Inverse Synthetic Aperture Imaging by Nearest Neighbor Interpolation

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1. Introduction

The industrial application of submillimeter wave above 100GHz has become the latest frontier of industrial research, just as the millimeter wave for automotive radar and communication a few decades ago. The application of submillimeter wave to the inverse synthetic aperture imaging will enable the resolution with the order of millimeters so as to realize high-resolution imaging sensors [1]. Along with the propagation and reflection characteristics of the submillimeter wave, the application will range from industrial elasticity analysis of composite materials and plastics under the stress to a fluoroscopy and hidden weapons detection under the cloth, and to the medical diagnosis of skin. As an example of synthetic aperture imaging, the authors have reported the result of the line-of-sight image at 120-160GHz band [2]. In this paper, a method of interpolating the rectangular data from the polar coordinate data of diffraction pattern utilizing the nearest neighbor interpolation is at first introduced, and then the experimental results of the inverse synthetic aperture imaging at 120-160GHz, including the reconstruction of all round image of object, are reported.

2. Review of Frequency Diversity Inverse Synthetic Aperture Imaging

2. 1 ISAR System Coordinate

The measurement is based on the well-known ISAR theory. Referring to the system coordinate depicted in Fig. 1, the spatial reflectivity function $g(x, y)$ of the object and its Fraunhofer diffraction pattern expressed in the spatial frequency domain $G(f_x, f_y)$ constitute a two dimensional Fourier transform pair, and the reconstructed object image $g_R(x, y)$ can be obtained by the inverse Fourier transform of the diffraction pattern[3]. Namely,

$$G(f_x, f_y) = F\{g(x, y)\} \qquad (1)$$

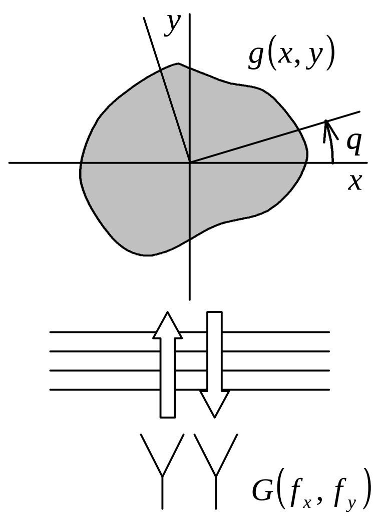

Fig. 1. ISAR system coordinate.

where $f_x=2sinq/l$ and $f_y=2cosq/l$, and q, l are respectively the rotating angle of the object and the wavelength, and thus

$$g_R(x,y)=F^{-1}\{G(f_x,f_y)\}. \quad (2)$$

2. 2 Fixed Scene Image Reconstruction

The diffraction pattern of object is measured with the frequency swept at every measurement angle, so that the diffraction pattern expressed in the spatial frequency domain (f_x , f_y) is obtained in the polar coordinate. In order to obtain a fixed scene image, the polar coordinate data of the diffraction pattern has to be transformed to the rectangular coordinates, whose grid angle is specified between v axis of the rectangular grid and f_x axis and is kept at 90 degrees as shown in Fig. 2. Then, the reconstructed image obtained by the inverse Fourier transform of the rectangular grid data can be maintained in the fixed orientation, the façade view in this case, regardless of the rotation angle of object [4]. The cross-range cell size r_c and the down-range cell size r_r in the reconstructed image are respectively given as

$$r_c=1/F_x\ ,\quad r_r=1/F_y \qquad (3)$$

where the F_x and F_y are the sizes of the rectangular grid, respectively.

2. 3 Rectangular Grid Interpolation

As the method of interpolating the rectangular coordinates from the polar coordinate data of diffraction pattern in the fixed scene image reconstruction, the nearest neighbor interpolation utilizing the Delaunay triangulation is employed [5]. Delaunay triangulation is one type of the element division methods, in which data points are divided into a set of triangles in such a way that the circumscribed circle of a divided triangle does not include other data point in the inside the circle [6]. Fig. 3(a) shows an assumed diffraction pattern

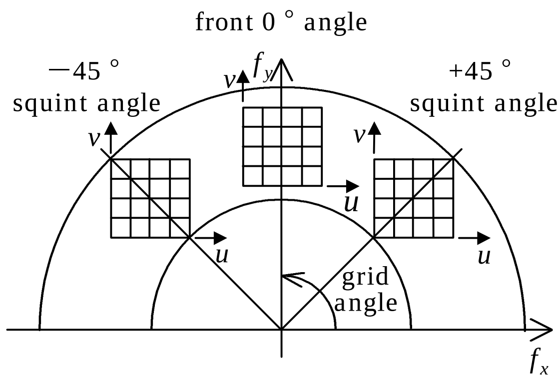

Fig. 2. Fixed scene image.

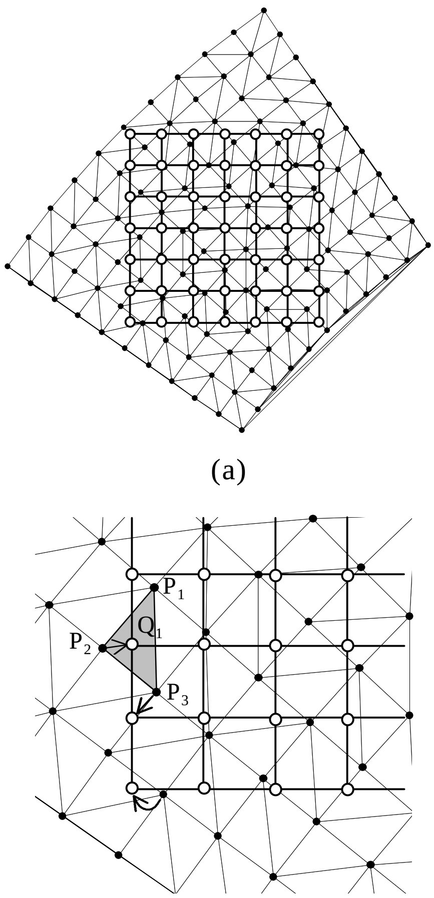

Fig. 3. (a) Polar/rectangular coordinate data point and Delaunay triangulation, (b) the algorithm of the nearest neighbor interpolation.

in the polar coordinate, the corresponding Delaunay triangulation and the interpolated rectangular grid data. Fig. 3(b) depicts the algorithm of the nearest neighbor interpolation. For example, the rectangular grid data point Q_1 is interpolated as the nearest neighboring point out of three vertex of $\triangle P_1P_2P_3$, which is derived by the Delaunay triangulation. Namely, $Q_1=P_2$. By this way, the interpolation is executed for all rectangular grid data point.

3. Experiment

3. 1 Measurement of Reflection Pattern

The component of the current setup consists of a vector network analyzer (VNA), and a set of RF heads. A RF head consists of horn antenna, directional coupler, isolator, and each mixer for transmitter and receiver. The combination of VNA and RF head provides D-band source. The signal processors include FFT/IFFT and data sample interpolation. The object is consisted of four cylindrical metal poles, each 6mmφ and erected at the corners of 3.5 cm-square, and is mounted on the rotating table as shown in Fig.4. The magnitude and phase of the reflection signal is measured over ±5° at the squint angle of −45°, 0°, +45° with 0.25-degree step. The frequency is swept over 120-160GHz at each measurement. The result is shown in Fig. 5.

3.2 Fixed Scene Imaging

Fig.6(a), (b), (c) are the reconstructed images through the inverse Fourier transform of the interpolated rectangular grid data at the façade 0° and the squint angle −45° and +45°. It is seen in the all figures that the alignment of poles' image are in good agreement with the actual orientation, and the poles in the shadow position will not appear as

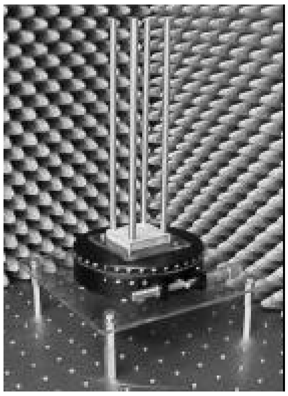

Fig. 4. The object.

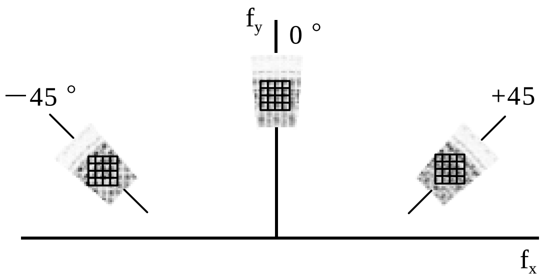

Fig. 5. The coordinate for imaging with fixed orientation.

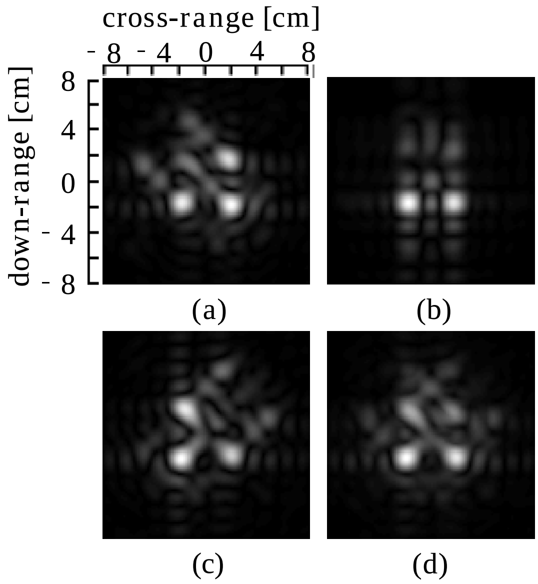

Fig. 6. Fixed scene images: (a) −45° squint angle; (b) front 0° angle; (c) +45° squint angle; (d) all round image.

expected. Fig. 6(d) is an all round image summed together from Fig. 6(a) and (c) on a pixel-by-pixel basis.

As an application of the fixed scene imaging, a fluoroscopic imaging for the same object placed behind a plastic material (acrylic board) has been examined. The incident angle at the acrylic board is aligned at the Brewster angle (57°). As before, both the fixed scene images as Fig. 7(a), (b), (c) and the all round image as Fig. 7(d) which is summed together from Fig. 7(a) and (c), are successfully reconstructed.

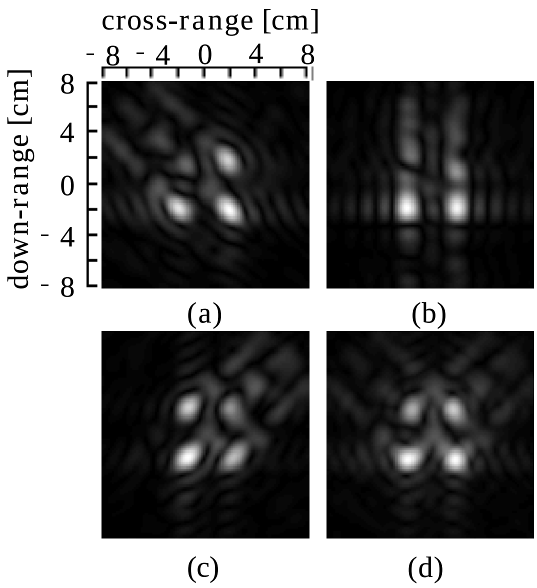

Fig. 7. Fluoroscopic fixed scene images: (a) −45° squint angle; (b) front 0° angle; (c) +45° squint angle; (d) all round image.

4. Conclusion

Under the experimental study of the inverse synthetic aperture imaging at 120-160GHz, the fixed scene imaging and all round imaging have been investigated. For the transform of polar data to the rectangular data, a new interpolation algorithm utilizing the nearest neighbor interpolation based on the Delaunay triangulation is employed and its effectiveness is verified in the reconstruction process.

References

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