Hybrid Method combining RMT and ABP Algorithm for Microwave Imaging

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Microwave imaging is a technique aimed at sensing a given region by means of interrogating electromagnetic waves. In practice, the range migration technique (RMT) as a kind of synthetic aperture radar (SAR) imaging algorithm has a high computational efficiency and accuracy in reconstruction. However, this approach involves a frequency domain interpolation, which may adversely affect the accuracy of image reconstruction. The back-projection (BP) algorithm originated from medical imaging techniques achieves fine reconstructed images because it avoids frequency domain interpolation, but usually has a huge computational cost. To overcome these disadvantages, this paper proposes the hybrid method combining RMT and adaptive BP (ABP) algorithm for reconstruction with high-quality. Then, simulated and experimental data are obtained to validate the performance of the proposed algorithm.

***Index Terms*— adaptive back-projection, electromagnetic wave, microwave imaging, range migration, synthetic aperture radar.**

I. Introduction

NOTABLE RESULTS in microwave imaging applications have been obtained using synthetic focusing techniques [1]. These methods are based on the concept of synthetic aperture radar (SAR) system [2]. Particularly, the range migration technique (RMT) is an attractive imaging technique because it does not suffer from space-variant defocusing due to its ability to compensate for range curvature. However, it requires the interpolation procedure in frequency domain, namely Stolt interpolation, which may cause artifacts in reconstructed images.

The back-projection (BP) algorithm known as a kind of time domain approach can eliminate these problems, and offers a lot of advantages over the traditional microwave imaging technique, such as compensation of curve wave-front effect without geometric distortions, and aperture-dependent motion compensation. Additionally, it is the preferred method due to its simplicity and offers an intuitive imaging technique for microwave imaging researchers. However, it has high computation burden in case of the integral procedure [3].

To overcome these drawbacks, this paper proposes the hybrid method combining RMT and adaptive BP (ABP) algorithm for microwave imaging with high-quality. It avoids interpolation and intensive computation burden. For algorithm implementation, the phase compensation is to be conducted. Then, the compensated data is integrated over each antenna position to adaptive range cells that have high probability of presence in terms of targets as predetermined target region.

Furthermore, superior performance of proposed algorithm is verified by comparing it with results obtained from RMT as a conventional SAR imaging algorithm.

II. Proposed Algorithm

A. Signal Models

The data collection geometry in Fig. 1 provides the basis for a convenient SAR signal model. The antenna is positioned at

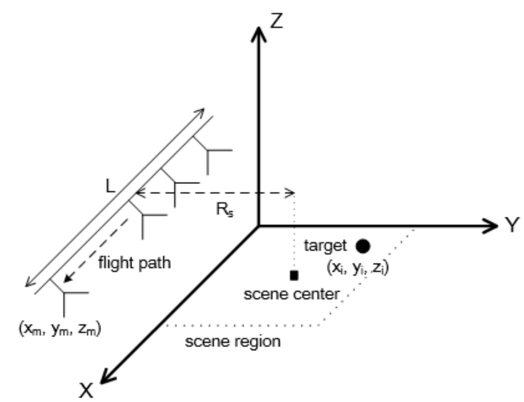

Fig. 1. Data collection and imaging geometry.

(x_m, y_m, z_m) and traverses a straight flight path parallel to the X-axis. Assuming that there is a point target located at (x_i, y_i, z_i) with reflectivity σ_i, then the received signal which is assumed to be restricted to the xy-plane, can be modeled as

$$S\left(x_m, k_r\right) = \sigma_i e^{-jk_r\left(r_i - R_s\right)} \qquad i = 1, \ldots, D \tag{1}$$

where D is the total number of targets, c is the velocity of light, k_r is two-way frequency wavenumber, and R_s establishes the phase reference that is a line parallel to the linear aperture at the origin of the coordinate systems. And r_i is the range from antenna to the ith target, i.e.,

$$r_i = \sqrt{\left(x_m - x_i\right)^2 + y_i^2} \tag{2}$$

Consequently, the raw data can also be denoted as S in (1).

B. Hybrid Method combining RMT and ABP algorithm

The main steps as shown in Fig. 2 involved in concept of proposed algorithm are as follows. The first step is to calculate the FFT with respect to cross range, given by

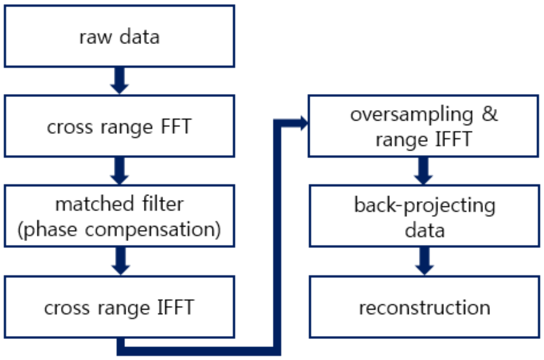

Fig. 2. Block diagram of the proposed hybrid method.

$$S(k_x, k_r) = \int S(x_m, k_r) e^{-jk_x x_m} dk_x x_m \approx |S(k_x, k_r)| e^{-j\left[k_x x_i + y_i \sqrt{k_r^2 - k_x^2} - k_r R_s\right]} \quad (3)$$

where k_x is the cross range spatial frequency. This kind of integrals can be evaluated analytically by using the principle of stationary phase (PSP) [4].

The second step is to generate function of matched filter. The RMT uses the space-invariant term R_s in function of matched filter, and application of this function is given by,

$$\phi_{pc} = -k_r R_s + R_s \sqrt{k_r^2 - k_x^2} \quad (4)$$

$$S_{mf}(k_x, k_r) = S(k_x, k_r) \otimes e^{j\phi_{pc}} = |S(k_x, k_r)| e^{-jk_x x_i + j(R_s - y_i)\sqrt{k_r^2 - k_x^2}} \quad (5)$$

The third step of proposed algorithm is to conduct IFFT with respect to cross range. The data is transformed to $S_{mf}(x_m, k_r)$. The analytical processing for calculation will be presented to full paper, in detail.

The next step is to conduct oversampling and IFFT respect to range direction. The data is transformed from $S_{mf}(x_m, k_r)$ to $S(x_m, y)$. Also, the analytical processing for calculation will be presented to full paper, in detail. All of the integral processing in this paper is based on PSP. For the adaptive processing, this paper determines the range cell that has high probability of presence in terms of targets. It is implemented by level set approach. The detailed explanation of level set approach for adaptive processing will be discussed in full paper.

Finally, the final image can be obtained by adaptive back-projecting the data.

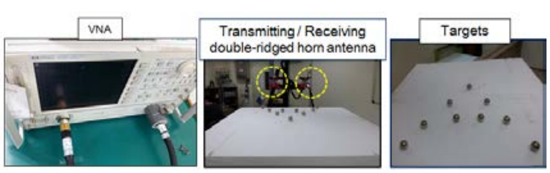

Fig. 3. Experimental setup.

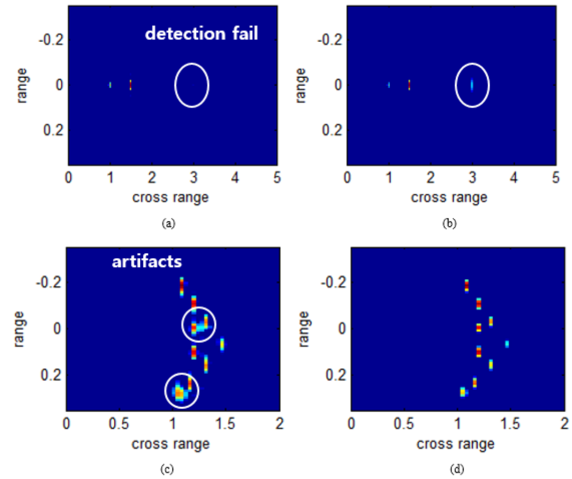

Fig. 4. Final reconstructed images. (a) Point targets from RMT, (b) Point targets from proposed method, (c) Experimental result from RMT, (d) Experimental result from proposed method.

III. Simulated and Experimental Results

In numerical simulation, we used ideal point targets with low SNR (5 dB) environment. And the experimental setup is shown in Fig. 3. The *S*-parameter S_{21} as raw data were collected using vector network analyzer (VNA) operating from 8-12 GHz, controlled using a positioning system, with a bi-static configuration of a double-ridged horn antenna. The targets used are spheres, made up of conductors.

The images obtained by proposed and conventional RMT are shown in Fig. 4. Then, to exhibit quantitatively the effect of the artifacts, we evaluate the error of the final image by integrated side lobe ratio (ISLR) [5] as shown in Table I.

IV. Conclusion

The hybrid method for microwave imaging is proposed and experimentally validated in a real environment. The proposed method improves the performance of conventional RMT in terms of both computational time and image quality.

TABLE I
Comparison Results of Proposed Algorithm

		RMT	Proposed algorithm
simulated	calculation time (sec)	4.50	1.80
	ISLR (dB)	12.27	4.83
experimental	calculation time (sec)	4.52	2.00
	ISLR (dB)	12.06	4.99

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