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Removal of direct coupling in a Walled-LTSA array to visualize plastic landmines

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1. Introduction

Ground penetrating radars (GPRs) are widely used in many fields such as underground pipe detection, ruin observation, and underground stream investigation. They are also expected to become a powerful measure to detect nonmetallic landmines [1]. There are various kinds of landmines, which are roughly categorized into anti-tank mines and anti-personnel ones. In this paper, our target is anti-personnel mines, which are in most cases buried shallowly in the ground.

The authors previously proposed a stepped-frequency radar imaging system employing a newly developed complex-valued self-organizing map (CSOM) to visualize plastic landmines [2]. It observes reflection as two-dimensional images of complex amplitude (amplitude and phase) at multiple frequency points. The totally three-dimensional (two real space and one frequency space) data is fed to the CSOM, in which three-dimensional local texture is evaluated [3]. Through an unsupervised learning, the CSOM generates an adaptively segmented image to show the respective regions of a plastic landmine, metal fragment, stone, and soil, depending on differences in the textures.

The process is completely different from most of conventional systems, which deals with simply the radar cross section of a reflecting object and tries to eliminate clutter. The texture observation brings not only a high-segmentation ability but also a high possibility to identify the reflecting objects.

We also fabricated an array antenna for landmine detection. It comprises 144 (12×12) Walled-LTSA (Walled Linearly tapered slot antenna) elements. They are switched electrically by RF mechanical switches to select trasmitting and receiving antenna pairs from the elements. However distances between transmitting and receiving elements are so close that the component of direct coupling is not negligible.

In this paper, first we measure the coupling components at respective transmitting and receiving pairs. Then we remove the components of direct coupling by subtracting them in frequency domain. We also compensate the phase shift caused by path length difference. After such processing, the measured complex ampitude (amplitude and phase) is fed to a CSOM to visualize landmines. We report the results in observations of plastic landmines with the proposed system. We confirmed a successful visualization of the targets by using the Walled LTSA array in combination with the adaptive and phase-sensitive CSOM signal processing.

2. System Construction

The system is mainly comprised of two parts, i.e., the Walled LTSA array and the switching circuit. For precise texture observation, a high resolution measurement is desirable, which originates from a small aperture size and an operation at a higher frequency band. The Walled LTSA we previously proposed is a wide-band (operating at 8-12GHz) element with a small aperture (14mm×28mm) [4] . The Walled LTSAs are placed two-dimensionally and switched electrically to realize a quick and high-resolution reflection image acquisition. The array structure is so simple that the cost is very low. The total aperture size of the array is approximately 180mm×360mm.

A switching circuit is designed to select receiving and transmitting Walled LTSAs out of 144 elements. That is, we can choose both of receiving and transmitting antennas out of 144 Walled LTSAs.

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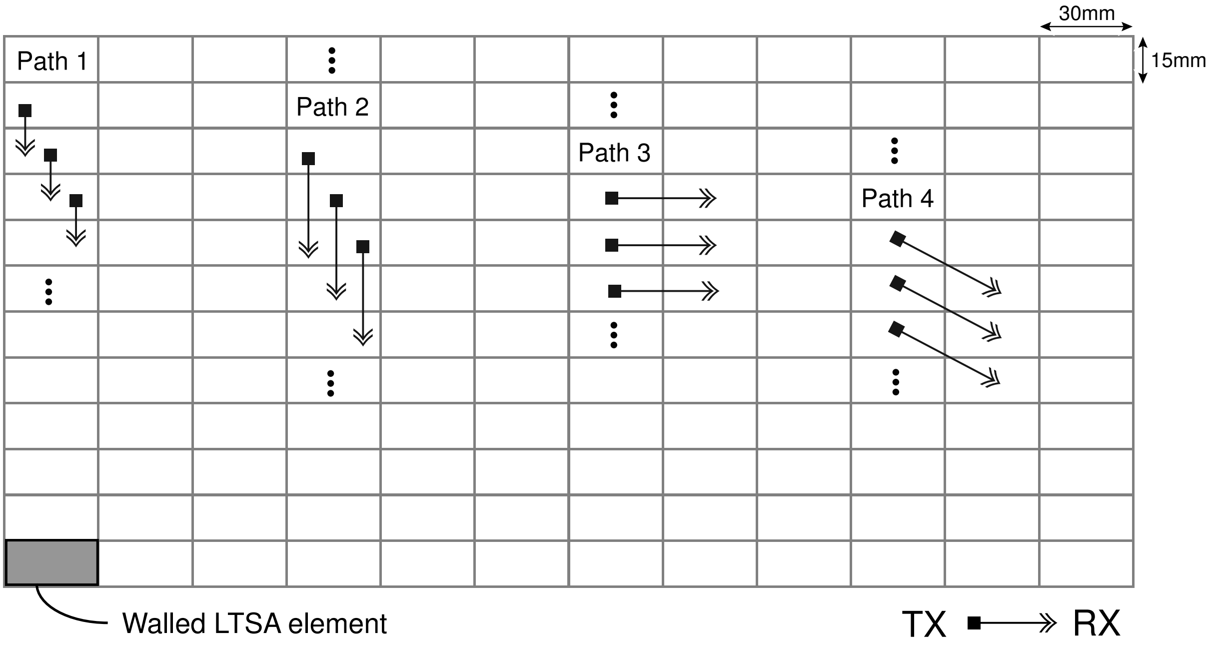

Figure 1: Selection of transmitting and receiving antenna pairs.

Switching circuit comprises 20 radio-frequency switches. The topology realizes a variety of transmitter – receiver pairs for an operation without an additional transmitter.

The switches are controlled by a personal computer (PC) through two USB-connected digital input/output boards (National Instruments, 96bits, 5V signal level). The 5V controlling signal is converted into 12V signal by a set of transistor drivers to drive the switches.

3. Visualization experiments of plastic mock mine

We report experimental results to visualize plastic mock landmines buried shallowly in the ground by using the Walled LTSA array system.

3.1 Physical setup

The array antenna is placed about 5cm above the land surface to measure the reflection from the ground. The vector network analyzer (VNA) observes complex transmission coefficient S_{21} (amplitude and phase) from 8 to 12 GHz. The number of the frequency sampling points is 401. Actually, in CSOM processing, only 10 out of 401 freqency data are used to obtain the classified image of landmines. The depth of the buried targets is about 1–3cm from dips of the land surface. As a target, we used a copy of TYPE 72 plastic landmine (diameter 78mm, height 40mm) except that the explosive powder is replaced by another material having the same dielectric constant as that of the powder.

The Walled-LTSA elements are switched electrically, yielding two-dimensional complex-amplitude images. Fig.1 shows the selections of transmitting and receiving element pairs. The number of measurement points are 132 (11×12), 120 (11×12), 110 (10×11), 121 (11×11) for Path 1, 2, 3 and 4, respectively, and 483 pairs in total. The middle point between transmitting and receiving elements corresponds to the position of pixels in the complex amplitude images.

3. 2 Removal of direct coupling

In this array system, distances between transmitting and receiving elements are very short. The component of direct coupling is not negligible, and should be removed by signal processing. First we measured only the component of direct coupling for each pairs at respective frequencies. Then in the object visualization, we remove the direct coupling by subtracting its value z_{coup} from the measured raw complex value z_{raw} as shown in (1). Here, (i, j) is the position of the measurement point and f is the frequency.

$$z_{\mathrm{tmp}}(i, j, f) = z_{\mathrm{raw}}(i, j, f) - z_{\mathrm{coup}}(i, j, f) \tag{1}$$

3. 3 Compensation of differences in pathlength

In this measurement, there are two types of differences to be compensated in pathlength. One is due to the fabrication accuracy of elements, and the other is caused by the distance between transmitting and receiving pairs. These two types of differences in pathlength are compensated in (2) shown below. As the former one is included also in the coupling component as a phase shift $\arg(z_{\mathrm{coup}})$, this difference is can be compensated by the subtraction of the phase value.

The latter one is caused by four different paths from Path 1 to Path 4 in Fig.1. To roughly compensate this difference, we calculated the phase shift θ_{path} at each path. In (3) below, d_{path} is the distances between transmitting and receiving elements, while h is the height of the array antenna. The height h is set to 5cm for a rough calibration. The pathlength in the object measurement is generally different from this reference pathlength, depending on the depth of targets and clutter sources as well as land surface roughness. In this sense, this process is a very rough calibration. However, the influence of the shift can be reduced enough for the CSOM to visualize a landmine in its adaptive and nonlinear complex-amplitude processing. In addition, the compensation also removes the differences in the characteristics of individual antenna elements. Note also that, in the CSOM processing, an approximately constant phase shift is not so harmful in principle to the clustering of the complex-amplitude pixels [2].

$$z_{\mathrm{after}}(i, j, f) = \exp\left(-i\theta_{path}\right) \cdot \exp\left(-i \arg(z_{\mathrm{coup}}(i, j, f))\right) \cdot z_{\mathrm{tmp}}(i, j, f) \tag{2}$$

$$\theta_{path} = \frac{2 \cdot 2\pi}{\lambda} \sqrt{{d_{path}}^2 + h^2} \tag{3}$$

3. 4 Results of plastic landmine visualization

We observed a plastic mock landmine shallowly buried in the ground. Fig.2(a) shows the amplitude and phase images at 10 frequency points with 0.4GHz intervals, after pathlength compensation, while Fig.2(b) shows the CSOM classification result obtained for the 10-frequency-point images.

In the amplitude and phase images, we can see slightly homogeneous area at the landmine pixels than those in the background, though it is still difficult to recognize the landmine. However, in the CSOM result, we find that the plastic landmine area is segmented from the surrounding area. The adaptive, nonlinear CSOM functions well in combination with the Walled-LTSA stepped-frequency system.

Note that, in a supervised-learning class-identifying process, which is following the present image segmentation process, we can examine the features of the classes to find which class is highly estimated as a landmine class [5]. The additional combination with this post process enables the system to estimate landmine areas in total in an adaptive and developmentally learning manner.

4. Summary

We observed a plastic mock landmine by using a Walled-LTSA array. The component of the direct coupling is removed by signal processing, and phase shift caused by the differences of pathlengh is also compensated. We demonstrated successful visualization of the target in combination with the adaptive CSOM processing.

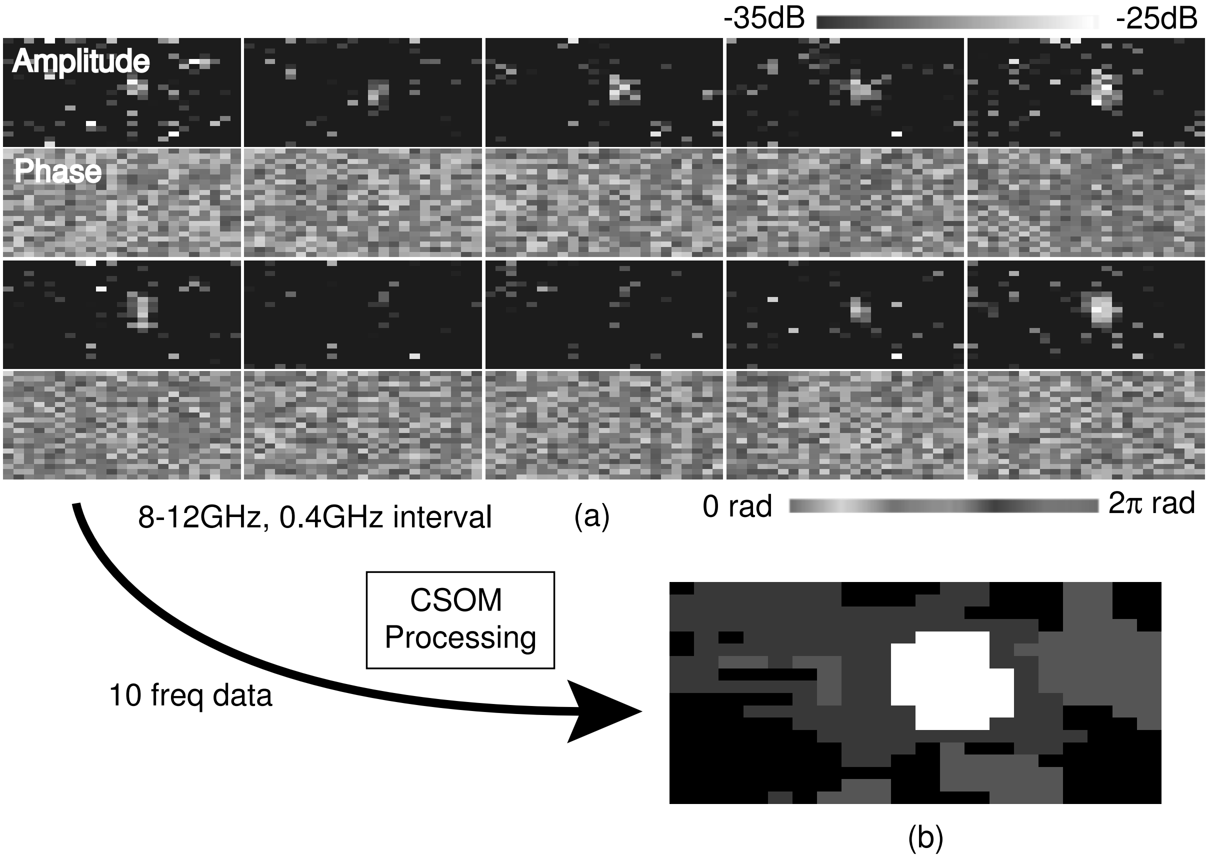

Figure 2: (a)Amplitude and phase, and (b)classification result of the plastic mock mine buried in the ground.

Acknowledgments

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