Wall Clutter Mitigation using a Modified Subspace Projection Method for Non-Parallel Measurement Through-the-Wall Radar Imaging

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***Abstract*—In this paper, a modified subspace projection method for non-parallel measurement through-the-wall radar imaging is proposed. The proposed modified subspace projection method includes equivalent time delay and normalization to remove wall clutter. Synthetic data are obtained using a finite-difference time-domain forward solver to verify the validity of the proposed method. The target-to-clutter ratio of the delayed-sum migration image after the proposed method was improved 21.6 dB compared to the conventional subspace projection method.**

***Index Terms*—Through-the-wall radar imaging (TWRI), wall clutter mitigation, subspace projection method**

I. INTRODUCTION

Through-the-wall radar imaging (TWRI) is an emerging area of research and development because of its various applications. Studies on TWRI have included TWR system architectures [1] and signal processing issues [2-5]. In signal processing, removing strong reflections from the wall is one of the most important factors because strong wall clutter often obscure the target signal.

There are many wall clutter mitigation methods, including spatial filtering and subspace projection. Most of the conventional wall clutter mitigation methods work in a certain assumption in which the measurement path is parallel to the wall and there are strong similarities between responses from the wall at each antenna location. In many practical scenarios, however, the assumptions are not satisfied for the case of non-parallel or non-uniform thickness walls.

The basic idea of the conventional subspace projection method is that the most significant terms of the spectrum of the data matrix are dominated by the wall clutter. Using singular value decomposition, responses from the wall can be mitigated by excluding some dominant singular vectors [2].

In this paper, we propose a modified subspace projection method that can be easily applied to the non-parallel measurement TWRI problems. To the best of our knowledge, there has been a single work about removing the wall clutter in a non-parallel wall problem. In that work, a threshold technique was used to segment the singular value spectrum into two classes, one of which was the wall clutter class. Range profiles of the wall clutter class were then compared to those of the dominant singular vector to identify the singular vectors spanning the wall subspaces [4]. The method proposed in this paper is simpler than the foregoing method and uses an equivalent time delay and normalization techniques. The method makes the form of the data matrix of the non-parallel wall measurement similar to that of the parallel wall. The proposed method can also be applied to other wall clutter mitigation techniques, such as spatial filtering.

II. MODIFIED SUBSPACE PROJECTION METHOD

We assume a TWRI scenario in which the wall is inclined to the radar measurement path (see Fig. 1). Figure 2 shows the singular values of the data matrix for parallel and non-parallel wall measurements. The singular value slope of the measured data in the non-parallel wall is less than the parallel wall. This means that it is difficult to directly apply the conventional subspace projection method to mitigate the wall clutter because the wall clutter cannot be represented with only a few dominant singular vectors. Conversely, if we can make the inclined wall measurement data the form of the parallel measurement data, it is possible to easily mitigate the wall clutter.

An electromagnetic wave radiated from different antennas experiences the same electrical response, excluding its time delay to the wall and the magnitude scaling. Therefore, an equivalent time delay ($\tau_{eq}(n)$) corresponding to the difference of each path (δ) and normalization of each A-scan can be adopted to make the form of the non-parallel wall measurement data similar to that of the parallel wall. The modified received signal r'(n,t) is given by

$$\mathbf{r'(n,t) = r(n, t + \tau_{eq}(n))} \tag{1}$$

where r(n,t) and n are the matched filtered received signal and the index of the antennas, respectively. The equivalent time delay $\tau_{eq}(n)$ is

$$\boldsymbol{\tau_{eq}(n) = 2(n-1)\, d \tan(\theta) / c} \tag{2}$$

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where c is the velocity of light in free space and each A-scan of r'(n ,t) is normalized to its maximum value.

By applying these techniques, the form of the data matrix in the non-parallel wall measurement changes to that of the parallel wall measurement, thus, the wall clutter can be effectively removed. After wall clutter mitigation, the same amount of equivalent time delay should be restored to correctly image the radar scene.

III. SIMULATION RESULTS

In order to verify the proposed method, we first consider the synthetic data obtained through an FDTD (finite-difference Time-domain) forward solver [6] with elementary current sources located at a standoff distance of L = 11.5 cm and h_s = 25 cm with step size d = 2 cm. The wall is inclined 26.5° with respect to reference line Ω. The target is 10 x 10 cm^2 PEC box centered at 1.5 m from the antenna array along the x-axis and the center of the measurement line Σ along the y-axis (see Fig. 1). Figure 3 shows the delayed-sum (DS) migration images after the conventional subspace projection method which is for a parallel wall and the modified subspace projection method. The target-to-clutter ratio (TCR) results are compared in Table I. The TCR was 21.6 dB higher compared to the conventional subspace projection method.

IV. CONCLUSION

In this paper, a modified subspace projection method was proposed to mitigate the wall clutter in non-parallel measurement TWR scenarios. The main procedures of the proposed method are equivalent time delay and normalization. These procedures can be applied to other wall clutter mitigation techniques because they produce the non-parallel measurement data in the same form as the parallel measurement data in which each A-scan has a strong similarity. Using the proposed method, the TCR is fairly improved. The method proposed in this paper, therefore, offers a practical solution to non-parallel measurement TWRI problems.

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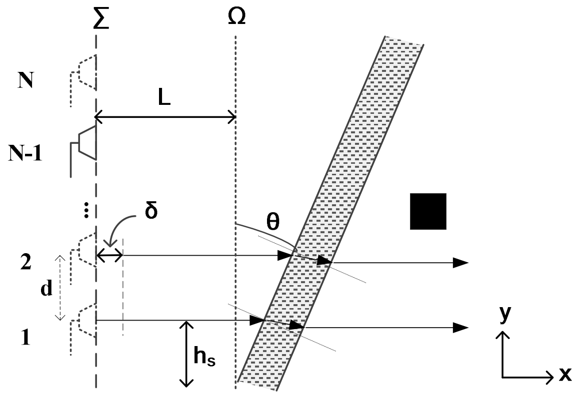

Fig. 1. The non-parallel measurement TWRI scenario

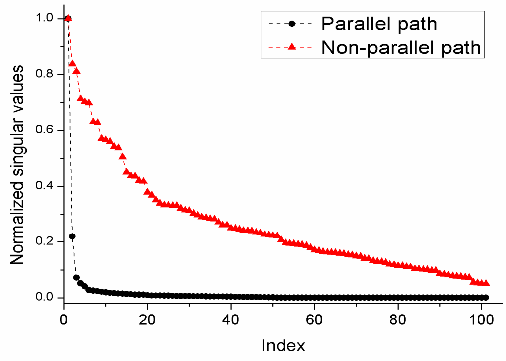

Fig. 2. Singular values of each measurment

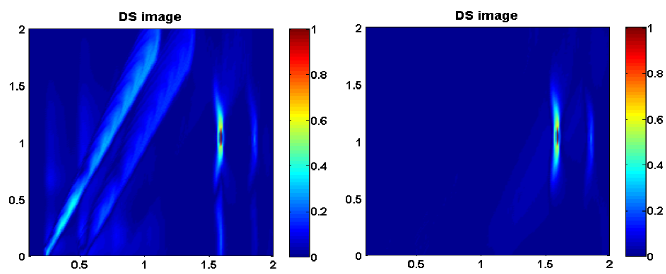

Fig. 3. DS images after the conventional subspace projection method (a) and the modified subspace projection method (b)

TABLE I. TCR MEASUREMENT RESULTS

Subspace projection method	**TCR [db]**
Conventional method	24.93
Proposed method	46.53

$$TCR = 20\log_{10}\left(\frac{\max_{(i,j)\in A_t}|f(i,j)|}{\frac{1}{N_c}\sum_{(i,j)\in A_c}|f(i,j)|}\right)$$