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A METOHD OF AUTOMATIC IMAGE RECONSTRUCTION FOR SNOW SEARCH RADAR

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1 Introduction

Snow Search Radar System(SSRS)[1] is a three-dimensional(3-D) imaging radar system for the searching of objects under accumulated snow using multi-frequency microwave holography. Multi-frequency holography is a combination of holographic and wide-band signal techniques. Although holographic imaging systems using microwave have good resolution in the lateral direction compared to that of conventional radar, resolution in the range direction is poor within SSRS's field. One of the technique for improving the resolution of the holography in the range direction is the use of the wide-band signal tequnique. Multi-frequency holography can provide good resolution on the order of one or two wavelengths in both directions. In order to reconstruct an image from collected SSRS's data, it is necessary to know the relative permittivity of accumulated snow. The assumed relative permittivity at X-band microwave of dry snow depends on the accurate measurement of its density. In this paper we propose a method of automatic estimation of the relative permittivity of snow utilizing certain characteristics of multi-frequency holography itself[2]. We are able to obtaine satisfactory results concerning image reconstruction of the SSRS's data.

2 Formulation

In multi-frequency holography, holograms are recorded by step up frequencies. The information in the range direction is determined by the phase rotation of the returned signal. However, the effects of snow in this case is ignored, as illustrated Fig. 1. It is assumed that the transmitter illuminates the target with a scattering rate distribution of $g(x_o, y_o, z_o)$, while the antenna is scanned in 2-D so that hologram data is collected in each frequency. The received signal $u(x, y, f)$ on the hologram plane, which is defined in terms of the lateral coordinates x and y, and frequency f, is given by

$$u(x,y,f) = \int_0^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} g(x_o,y_o,z_o) \cdot \exp\left(-j2\pi f\frac{2r}{v}\right) dx_o dy_o dz_o \tag{1}$$

where v is the velocity of light, and r is the distance between target and the observation points. We assume that r is within the distance in which the Fresnel approximation is applicable.

$$r \simeq z_o + \frac{(x-x_o)^2+(y-y_o)^2}{2z_o} \tag{2}$$

Let the frequency f be represented by a differential frequency f_d from a center frequency f_0, and in the case of $f_0 \gg f_d$, we can obtain the following approximation:

$$-j2\pi f\frac{2r}{v} \simeq -j2\pi f\frac{2z_o}{v} - j2\pi f_0\frac{(x-x_o)^2+(y-y_o)^2}{vz_o} \tag{3}$$

Substituting (2),(3) into (1) results in the following approximation:

$$\begin{aligned} u(x,y,f) &= \int_0^{+\infty}\exp\left(-j2\pi f\frac{2z_o}{v}\right)\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} g(x_o,y_o,z_o) \\ &\quad \cdot\exp\left\{-j2\pi f_0\frac{(x-x_o)^2+(y-y_o)^2}{vz_o}\right\}dx_o dy_o dz_o \end{aligned} \tag{4}$$

Let the inner integral of (4) be as in the following expression:

$$\begin{aligned} h(x,y,z_o) &= \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} g(x_o,y_o,z_o) \\ &\quad \cdot\exp\left\{-j2\pi f_0\frac{(x-x_o)^2+(y-y_o)^2}{vz_o}\right\}dx_o dy_o \end{aligned} \tag{5}$$

Using the relation show in (5), we can rewrite (4) as follows:

$$u(x,y,f) = \int_0^{+\infty} h(x,y,z_o)\cdot\exp\left(-j2\pi f\frac{2z_o}{v}\right)dz_o \tag{6}$$

Here $u(x,y,f)$ represents a 1-D Fourier transformation of $h(x,y,z_o)$ with respect to z_o. And $h(x,y,z_o)$ represents a 2-D Fresnel transformation with respect to the lateral direction, which is independent of a frequency coordinate. Therefore, we find that the multi-frequency hologram $u(x,y,f)$ contains information on the lateral and range direction independently in the x–y sectional plane and frequency coordinate. We can obtain a reconstructed objects image from multi-frequency hologram in the following way. First, the multi-frequency hologram is compressed in the range direction by 1-D inverse Fourier transformation with respect to the frequency. A reconstructed image is achieved from the compressed range data by an inverse Fresnel transformation.

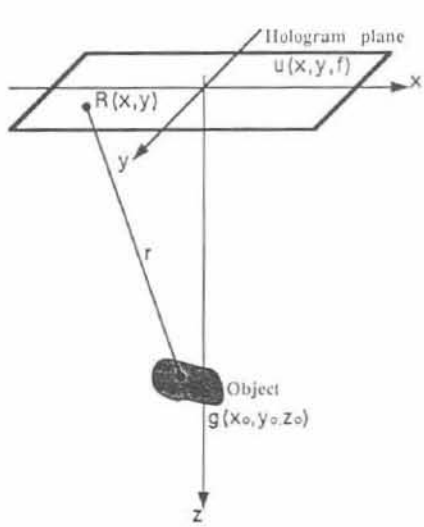

Fig.1 Coordinate system of multi-frequency holography.

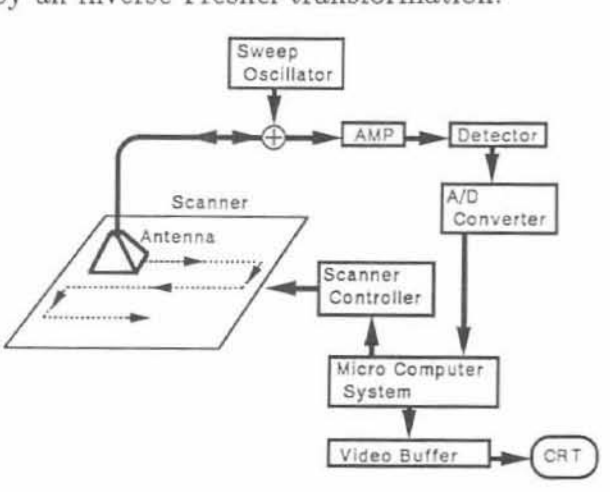

Fig.2 Block diagram of the snow search radar system.

3 Effect of Snow

The penetration depth of the microwave in accumulated snow is determined by snow liquid-water content, temperature, wavelength, and density. The experiments of SSRS were performed in dry snow, for the reason that the microwaves penetrate only in the order of centimeters in wet snow. The wavelength in snow is shorter in inverse proportion to the square root of the relative permittivity. We assume that the wavelength isn't shorter in snow, so distance parameter z_o'(range direction),z_o''(lateral direction) are given by

$$z_o' = \sqrt{\epsilon_r} z_o \quad (7)$$

$$z_o'' = \frac{z_o}{\sqrt{\epsilon_r}} \quad (8)$$

where ϵ_r is the relative permittivity of snow. Substituting (7),(8) into (2) results in the following expression:

$$r_{\epsilon_r} = z_o' + \frac{(x - x_o)^2 + (y - y_o)^2}{2z_o''} \quad (9)$$

The above means that the reconstructed image is out of focus when the relative permittyvity was an unknown quantity. Conversely, when the reconstructed image is in good focus, we can estimate the relative permittyvity of snow.

4 Experimental Results

A block diagram of the SSRS is shown in Fig. 2. The hologram data is acquired at the sampling points of 32 × 32 on the area by stepping up the frequency from 8GHz to 10GHz. The number of sampling points with respect to frequency axis is 64. Fig. 3 is the photograph of the scanner part of the SSRS, where the scanning antenna is shown.

Two metalic cylinders were used as targets buried in the snow in the configuration shown in Fig. 4. The recorded SSRS's data is reconstructed by using the process as shown in Fig. 5. The highest intensity data plane processed by the range compression is inversely Fresnel transformed with the variable of the relative permittyvity. The relative permittivity of snow can be estimated by analysis of reconstructed images. We

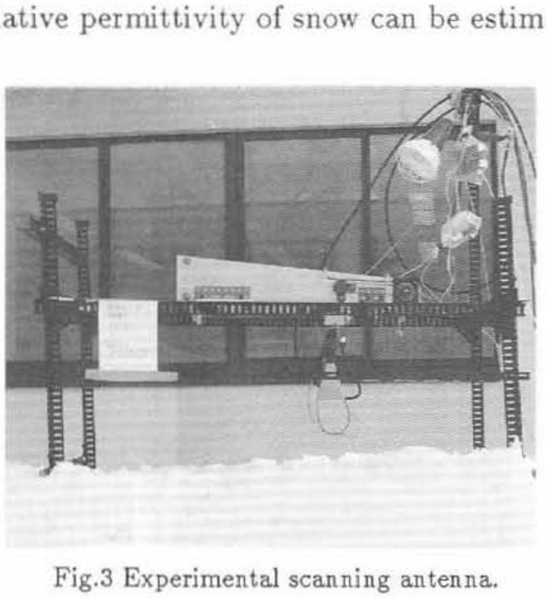

Fig.3 Experimental scanning antenna.

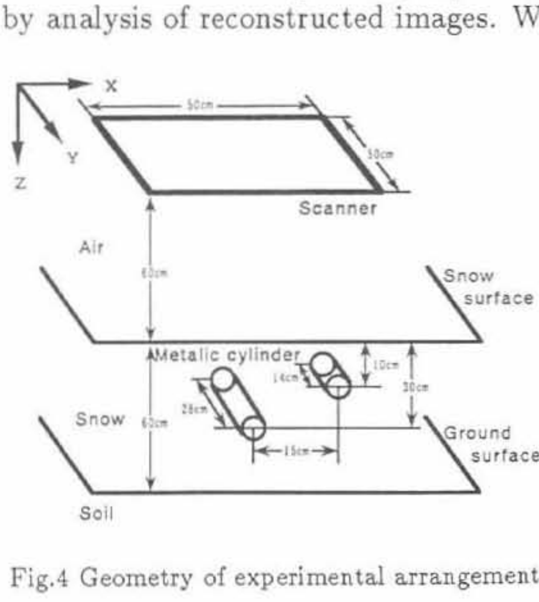

Fig.4 Geometry of experimental arrangement.

employed a weighting function in direct proportion to the spatial frequency of the images, for judgment of the relative permittivity. Fig. 6 is the result of analysis. We estimated that the relative permittivity of the snow was 1.27(Fig. 6). Which is in close agreement with previous techniques(by density of snow). Shown in Fig. 7 is the reconstructed 3-D image obtained by the proposed reconstruction method.

5 Conclusion

This paper has described a method of automatic estimation of the relative permittivity of snow and reconstruction of the image utilizing the inherent characteristics of multi-frequency holography. We were able to obtain satisfactory results regarding image reconstruction of SSRS's data. By utilizing this method, reconstruction of the SSRS image without prior measurement of the relative permittivity of the snow, was achieved.

References

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[2] R. Mitsuhashi, Y. Sakamoto, and Y. Aoki,"A Method of Image Reconstruction for Snow Search Radar Considering the Propagation of Multi-Frequency Holograms in Snow", IEICE, Tech. Rep, A-P91-73(1991)

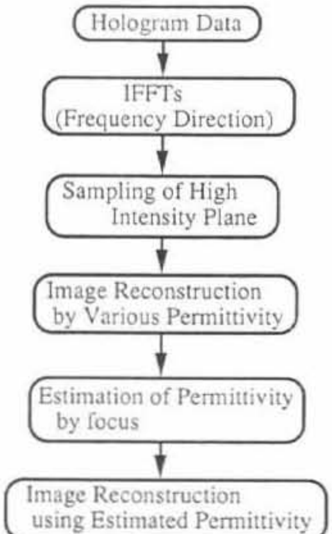

Fig.5 Algorithm of the reconstruction.

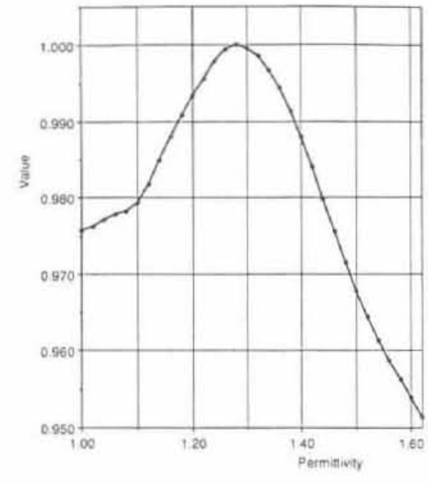

Fig.6 Estimation of focus for permittivity.

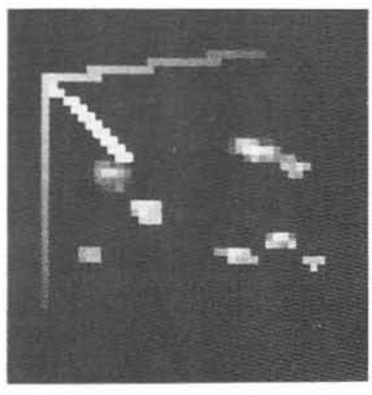

Fig.7 Reconstructed image.