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EM Estimation of a Generic 2D Object Model based on a Sparse Set of Incomplete ISAR Images

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Abstract— **This paper addresses the estimation of a two-dimensional model of an object, based on measurements with a network of High Range Resolution (HRR) scanning surveillance radars. While considering a dynamic radar scene, the data collected from the multiple radars at multiple scans of the antenna provide a wide, but highly sparse, coverage in 2D space. The multi-radar multi-scan data are treated as asynchronous. Inverse Synthetic Aperture Radar (ISAR) 2D imaging is independently performed within the narrow angular sector which is covered during each single radar scan. Each of the formed ISAR images is a rotated and incomplete version of the 2D profile of an extended object. The multi-look images are aligned and incoherently fused in a common 2D space. Their complementary information content is thus combined in a unique composite image. The Expectation-Maximization (EM) algorithm is further applied for parametric estimation of a low-dimensional 2D object model. This model constitutes a feature vector, useful for object classification. The local-only use of the phase in this overall sparse, but locally dense, sampling scheme accelerates significantly the de-ghosting of the formed 2D target images. Quicker convergence to an unambiguous estimate of the generic 2D object model is achieved, as compared to a purely incoherent processing of the sparse dataset.**

I. INTRODUCTION

The added-value from use of widely-separated views, as potentially available in a radar network, for a more complete 2D characterization of a radar target has been the subject of several studies [1], [2], [3], [4], [5].

While considering an asynchronous network of scanning radars, a highly sparse sampling scheme of the 2D reflectivity function of a radar target, as generated from radar-to-radar and from scan-to-scan, has to be incoherently processed [5]. Even if the Time-on-Target is limited within each single radar scan, coherent processing of the therein collected radar target echoes at slightly varying view angle can lead to enhancement of the achieved 2D resolution, as compared to the results of [5] and [6]. This is the objective of the study that is presented in this paper.

The high degree of irregularity of the sampling scheme under consideration complicates the 2D imaging method if it is to be applied in a common multi-radar multi-scan domain [7],[8],[9]. Multi-look ISAR imaging, by splitting of the imaging in several sparsely located sectors and fusing the resulting sub-images is a simpler and more convenient approach in this case [3]. This approach is followed here.

The paper is structured as follows: In Section II, a map of the available sampling resources in the 2D k-space is given. The irregular sampling problem is identified. In Section III, a multi-look ISAR imaging method is applied to the sparse dataset and a composite multi-radar 2D object image is formed. In Section IV, the result from application of the EM algorithm to the composite image, for estimation of a low-dimensional 2D object model, is presented. The result after multi-look ISAR-processing is compared with the result after imaging based on single range profiles. This comparison demonstrates the achieved acceleration in de-ghosting and convergence to an unambiguous 2D model estimate, with local exploitation of the phase in an asynchronous radar network. In Section V, the validity of the method is demonstrated by application to a real measured radar dataset.

II. SAMPLING RESOURCES

The source of information for the application of interest is High Range Resolution (HRR) data, which are collected by multiple surveillance radars at multiple scans. Each of the complex radar video measurements is further denoted as $A\left(f,\phi\right)$, where f stands for the illumination frequency and ϕ for the view angle of the extended object at the moment of the measurement.

The wavenumber (k-)space is an appropriate sampling domain when data from multiple radar systems, with frequency and/or angular diversity, are involved in the processing scheme. Each of the dimensions of the 2D k-space is specified as:

$$\left\{ \begin{array}{l} k_x = \frac{2\pi f}{c} \cdot cos\phi \\ k_y = \frac{2\pi f}{c} \cdot sin\phi \end{array} \right\} \tag{1}$$

where c is the speed of light.

A 2D image $Im(x,y)$ of the radar scene under surveillance can be retrieved from the available data, by applying the general inversion formula:

$$Im\left(x,y\right) = \iint_S A\left(k_x,k_y\right) \cdot e^{j\cdot 2(x\cdot k_x + y\cdot k_y)} dk_x dk_y \tag{2}$$

In Eq.(2), S is the support domain of the available data $A(k_x,k_y)$ in the 2D k-space. As depicted in Fig.1, S is highly sparse for the herein considered dataset. The example used for this visualization involves HRR data from $M = 4$ radars at