Comparison between Wavefront-Based Shape Reconstruction and Beamforming for UWB Near-Field Imaging Radar

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Abstract— **This paper investigates the performances of a wavefront-based shape reconstruction algorithm, known as Envelope, for ultra-wideband (UWB) near-field imaging. In contrast with conventional beamforming, surface estimation is based on identification of wavefronts within the received data and direct transformation from delay time to the target shape. The algorithm is compared with conventional beamforming in terms of both imaging accuracy and speed. The influence of sparsity of data acquisition on the estimated surface image is further compared showing both advantage and problems of the methods.**

I. Introduction

UWB radar system offers great potentials for applications which require high resolution near-field imaging, such as surveillance and airport security, etc. By combining with digital beamforming, such system is capable of delivering high resolution three-dimensional (3-D) images with real-time perception of the target under test. Various beamforming algorithms have been proposed [1]. However, a relative intensive computation is required for most of them in order to obtain a high quality image. Moreover, a rigid half-wavelength spatial sampling must be followed for data acquisition in order to avoid grating lobes in the resulting image from beamforming. This requires a large data volume which in turn leads to greater computation effort and longer imaging time. Therefore, we further consider the possibility of reconstructing the target shape without the integral process of digital beamforming.

A fast imaging algorithm, referred as SEABED (Shape Estimation Algorithm based on BST and Extraction of Directly scattered waves), has been proposed for UWB pulse radar [2] [3]. It directly transforms delay time to target shape by using the information obtained from the wavefront, specifically derivatives of the received data. However, the image becomes unstable when the extracted wavefront is less ideal under noisy and complex target conditions. To solve this problem, another algorithm based on the envelope of circles is proposed [4]. The algorithm calculates circles with estimated delays for each scan position and utilizes the principle that the envelope of circles surrounds the target boundary. By avoiding the derivative of the data, some error caused by SEABED can be resolved. In this paper, we test the wavefront-based algorithm for UWB near-field imaging and compare the results with conventional beamforming algorithms. Advantage and disadvantage of the algorithms are indicated under specific conditions, which help indicate directions for further development. The algorithms are further applied for 3-D imaging problems with complex target shape by synthetic aperture radar (SAR) experiments.

The paper is organized as follows. Section II introduces the formulations of the problem and algorithms. The procedure of the method is also discussed. In Section III the performance of the algorithms are compared in terms of accuracy, speed, and degradation of aperture thinning. Three-dimensional experimental results are presented and discussed in Section IV. Conclusions are summarized in the final section.

II. Formulation

In this section, the system model and formulation of the algorithms are introduced. The implementation procedures are explained and illustrated by intermediate results.

A. System Model and Numerical Simulation

Two-dimensional model is assumed for better illustration of the procedure. The antenna scans along the line with fixed sampling step in front of the target under test. UWB pulses are transmitted at each scan location. Reflections from the target are captured by the same position. The target is estimated by using the received data set or B-scan. In the numerical simulation, the antenna is assumed to be non-dispersive and isotropic. The propagation speed of the electromagnetic wave is regarded as constant in the medium. The synthetic data is generated in frequency domain in order to accurately define the operational bandwidth. The contributions of the reflected wave from each part of the target in the scene are integrated without taking into account the interactions among them. For each scan location at certain frequency, the data represents a summation of complex exponentials, each with the corresponding phase depending on the position of the antenna and target shape.

$$P(\omega) = \sum_{i=1}^{N} \frac{1}{4\pi R_i} \cdot e^{-j\omega 2R_i/v} \tag{1}$$

where R_i represent the propagation distance between the antenna and the i^{th} reflecting point on the target, ω is the angular frequency, and v denotes the propagation speed in the medium. The frequency-domain data is tapered first to reduce