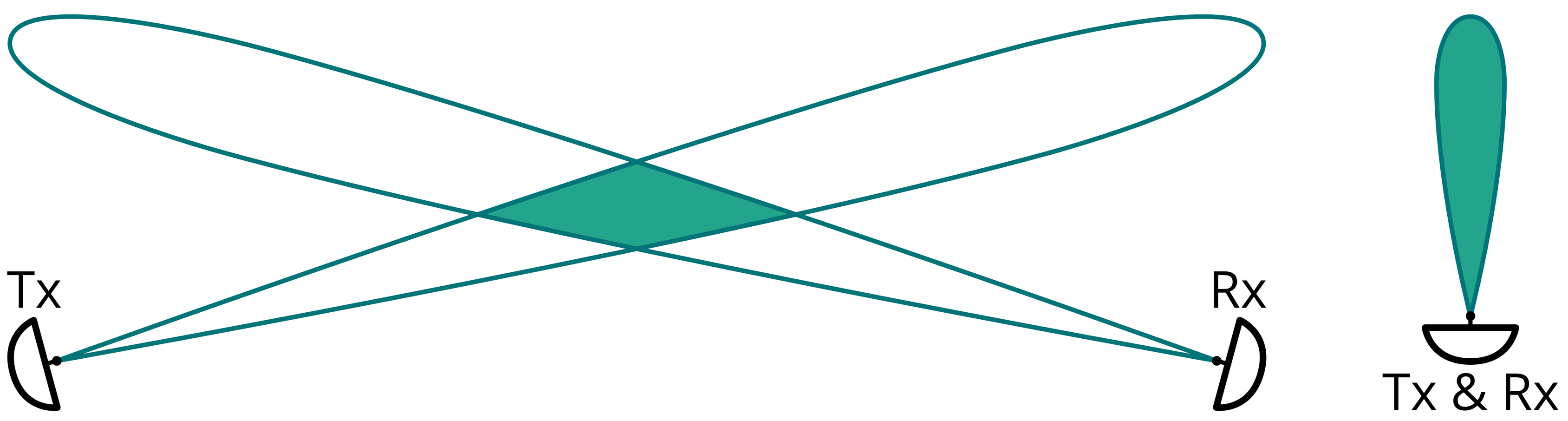

Figure 1. The directional antenna beams of a bistatic (left) and a monostatic (right) radar, with the detection region show (filled region).

One approach is to use an antenna array and form a fan beam [2] to cover a larger area as shown in Figure 2, and then process each beam individually.

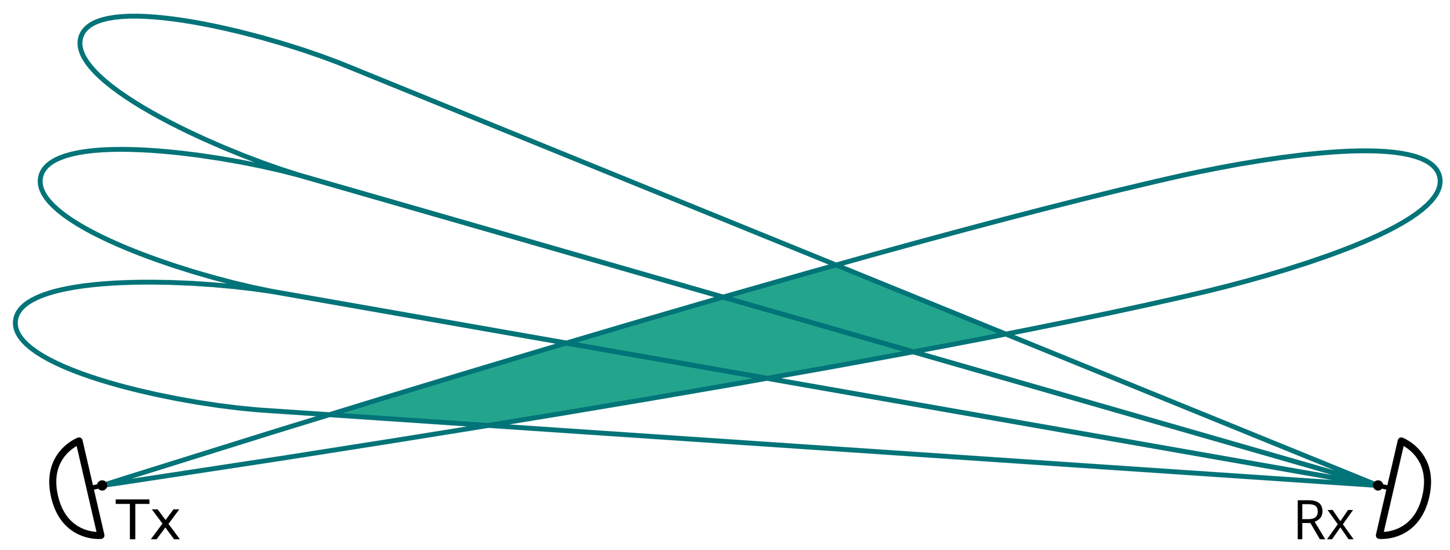

Figure 2. Fan-beam bistatic configuration, with detection region (filled).

In order to overcome these limitations, phase-interferometry [3], and beamforming [4] have been applied to range-Doppler maps (i.e. after matched filtering). However, these methods are simple and display performance limitations. In the post-matched filter environment, a number of super-resolution and adaptive methods can be applied which can result in improved target separability and sidelobe suppression.

Angular Separability

Established adaptive and super-resolution methods can be applied post-matched filter. However, in this environment there is only a single time sample, which makes the accurate estimation of statistical properties difficult. The performance of super-resolution adaptive methods are therefore not comparable to a pre-matched filter implementation.

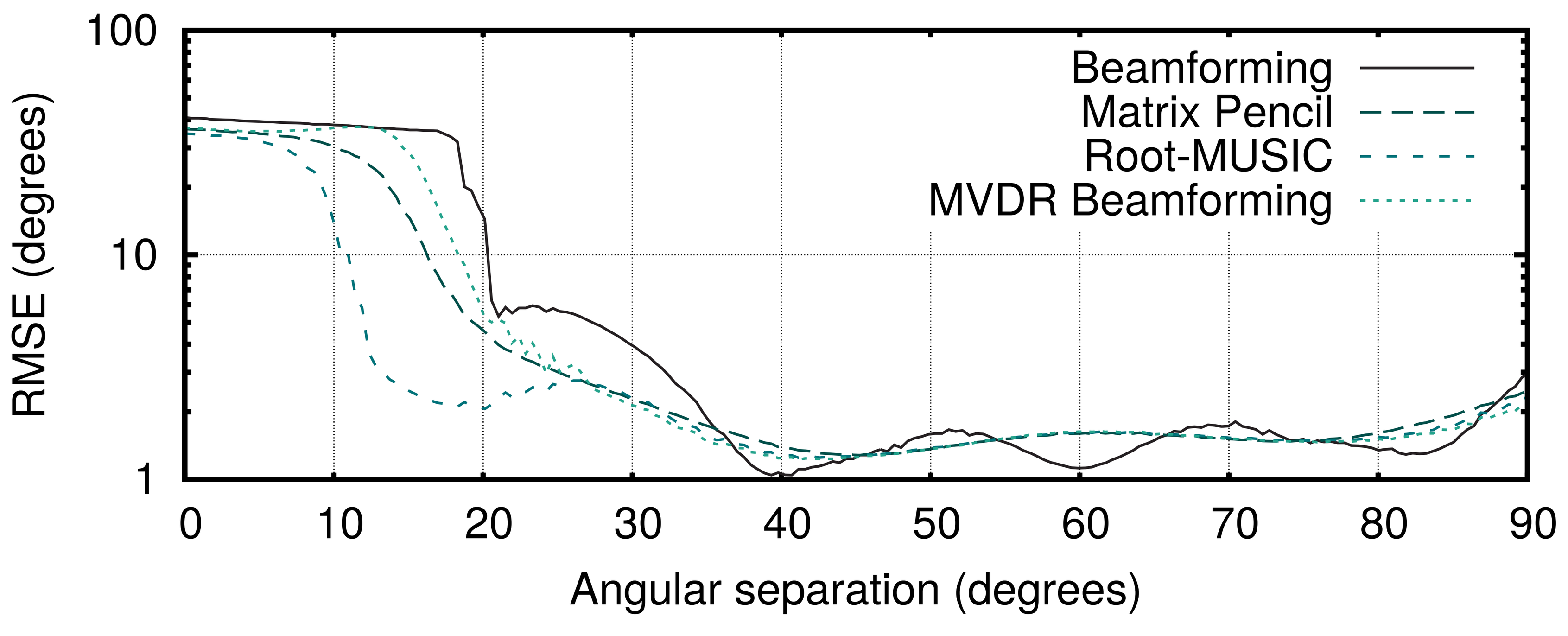

Figure 3. Broadside accuracy of a five-element linear array with two signals.

Figure 3 compares the angular resolution of a few post-matched filter DF estimation methods at a signal to noise ratio (SNR) of 15dB. Beamforming is only able to achieve a root mean square error (RMSE) of 5° when the angular difference is at least 37°. The more advanced methods are seen to improve the accuracy with Root-MUSIC achieving a 5° RMSE with a 56% smaller angular separation. Furthermore, the accuracy of the advanced methods is more stable as the angular separation varies.

Eigenvalue Detection

One issue that arises when applying super-resolution DF techniques is that traditional radar-detection techniques cannot be applied. Fortunately, eigen-decomposition of the covariance matrix is an integral part of many DF methods. The eigenvalues produced by this decomposition can be used to estimate the number of signals present in a given data set.

Figure 4 shows the probability of detection for a five-element array with a probability of false alarm (PFA) equal to 10^{-3}. The Neyman-Pearson bound is the theoretical best that a threshold algorithm can achieve [5], CA-CFAR is a cell averaging constant false-alarm rate detector using four interference samples. MME is a method where the maximum eigenvalue is compared to the smaller eigenvalues' mean. The number of time samples used to estimate a covariance matrix is denoted by K, and the SNR is adjusted to compensate for the coherent gain achieved when combining multiple time samples.

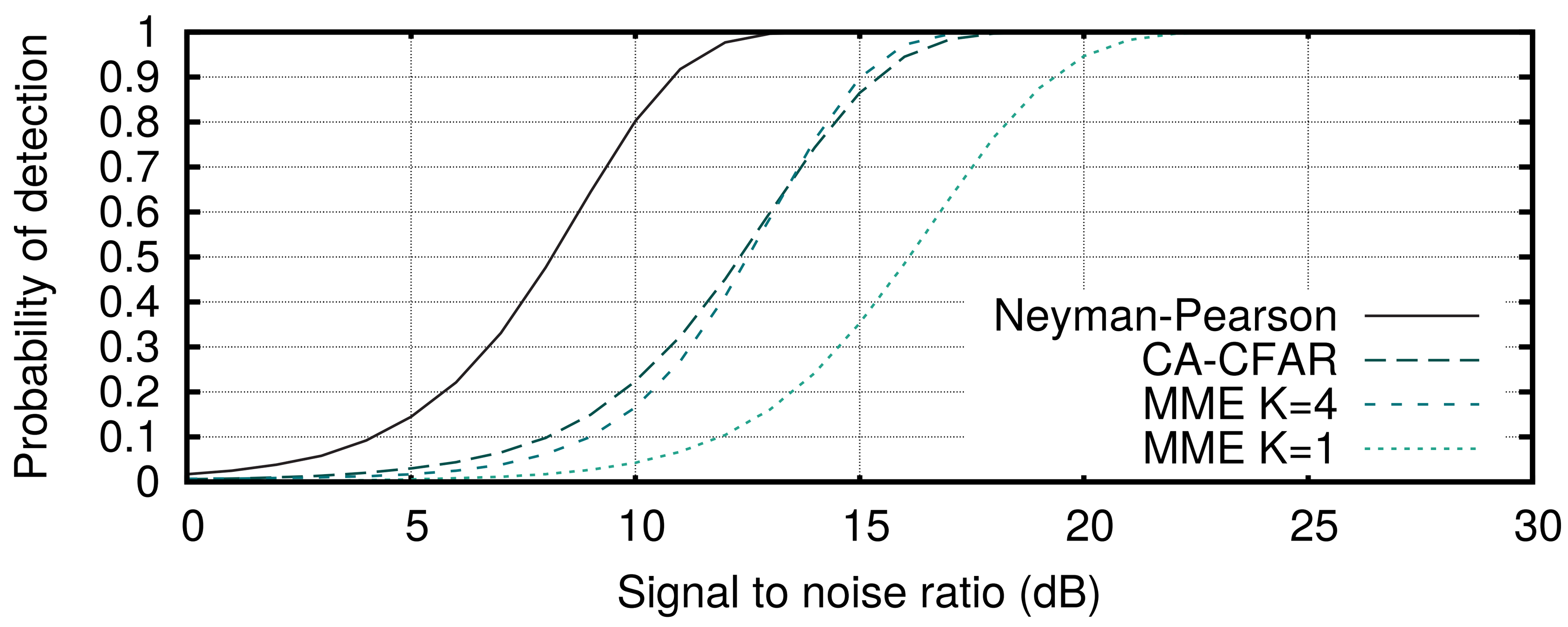

Figure 4. Probability of detection for a five element array with PFA=10^{-3}.

It can be seen in Figure 4 that the MME detector's performance is far worse than that of the CFAR detector with one time sample. However, the MME detector's performance is similar to that of the CFAR detector with four time samples. It should be noted, that the MME detector detects the presence of a signal over the entire angular dimension, while the CFAR and Neyman-Pearson detectors only test a single direction. As such, the true false-alarm rate of the MME detector is lower than the CFAR and Neyman-Pearson detectors for a given PFA.

Conclusion

It is possible to use an antenna array and super-resolution DF techniques to improve the angular separability of a passive bistatic radar. Using eigenvalue-based detection methods allows comparable detection performance to a conventional radar, but only when multiple time samples are used to estimate the covariance matrix.

References

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