High-Resolution DOA Estimation Using Maximum Likelihood Methods with Low RCS Targets

SANG-YEON LEE
School of Electronic Engineering
Soongsil University
Seoul, Korea
leesy0916@soongsil.ac.kr

YONG-HWI KWON
School of intelligent semiconductors
Soongsil University
Seoul, Korea
rnjsdydgnl2@soongsil.ac.kr

CHUL-KI KIM
School of Electronic Engineering
Soongsil University
Seoul, Korea
chulki@ssu.ac.kr

A. Introduction

Accurate direction-of-arrival (DOA) estimation is a critical task in automotive radar systems. This paper proposes a single-snapshot DOA estimation algorithm based on the maximum likelihood method, designed for low-RCS environments.

B. DML Algorithm

The proposed approach first identifies the maximum peak from the FFT-based beamforming spectrum and refines it through quadratic interpolation. The power difference of the maximum peak across transmit-receive antenna pairs is then analyzed to distinguish between single-target and multi-target scenarios. If the power difference is small, the single-target case is assumed and the FFT beamforming output is directly adopted. Otherwise, the multi-target case is considered. For the multi-target scenario, a resolution flag is set according to the location of spectrum nulls. Candidate peaks, excluding the maximum peak, are filtered using an adaptive threshold, where stricter criteria are applied to peaks located closer to the mainlobe. Among these, the top four candidates are selected and compared with the maximum peak. Each candidate is then processed by the Deterministic Maximum Likelihood (DML) algorithm to identify the most suitable peak. To reduce computational complexity, steering matrices and projection operators required for the DML are precomputed based on the distance from the maximum peak and stored in a look-up table (LUT). The cost function of the DML algorithm can be formulated as

$$\arg\min_{\theta}\{\boldsymbol{I} - \boldsymbol{x}^H \boldsymbol{A}(\boldsymbol{A}^H \boldsymbol{A})^{-1} \boldsymbol{A}^H \boldsymbol{x}\}$$

Depending on the resolution flag, two refinement strategies are applied. When the flag is set to 0, the selected peak is further refined by applying the DML algorithm to its ±1 neighboring indices. When the flag is set to 1 or 2, instead of using only the ±1 indices, the DML algorithm is repeatedly applied with progressively increasing offsets from the selected peak to search for the optimal estimate. Fig. 1 is a block diagram illustrating the overall flow of the proposed DOA estimation procedure for both single- and multi-target scenarios.

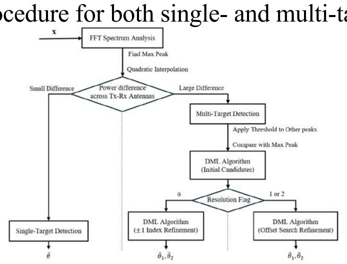

Fig. 1. Block diagram of DOA parameter estimation for one or two targets using a single snapshot

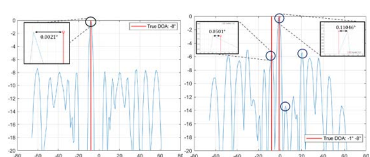

Fig. 2. DOA estimation results for one(left) and two(right) targets

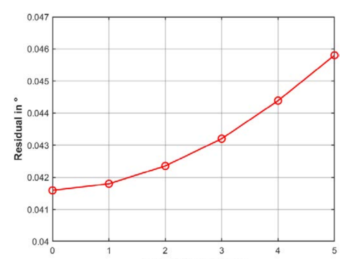

Fig. 3. Simulation Results

C. Conclusion

Simulation results demonstrate that the proposed algorithm maintains computational efficiency while achieving high estimation accuracy for both single- and multi-target cases, making it suitable for real-time automotive radar applications. Fig. 2 illustrates the DOA estimation results depending on the number of targets. In the single-target case (left), the true direction is accurately estimated, whereas in the multi-target case (right), the algorithm identifies the two optimal peaks among four candidate peaks. Furthermore, Fig. 3 shows the residual error in degrees as a function of the RCS difference (dB), indicating a consistent increase with larger RCS differences while remaining at a low level, which confirms the robustness of the proposed method. Although the proposed approach provides accurate DOA estimation, occasional misjudgments may occur in multipath environments or when interference from other vehicle radars is present. To address this, we plan to incorporate prediction-based target tracking, where discrepancies between predicted and estimated DOA values are used to identify and correct potential errors.

References

[1] J. Cordero, "DOA estimation of two targets using beamformer based methods with application to automotive radar," M.S. thesis, Technische Universität Darmstadt, Darmstadt, Germany, Sep 2011.