NEAR FIELD IMAGING FOR CONDUCTING OBJECTS

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I. INTRODUCTION

Microwave images of conducting objects obtained from microwave diversity imaging have been interpreted and predicted [1,2]. The distance between the antennas and the object is assumed in the far field region and the equiphase surface is therefore a plane. Under this assumption either a two–dimensional Fourier transform (FT) method or a back–projection method can be used to reconstruct the image and these two methods are equivalent [3].

When the distance between the object and the antennas becomes much shorter than the distance required in the far field condition, the equiphase surface can no longer be assumed a plane. The image might be blurred or distorted if the mentioned reconstruction algorithms were applied. Since the equiphase surface is spherical in general, it is reasonable to reconstruct the image through a generalized "spherical" back–projection method. In this paper we will describe this method and employ it to reconstruct the near field images of conducting objects.

II. IMAGE FORMATION BY THE SPHERICAL BACK–PROJECTION METHOD

A two–dimensional object with reflectivity density function $f(r,\phi)$ as shown in Fig.1 is seated on a rotating pedestal, and is illuminated by spherical waves with frequencies covered within a wide bandwidth. The back–scattered near field at each step frequency is received. The object is then rotated and measurement is repeated to obtain the multiaspect stepped frequency response of the scattering object.

Let the distance between the rotation center and the antenna be R_0. Rotating the object is equivalent to rotating the antenna around the object. When the antenna is rotated around the object through an angle θ, the distance between the source point (r,ϕ) and the antenna becomes R_θ.

If the origin of the coordinate system is moved to the center of the antenna, the coordinate (r,ϕ) becomes (R_θ,δ_θ) where δ_θ is the angle between the lines connecting the new origin to the rotational center and the source point (r,ϕ) as shown in Fig. 1. With this new coordinate system, the scalar field received can be expressed as

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$$G(k,\theta)=C(k)\int\left[\int f(R_\theta,\delta_\theta)\,d\delta_\theta\right]e^{-j2kR_\theta}\,dR_\theta$$

$$=C(k)\int g_1(R_\theta)\,e^{-j2kR_\theta}\,dR_\theta \tag{1}$$

where k is the wave number, C(k) is a function of k, and

$$f(R_\theta,\delta_\theta)=\begin{cases} f(r,\phi+\theta) & \text{if } (R_\theta,\delta_\theta) \text{ is within the object} \\ 0 & \text{if } (R_\theta,\delta_\theta) \text{ is outside the object} \end{cases} \tag{2}$$

and

$$g_1(R_\theta)=\int f(R_\theta,\delta_\theta)\,d\delta_\theta \tag{3}$$

It is clear that $g_1(R_\theta)$ is the spherical projection of the reflectivity density function along a constant range R_θ at the aspect θ. This function is also referred to as the range profile. From Eq.(1) one can see that $g_1(R_\theta)$ and $G(k,\theta)/C(k)$ are Fourier transform pairs and $g_1(R_\theta)$ can be estimated by inverse Fourier transforming the measured $G(k,\theta)/C(k)$ with respect to k.

Assume the field $G(k,\theta)$ has been measured over a frequency window and an angular window. It is desired to reconstruct the reflectivity density function $f(r,\phi)$ from the near field data. The two–dimensional Fourier transform method and the back–projection method have been used to reconstruct the far field image [1,2,3]. Similar to the back–projection method, an approximate method to reconstruct the image is to estimate the spherical projection $g_1(R_\theta)$ from the measured data for each aspect θ, and then spherically back–project the estimated $g_1(R_\theta)$ to each image pixel. Implementation of the spherical back–projection method is summarized as follows:

1. Estimate the spherical projection $g_1(R_\theta)$ of each aspect θ by inverse Fourier transforming the measured $G(k,\theta)/C(k)$ with respect to k over the frequency window.
2. The estimated $g_1(R_\theta)$ of each aspect θ is then spherically back–projected to each image pixel.

III. EXAMPLES

In this section we give numerical and experimental examples to demonstrate the near field images of conducting objects reconstructed by the spherical back–projection method and other methods. In the following numerical examples, the frequency coverage is from 6 GHz to 16 GHz, and the distance between the antenna and the rotational center is 100 cm.

In the first example we compare the near field images of point scatterers reconstructed by the Fourier transform (FT) method, the coherent and the incoherent spherical back–projection methods. The FT method obtains the image by the two–dimensionally Fourier transforming the range–corrected data in the same way as in the far field case. The incoherent spherical back–projection method obtains the image pixel value by summing the estimated absolute range profile of each aspect incoherently.

Consider a point scatterer initially located at X = 0 cm, Y = 30 cm. The rotation center is chosen as the origin. The images reconstructed by the FT method, the coherent and the incoherent spherical back–projection methods from data collected over one revolution are shown in Fig. 2(a), 2(b), and 2(c) respectively. It is seen that the image of Fig. 2(a) has been spread and is not well focused. The image of Fig. 2(c) is fatter than that of Fig. 2(b) and has higher background value. The image in Fig. 2(b) is well focused.

In the second example we demonstrate the near field images of a continuous object – a conducting cylinder. The cylinder is 10 cm in radius and its axis is parallel to the rotation axis and is 30 cm from the rotation center. The images obtained by the FT method and the coherent spherical back–projection method from data collected over one revolution are shown in Fig. 3(a) and (b) respectively. It is seen that the image shape in Fig. 3(a) has been distorted, while Fig. 3(b) gives corrected shape of the cylinder.

In the third example we demonstrate the image of a complex object. The object is a modeled airplane as shown in Fig. 4(a). The inclination angle of the airplane is about 20°. Zero degree is defined as the aspect with the line of sight normal to the fuselage. The distance between the rotating pedestal and the antennas is about 150 cm, which is much shorter than the far field distance ($2D^2/\lambda \approx 16$ m). The frequency coverage is from 7 GHz to 14 GHz. The images reconstructed from data collected over an angular window from $\phi = -10^{\circ}$ to $\phi = 80^{\circ}$ using the Fourier transform method and the coherent spherical back–projection method are shown in Fig. 4(b) and Fig. 4(c) respectively. One can find that the image reconstructed by the spherical back–projection method is much better focused, especially for those portions farther apart from the rotational center.

REFERENCE

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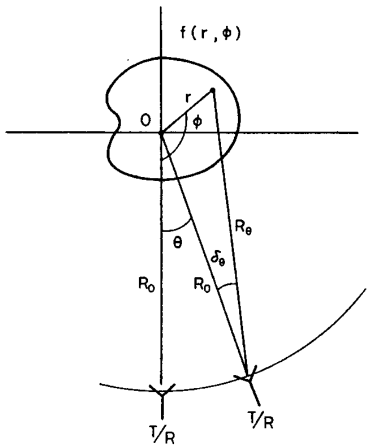

Fig. 1. A near field imaging scheme for a two–dimensional object.

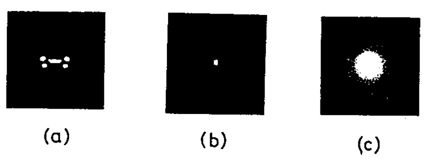

Fig. 2. Images of a point scatterer reconstructed by (a) the Fourier transform method, (b) the coherent spherical back–projection method, and (c) the incoherent spherical back–projection method.

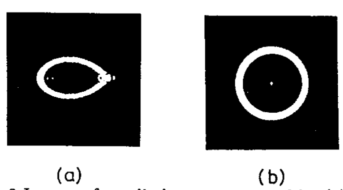

Fig. 3 Images of a cylinder reconstructed by (a) the Fourier transform method, (b) the coherent spherical back–projection method from data collected over one revolution.

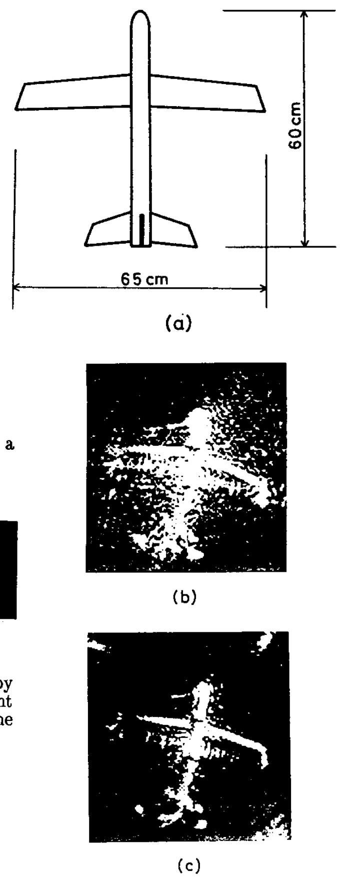

Fig. 4. (a) Sketch of a modeled airplane. Images of a modeled airplane reconstructed by (b). The Fourier transform method, and (c) the spherical back–projection method.