Sampling Interval Parameter Design Based on Active Millimeter Wave Imaging

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Abstract

Millimeter wave has good penetration and security, which can be better applied in security check system. The security system needs to consider the imaging time and resolution, so it has great significance to rapidly reconstruct the imaging and improve the resolution for active millimeter-wave imaging. In this paper, the design of millimeter wave reconstruction imaging sampling interval is studied. Through analysis and experiment, the sampling interval is optimized, and the imaging results of traditional millimeter wave reconstruction algorithm and accurate millimeter wave algorithm are verified, which provides a theoretical basis for the design of active millimeter wave imaging system.

Introduction

In the actual imaging process, the data must be discretized before reconstruction, and the discretization of the collected data requires an appropriate sampling interval. The size of the sampling interval will directly affect the length of sampling time and the quality of the final reconstructed image, and the sampling interval is related to several parameters of the system [1]. In theory, if the image information needs to be accurately restored, Nyquist sampling theorem should be satisfied when sampling the received data [2]. Received data information changes mainly reflects on the phase information, and amplitude information change more slowly. To avoid spectral aliasing, the sampling interval of scattered echo data in the spatial domain cannot exceed half of the wavelength corresponding to the highest frequency, that is, the phase interval of adjacent sampling points in the frequency domain is less than π [3-5]. The spatial frequency of the phase information is expressed as follows:

$$f_x = \frac{1}{2\pi}\frac{\partial\phi}{\partial x} = \frac{2}{\lambda}\frac{(x-x_0)}{\sqrt{(x-x_0)^2+(y-y_0)^2+(z-z_0)^2}} \quad (1)$$

The maximum value of fx can be calculated:

$$\left|\max(f_x)\right| = \frac{2}{\lambda}\frac{L_x}{\sqrt{L_x^{\,2}+Z_0^{\,2}}} \quad (2)$$

Lx is the transverse distance of the scanning range, and Z0 is the distance between the front surface of the target and the scanning surface. According to the sampling theorem [6], the transverse sampling interval Δx is:

$$\Delta x \le \frac{\lambda}{4}\frac{\sqrt{L_x^{\,2}+Z_0^{\,2}}}{L_x} \quad (3)$$

It can be seen that the size of the sampling interval and the wavelength of millimeter wave, target, and the size of the scanning range and imaging distance are related [7-8], sampling interval had a great influence on reconstruction image quality, so it is very important for the selection of sampling interval, different system parameters should select the appropriate sampling interval to ensure better reconstruction image.

SAMPLING INTERVAL SIMULATION AND ANALYSIS

Fig.1 The two-dimensional target object

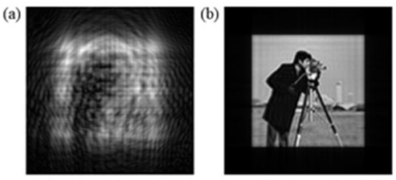

Fig.2 Two-dimensional reconstruction image (a) Holographic amplitude image (b) Reconstruction of the image

Firstly, the sampling interval condition of millimeter-wave holographic imaging is verified experimentally. Taking two-dimensional millimeter-wave holography as an example, two-dimensional millimeter-wave holography uses single-frequency millimeter-wave transmitting source. It is assumed that the frequency of single-frequency millimeter wave transmitting source is 80 GHz (corresponding wavelength is 3.75mm) and the imaging distance is set as 3m. The two-dimensional target object is shown in Fig.1. The gray level of the image represents the reflectivity of the target, and the pixel of the target image is 256×256. Assuming that the pixel interval of the original image is 2 mm, if the sampling number of the scanning plane is also set as 256×256, the sampling interval required by the sampling condition can be calculated as Δx0 ≤3.50 mm, so the sampling interval is set as 3 mm. The scattering echo data of two - dimensional target is collected. The amplitude diagram and reconstruction diagram of the millimeter-wave hologram of the calculated target are shown in Fig.2. It can be seen from Fig.3(a) that the holographic amplitude of the target is the superposition of interference fringes of each pixel, and each point in the image contains the information of the whole image. Since the reconstruction process is equivalent to spatial filtering, and the high frequency information representing the details such as the image contour and other dramatic changes are filtered out, the details of the reconstructed image are less effective than the original image, but the overall restoration can be achieved very well. Change the size of the sampling interval, so that the sampling interval becomes 6 mm. If the size of the scanning aperture is not changed at this time, the number of sampling points becomes 128×128. At this time, according to the calculation formula of sampling interval, the sampling interval should meet Δx0 ≤ 4.73mm. The reconstructed image obtained as shown in Fig.3. When the sampling interval does not meet the sampling conditions, the phase spectrum will be aliasing.

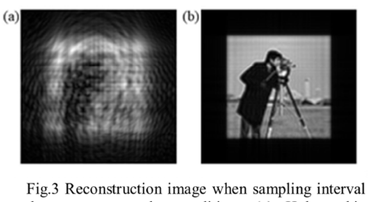

Fig.3 Reconstruction image when sampling interval does not meet the conditions (a) Holographic amplitude image (b) Reconstruction of the image

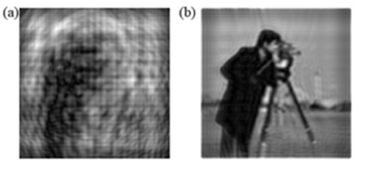

Fig.4 Reconstruction image when the scanning aperture smaller (a) Holographic amplitude image (b) Reconstruction of the image

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When the sampling interval is satisfied, the size of the sampling interval is set to be the same as the pixel interval of the original image, and the number of sampling points is also 256×256. In this case, the size of the scanning aperture is the same as that of the original image. It is known that electromagnetic wave will diffuse with distance in the process of spatial propagation, such as the propagation of light field. When the electromagnetic wave scattered by the object surface propagates over a certain distance and then reaches the receiving plane, part of the received data is bound to be missing. At this time, the obtained hologram and reconstructed image are shown in Fig. 4. It can be seen from the observation of the reconstructed image that when the scanning aperture is small, even if the sampling interval is satisfied, the reconstructed image is extremely blurred and artifacts appear due to the lack of some information of the target. The details in the image, such as buildings and stents, are much different from the original image. Reconstruction images of the three situations were compared uniformly, as shown in Fig.5. By comparing the reconstructed images in the three cases, it can be seen that the target reflectivity information can be recovered well under the condition that the sampling conditions are met and the scanning aperture is sufficient. However, the reconstructed image will be blurred if the sampling interval is not met or the scanning aperture is insufficient. Therefore, in the actual imaging process, appropriate sampling interval and scanning aperture should be selected to provide good data for subsequent reconstruction of images.

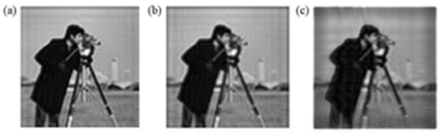

Fig.5 Comparison of reconstructed images under different sampling conditions (a) Normal reconstruction (b)The sampling interval does not meet the requirements (c) The aperture decrease

ACCURATE RECONSTRUCTION ALGORITHM OF MILLIMETER WAVE

The accurate reconstruction algorithm of millimeter-wave holography based on spherical wave is verified by simulation. Assuming that the millimeter-wave signal source frequency is 80 GHz (wavelength is 3.75mm), the imaging distance is 3 m, and the number of sampling points is 256×256, the two-dimensional image is reconstructed under these conditions. The image reconstructed by the traditional algorithm based on spherical wave expansion is shown in Fig.6(a), and the reconstructed image obtained by the accurate millimeter wave reconstruction algorithm is shown in Fig.6(b). The accurate reconstruction algorithm of two-dimensional millimeter wave holography can recover the target more accurately.

By comparing the values of the real part of the center section of the original image and the reconstructed image, as shown in Fig.7(a), it can be seen that the millimeter wave precise reconstruction algorithm can accurately restore the target in terms of both phase and numerical values. Fig.7(b) shows the values of the traditional reconstructed image based on spherical wave expansion. It can be seen that not only the positive and negative values are wrong, but also the values are far from the real target in order of magnitude. It can be seen that the MMW actuarial method proposed in this paper can guarantee the accuracy of reconstructed images in terms of phase and numerical values.

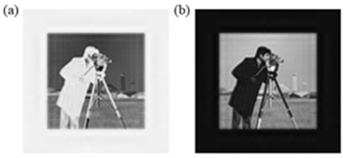

Fig.6 Imaging results of different reconstruction methods (a) Imaging results by traditional methods (b) Accurate millimeter wave imaging results

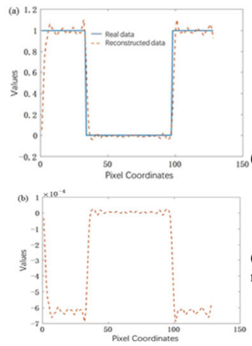

Fig.7. Reconstruction of the image center section value (a) Accurate reconstruction compared to the original image (b) Traditional reconstruction

Conclusion

In this paper, the influence of sampling conditions on imaging results is analyzed. In the case that sampling conditions are satisfied and the scanning aperture is sufficient, the target reflectivity information can be recovered well. However, when the sampling interval is not satisfied or the scanning aperture is insufficient, the reconstructed image will be blurred. Therefore, in the actual imaging process, appropriate sampling interval and scanning aperture should be selected to provide good data for subsequent reconstruction of images. At the same time, the millimeter-wave holographic accurate reconstruction algorithm can not only restore the original target image from the value and phase, but also recover the gray distribution of the image well, which can better ensure the details of the image to a certain extent, which provides a theoretical basis for the design of millimeter-wave imaging system.

References

[1] Sheen D M, Mcmakin D L, Hall T E. Three-Dimensional Millimeter-Wave Imaging for Concealed Weapon Detection[J]. IEEE Transactions on Microwave Theory & Techniques, 2002, 49(9):1581-1592.
[2] Chattopadhyay G, Cooper K B. 670 GHz FMCW Radar for Imaging and Science Applications[C]. International Conference on Electromagnetics in Advanced Applications. 2017:506-506.
[3] Ahmed S S, Schiessl A, Schmidt L P. A Novel Active Real-Time Digital-Beamforming Imager for Personnel Screening[C]. European Conference on Synthetic Aperture Radar. VDE, 2012:178-181.
[4] Roe K J, Gregory C W. Wave-Based Sensing and Imaging for Security Applications[C]. European Conference on Antennas and Propagation. IEEE, 2015:1-5.
[5] Zhang B, Pi Y, Li J. Terahertz Imaging Radar with Inverse Aperture Synthesis Techniques: System Structure, Signal Processing, and Experiment Results[J]. Sensors Journal IEEE, 2015, 15(1):290-299.
[6] Tan K, Wu S, Wang Y, et al. A Novel Two-Dimensional Sparse MIMO Array Topology for UWB Short-Range Imaging[J]. IEEE Antennas & Wireless Propagation Letters, 2016, 15:702-705.
[7] Jing H , Li S , Cui X , et al. Near-Field Single-Frequency Millimeter-Wave 3-D Imaging via Multi-Focus Image Fusion[J]. IEEE Antennas and Wireless Propagation Letters, 2020, PP(99):1-1.
[8]Gu S , Li C , Gao X , et al. Terahertz Aperture Synthesized Imaging With Fan-Beam Scanning for Personnel Screening[J]. IEEE Transactions on Microwave Theory and Techniques, 2012, 60(12):3877-3885.