POLARIMETRIC DETECTION OF BURIED OBJECTS BY FM-CW RADAR

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ABSATRACT

The subsurface radar suffers from strong clutter from surface and severe wave attenuation in the underground. This paper presents a unique countermeasure to these problems using a polarimetric FM-CW radar equipped with equivalent time sensitivity control (STC) technique. We first apply the polarimetric filtering principle to suppress surface clutter, then, use an equivalent STC technique suited for FM-CW radar for a deep sounding to compensate wave attenuation. These techniques contribute to a significant improvement of the radar performance. The field experiments were carried out to show the usefulness of the method.

INTRODUCTION

In subsurface radar sensing, strong surface clutter sometimes masks the echo of shallow target even if the target is detectable. This is also relevant to power leakage from a transmitting antenna to a receiving antenna when two antennas are located near the surface. For reduction of this undesired signal, cross-polarization antenna arrangement [1] or time-gated signal sampling [2] have been proposed in the pulse radar system. However, this time gating approach is not applicable to CW radar systems except for a gated stepped frequency radar [3].

The wave attenuation in the underground is also a challenging problem. The attenuation is dependent on the conductivity of the medium and the frequency, and is independent of radar types. For compensation of attenuation, the pulse radar can use sensitivity time control (STC) system. On the other hand, there has been no solution to this problem for the CW radar systems, except for a hardware frequency-dependent-amplification of IF signal [4].

In this paper, we present a countermeasure to these problems for the FM-CW radar subsurface sensing. The principal purpose is to provide a method to suppress surface clutter [5], whereas to detect deep objects. The first strategy for the surface clutter rejection is a polarimetric filtering approach, i.e., to use a null polarization state for the surface to null out the echo. The second strategy is to use an equivalent STC technique for a deep object to overcome the attenuation and to improve the resultant radar image contrast. This equivalent STC technique is based on the property of Fourier transform in the beat signal of FM-CW radar [6], and can be realized by simple software or hardware implementation. We propose the combined use of these two techniques for subsurface sensing applications.

Field experiments were carried out in Niigata University campus. The detection result is presented in Section IV, indicating that the null polarization state imaging and the equivalent STC technique highly enhance the radar sounding capability.

POLARIMETRIC SUPPRESSION OF CLUTTER

If a polarimetric measurement is conducted in the HV polarization basis, the FM-CW SAR provides scattering matrices $\left[S(HV) \right]$ along the range direction, whose element is derived by target reflection coefficient. It is possible to synthesize a radar channel power at any polarization state from the scattering matrix.

The Co-polarization channel power is obtained from

$$P_c = \left| \boldsymbol{E}_t^T \left[S(HV) \right] \boldsymbol{E}_t \right|^2 \tag{1}$$

where $$E_t = \frac{1}{\sqrt{1+\rho\rho^*}} \begin{bmatrix} 1 \\ \rho \end{bmatrix}, \qquad \rho : \text{polarization ratio} \tag{2}$$

We define a contrast enhancement factor by the power ratio as

$$C = \frac{P_1}{P_2} = \left| \frac{E_t^{\mathrm{T}} [S]_1 E_t}{E_t^{\mathrm{T}} [S]_2 E_t} \right|^2 \tag{3}$$

The subscript 1 corresponds to a desired target for which we wish to enhance and the subscript 2 corresponds to undesired target to be eliminated. The maximum contrast factor is given by choosing the null polarization state of undesired target. If the radar system is assumed to be monostatic ($S_{HV} = S_{VH}$), the null polarization states are given by

$$\rho_{cn1}, \rho_{cn2} = \frac{-S_{HV} \pm \sqrt{S_{HV}^2 - S_{HH}S_{VV}}}{S_{VV}} \tag{4}$$

Since the null polarization state is easily obtained, it is possible to recalculate the corresponding channel power in all pixels of a SAR imagery. This polarimetric imaging suppresses surface echo, while enhances the desired target. Although the power for the desired target may be somewhat reduced by this polarimetric filtering, the contrast enhancement become large.

The polarimetric filtering works well in the case where target 1 and target 2 have different polarization properties. If these scattering matrices are similar to each other, this technique does not enhance the target. However, in the subsurface radar sensing, we take target 1 as desired target and 2 as undesired target. Target 2 is, for example, surface clutter which generally has different polarimetric properties from the target. In addition, we know from the outset the location of surface from the radar. This information is important in the subsurface sensing because we do not know where the desired target is located within the underground. Therefore, just by choosing a null polarization state of surface for polarimetric imaging, the radar would enhance the desired target versus the surface .

EQUIVALENT SENSITIVITY TIME CONTROL TECHNIQUE TO FM-CW RADAR

The FM-CW radar measures a distance from an antenna to an object by the beat signal of transmitted signal and reflected signal from the object. The beat signal can be expressed as a function of time,

$$S_b(t) = g\, A(r_b)\, \mathrm{Re}\left\{ \exp\left[j\ 2\pi \left(f_b t + \theta \right) \right] \right\} \tag{5}$$

where, g : reflection coefficient from target, $A(r_b)$: amplitude factor,
f_b : beat frequency, θ : phase.

$\mathrm{Re}\{\bullet\}$ means the real part of the argument. f_b is the beat frequency proportional to the distance r_b . g is a reflection coefficient from target which includes the effect of inhomogeneity within the medium. $A(r_b)$ is an amplitude factor due to the path length.

Since the beat frequency f_b in the FM-CW radar system can be obtained by the Fourier transform to (5), we go back to (5) and make use of the property of Fourier transform as

$$FT\left[S_b(t) \right] = \tfrac{1}{2} g\, A(r_b)\, \delta(f - f_b) \exp\left[j\ 2\pi\theta \right] \qquad f \ge 0 \tag{6}$$

$$FT\left[\frac{d^n}{dt^n} S_b(t) \right] = \tfrac{1}{2} g \left(j\ 2\pi f_b \right)^n A(r_b)\, \delta(f - f_b) \exp\left[j\ 2\pi\theta \right] \qquad f \ge 0 \tag{7}$$

where FT denotes Fourier transform. It should be noted in (6) that the amplitude term is multiplied with $\left(j\ 2\pi f_b \right)^n$. This means the factor is amplified with f_b which is proportional to the target distance. This multiplication would compensate the attenuation due to path length. We use the term $\left(j\ 2\pi f_b \right)^n g\, A(r_b)$ as the element of scattering matrix, instead of $g\, A(r_b)$. This technique is similar to the time sensitivity control (STC) concept used in pulse radar systems. The degree to the compensation rate is dependent on the number of differentiation with respect to time for the beat signal (7).

In addition to this simple compensation method, this technique conserves the relative phase information necessary for SAR processing. Therefore, the attenuation compensated beat signal (7) can be applied to radar polarimetry and synthetic aperture processing where the phase information plays a decisive role.

EXPERIMENTAL RESULT

In order to confirm these combined methods, we carried out an experiment for target detection in underground at the Niigata University Campus. The measurement situation is shown in Fig.1. The dynamic range of the system was approximately 40 dB with maximum RF power of 10 dBm. The antenna was a single ridge horn operative from 350 MHz to 1.0 GHz. The target was a metallic plate of 20 cm width and 85 cm long, buried at the depth of 125 cm in a sandy ground. The polarimetric detection was conducted in the conventional linearly polarized *HV* basis. In this measurement, *H* stands for the polarization being parallel to the scanning direction and *V* for the orthogonal polarization to *H*. The target was oriented 135 degrees with respect to the scanning direction. We obtained three fixed (*HH*, *HV*, *VV*) polarization radar images in Fig.2 after the SAR processing. The target echo appears at the depth of 125 cm in the Co-pol channel (*VV* and *HH*) images. On the other hand, the surface clutter exists in all fixed polarization images.

Figure 3 shows the Co-pol null image of the surface. It is seen that although the surface echo is suppressed, the metallic plate echo is weak and another clutter above the plate becomes strong. This phenomenon depends on polarization property of ground inhomogeneity. The weak target echo is due to severe attenuation of wave in the underground. In order to compensate the attenuation, the equivalent STC technique was applied to Fig.4 (the first order differentiation). It is seen that the metallic pipe echo becomes strong and that surface echo is suppressed. Moreover, the null polarization image in Fig.5 with the second order differentiation clearly detected the pipe than in Fig.4. Therefore, the combined use of these two techniques enhances the detection capability.

CONCLUSION

We used a combined method of the polarimetric filtering and the equivalent STC technique for the subsurface FM-CW radar. Radar polarimetry suppresses clutter and the equivalent STC technique compensates the attenuation of wave with respect to the distance. The equivalent STC technique conserves the phase information of beat signal which is necessary for radar polarimetry. In order to confirm the validity of the combined use of these two techniques, we carried out the experiment. It was possible to detect clearly the metallic pipe buried at the depth of 125 cm in the sandy ground. This combined method is effective for detection of deep targets and enhances the FM-CW radar performance.

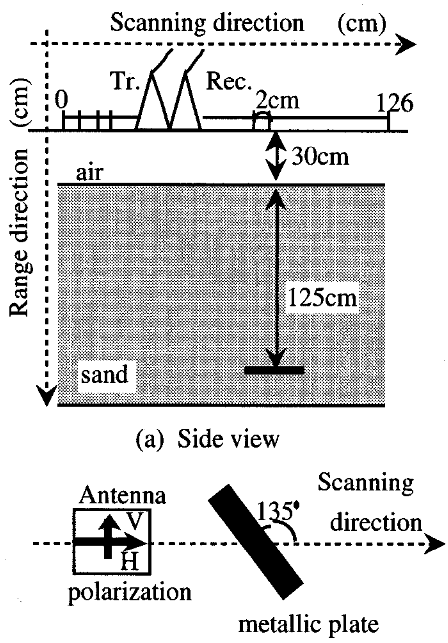

Fig.1 Measurement situation

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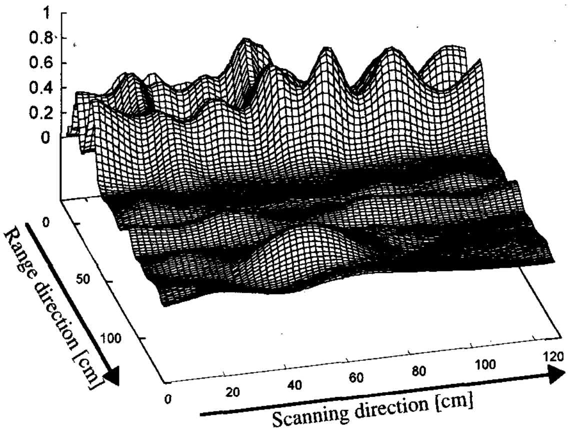
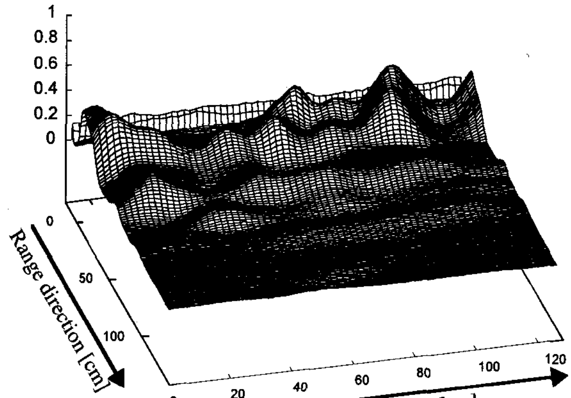
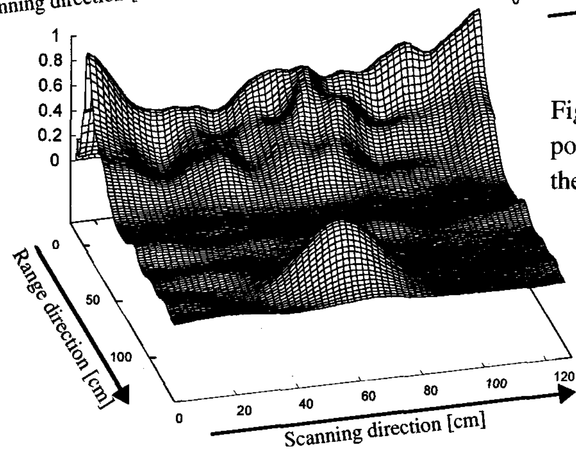


(a) *HH*



(b) *HV*



(c) *VV*

Fig.2 Three fixed (*HH,HV,VV*) polarization radar images after the SAR processing.

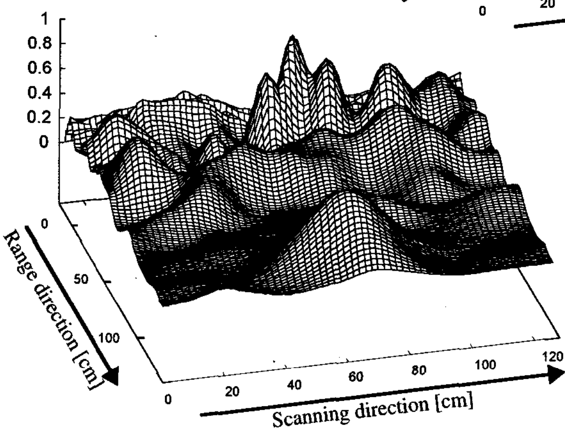


Fig.3 The Co-pol null image of the surface.

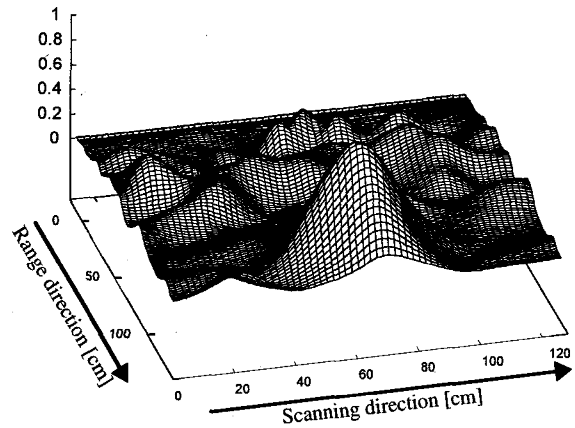


Fig.4 The Co-pol null image of the surface using the equivalent STC technique (the first-order differentiation).

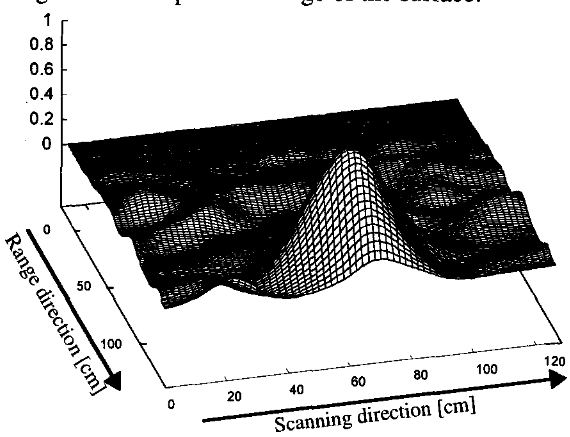


Fig.5 The Co-pol null image of the surface using the equivalent STC technique (the second-order differentiation).