Chapter 10
MIMO Radar Systems:
Deep Learning vs. Traditional Approaches

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ABSTRACT

Unlike traditional phased-array radars that need successive scans to cover the entire field of view, MIMO radar transmits orthogonal waveforms from each antenna element simultaneously, allowing the illumination of all targets at once. Also, better detection performance and a high spatial resolution can be obtained using all the components extracted by the matched filters. MIMO radar systems can detect the range, angle, and doppler of the targets, using traditional techniques such as the fast fourier transform (FFT), the multiple signal classifier (MUSIC), and the minimum variance distortionless response (MVDR). On the other hand, deep learning (DL) techniques have been proposed for MIMO radar systems as an alternative to traditional techniques that are computationally expensive and very sensitive to clutters and interferences. This chapter presents the performance of MIMO radar systems in a cluttered environment using both conventional and DL techniques.

DOI: 10.4018/978-1-6684-5955-3.ch010

INTRODUCTION

Multi-input and multi-output (MIMO) radar systems have recently received considerable research interest in the automotive industry (Fishler, E. & al., 2004; Stankovic, L., 2013; Li, J. & Stoica, P., 2008; Moo, P. & al. 2013; Bekkerman, I. & Tabrikian, J. 2006; Hefnawi, M. & al. 2019; Gottinger, M. & al. 2021). Compared to traditional phased-array radars (PARs) that need successive scans to cover the entire Field Of View (FOV), MIMO radar systems transmit orthogonal waveforms from each antenna element simultaneously, allowing the illumination of the entire FOV at once. The orthogonality of the waveforms can be achieved using multiplexing techniques such as time-division multiplexing (TDM), frequency division multiplexing (FDM), code division multiplexing (CDM), or space division multiplexing (SDM) (Gini, F., DeMaio, A., & Patton, L., 2012). There are two main distinct MIMO radar architectures; the widely separated antenna (Fishler, E. & al., 2006; Nikolaus, H. & al, 2007) and the colocated antenna (Li, J. & Stoica, P., 2007, 2008). In the widely separated antenna architecture, the transmitting antenna elements are widely separated such that each views different aspect angles of the target, allowing a better detection performance. In the colocated antenna configuration, the transmitting antennas are closely spaced relative to the working wavelength such that all antenna elements see the target from the same aspect angle. A better spatial resolution can be obtained by extracting all the transmitting paths using matched filters.

MIMO radar signal processing techniques can be achieved using traditional techniques such as the Fast Fourier Transform (FFT) or high-resolution algorithms such as the Multiple Signal Classifier (MUSIC) (Schmidt, R.,1986), the Estimation of Signal Parameters via Rotational Invariance Techniques (ESPRIT) (Roy, R. & Kailath, T., 1989), and the Minimum Variance Distortionless Response (MVDR) (Capon, J. 1969). On the other hand, Deep neural networks (DNNs) have recently been proposed for MIMO radar systems as an alternative to high-resolution techniques that are computationally expensive and very sensitive to clutters and interferences. This Chapter highlights the concept of MIMO radar and its advantage compared to the PAR. The performance of MIMO radar using traditional techniques is analyzed and compared to DL techniques in the context of automotive radar to emphasize the importance of DL-based MIMO radar techniques.

BACKGROUND

In MIMO radar, the RF signals received by the elements of the antenna array are arranged in a three-dimensional array called the radar data cube (RDC), as shown in Figure 1 (Gentile, R. & Donovan, M., 2016). To estimate the range and Doppler of the targets, the FFT can be applied along the fast-time and slow-time dimensions of the RDC, respectively. The analysis across the elements of the array is used to estimate the direction-of-arrival (DoA) of the targets. This analysis can be performed with the traditional beamscan, MUSIC, or MVDR techniques. For all three algorithms, the peaks of their spatial spectrum coincide with the DOAs of the targets. The MVDR algorithm can achieve a better angular resolution than the conventional beamscan, and MUSIC provides even better spatial resolution than MVDR. However, the MVDR and MUSIC are more sensitive to sensor position errors and to clutters and interferences. In addition, MUSIC requires the number of sources to be known or accurately estimated.