Antipersonnel Landmine Detection Using Ground Penetrating Radar

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Abstract: In this paper, ground penetrating radar (GPR), which has the capability to detect non metal and plastic mines, is proposed to detect and discriminate antipersonnel (AP) landmines. The time domain GPR - Impulse radar and frequency domain GPR - SFCW (Stepped Frequency Continuous Wave) radar is utilized for metal and non-metal landmine detection and its performance is investigated. Since signal processing is vital for target reorganization and clutter rejection, we implemented the MUSIC (Multiple Signal Classification) algorithm for the signal processing of SFCW radar data and SAR (Synthetic Aperture Radar) processing method for the signal processing of Impulse radar data.
Keywords: GPR, landmine detection, SFCW radar, Impulse radar, MUSIC, SAR,

1. Introduction

Landmine detection and discrimination has becoming a challenging issue for the radar researcher because it is a very difficult and dangerous job. According to United Nations data, there are an estimated 110 million antipersonnel land mine buried over 60 countries, which cost twenty-six thousand innocent lives throughout the world every year [2]. Despite the great efforts of UN Mine Action Program and other humanitarian demining organizations, only 100, 000 mines are found and destroyed per year from the earth. At this rate, clearing all the 110 million mines from the earth will require 1100 years, assuming no new mines are laid. There are thousand of types of landmines such as metallic type, plastic or low metal landmines, and so on. Metal detectors or EMIS (electromagnetic induction spectroscope) are the most popular and mature tools to detect the landmines. However, the probability of false alarm is very high, about 0.997 (that is for every item detected, there is a 99.7 percent that it is a scrap and 0.3 percent chances that it is a mine). Moreover, these are can not detect non metallic (plastic) mines.

In this paper, we propose the GPR (Ground Penetrating Radar) for the detection and discrimination of antipersonnel landmines, as a technique that has capability to detect metallic and non-metallic buried landmines. Simply speaking, GPR is a device, which transmits an electromagnetic wave into the earth and receives the echo (reflected signal) from the earth to investigate the signature of the buried target or subsurface layer. It has been a well-established and reliable technology for the underground pipes and cables detection, archaeological survey, and other civil engineering work [1]. It can discriminate the object when the dielectric constant is changed, so it can discriminate the landmine as its dielectric constant is different from soil, no matter whether it is metal or nonmetal landmine. In this research work, we used a vector network analyzer as a GPR, which is based on SFCW (Step Frequency Continuous Wave) radar. In addition, we used impulse radar having 150 Pico second pulse width, which operates in time domain.

2. Signal Processing Method

Signal processing is a vital step for landmine detection with GPR as GPR signals contain not only the response from a potential mine target, but also contains unwanted coupling signals from ground surface, clutter signal from the buried scraps such as nails, cans, and so on. In addition, they are very sensitive to the dielectric constant of the soil. So, for signal processing of SFCW radar, we proposed the super resolution technique MUSIC (Multiple Signal Classification) algorithm. The MUSIC algorithm converts the frequency domain signal of the SFCW radar into the time domain yielding very high vertical resolution. The precision of vertical resolution is very high, which helps to calculate the précised depth of the target. However, the data acquisition time is pretty long in this case. In contrast, the data acquisition by pulse radar is faster than in SFCW radar and can be measured in real time. For the signal processing of impulse radar, we proposed SAR processing method, which is based on migration technique to compress the azimuth resolution and also to reproduce the three-dimensional imaging.

2.1) MUSIC Processing

The GPR signals should be preprocessed before they undergo MUSIC processing because MUSIC fails to work properly when the signals are coherent. So, it is decorrelated or preprocessed by spatial smoothing process (SSP) [1]. The spatially smoothed covariance matrix is defined as the sample means of the sub array covariance and expressed as

$$\boldsymbol{S}_{SSP} = \frac{1}{M}\sum_{k=1}^{M} \boldsymbol{S}_k \qquad (1)$$

The position (delay time) of each reflection point can be estimated by searching the peak position of the MUSIC function (P_{music})

$$P_{music}(\tau) = \frac{\boldsymbol{a}(\tau)^* \boldsymbol{a}(\tau)}{\boldsymbol{a}(\tau)^* \boldsymbol{E}_N \boldsymbol{E}_N{}^* \boldsymbol{a}(\tau)} \qquad (2)$$

where, $\boldsymbol{a}(\tau)$ is a delay time mode vector and $\boldsymbol{E}_N$ is noise matrix. Due to eigen value analysis, MUSIC could achieve the high resolution signal.

2.2) Synthetic Aperture Radar (SAR) Processing

In SAR processing, a set of transmitting and receiving antennas are seperated equally over a synthetic aperature length. This is also known as migration technique. The echoes from the point target can be represented in the A-scope. When the co-ordinates of the point target are (x_i, y_j), the echoes or receiving signal are distributed along a trajectory, which is expressed as following

$$y^2 = (x - x_i)^2 + y_j{}^2 \qquad (3)$$

The echo received at the antenna which is just above the point target is higher than the echo received at the antenna which is away from the point target. All the distributed echoes along the trajectory are combined to get high signal level at (x_i, y_j), which is expressed as

$$Q(x_i, y_j) = \sum_{m=-M}^{M} D_m . (x_{i+m}, y_m) \qquad (4)$$

Where $y_m = \sqrt{(x_{i+m} - x_i)^2 + y_j{}^2}$ and D_m is a weighting function. $2M + 1$ is the total number of echoes along the trajectory.

3. Experiment

3.1) Experimental Setup

The main objective of the research work is to detect landmines in Afghanistan, where the ground is very dry sand. Therefore, the resulting experimental setup used for the work described in the paper is summarized in Fig. 1. The experimental set up consists of experiment field made in wooden container with dry sand, antenna moving bar on the top of container to scan the target, various types of landmine, pulse radar system, SFCW radar system, data storing computers, and so on. A wooden container has a dimension of 160 cm in length, 120 cm in breadth and 180 cm in height and absorption material is attached on the four sides and the bottom.

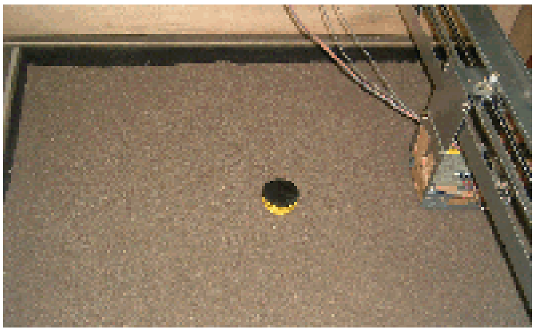

Fig. 1 Experimental Setup

The antenna is a vital component of GPR. In this experiment we used the bow-tie dipoles antenna having dimension 8 cm in length 6 cm in breadth and 4 cm in height with wide beam width antenna pattern. The antenna shields, filled in with absorbing materials, seem to have less effect on focusing of the radiated energy. It is noted that the landmines are generally buried between a few and 20 centimeters under the surface.

There are hundreds of types of landmines such as metal, plastic or very low metal nines, non-metal, and so on. It is cheap, effective, and stealthy when it is buried. In this experiment, we used TYPE-72 non-metal landmine (diameter 8 cm and height 4 cm).

3.2) Data Acquisition and Signal Processing Results

Table 1. Parameter setting for SFCW radar

Frequency Bandwidth	(500-1300) MHz
Frequency step (Interval)	1 MHz
No. of points	801
Relative permittivity of sand	3
Landmine type	Plastic
Target depth	20 cm
Antenna type	Bow-tie dipole

A TYPE-72 (nonmetal landmine) was buried in the experimental field at 20 cm. A Stepped Frequency Continuous Wave (SFCW) radar system based on commercial vector network analyzer was used for measurement campaign. The SFCW radar setting and the experimental settings are shown in Table 1.

The antenna (biostatic antenna configuration with closely separated) was fixed on the iron bar, which was moved by a motor at an interval of 2 cm to scan the buried landmines. The antenna was moved in only one direction, i.e., one-dimensional data was taken. The raw data collected from this experiment underwent conversion by the MUSIC algorithm, which converts the frequency domain signal into time domain signal. The A-scope signal of MUSIC result is shown in Fig. 2, when the radar antenna is just above the non-metal landmine.

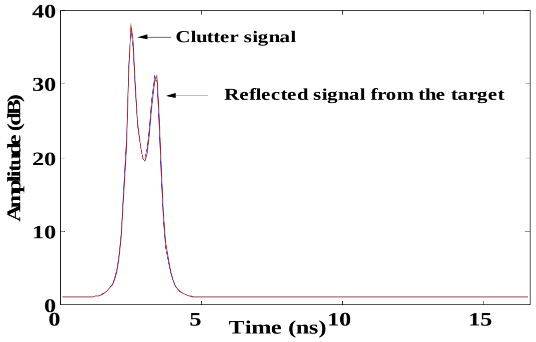

Fig. 2 The A-scan image processed by MUSIC.

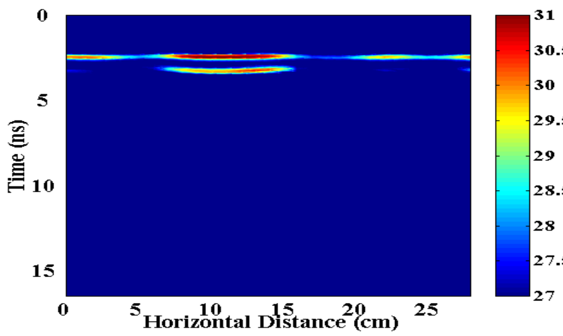

Fig. 3 The B-scan image processed by MUSIC.

The B-scan result is shown in Fig.3. The landmine target is distinctly seen and discriminated from the clutter because of super resolution potential of MUSIC algorithm. The longer computational time is major limitation of the MUSIC algorithm.

For real time measurement, we used impulse radar having a 150 pico second pulse width, in the time domain. The impulse radar generates the pulse with a wide frequency spectrum and performs sampling at successive pulse to obtain the signal waveform. In this experiment, we scan the two dimensional data in x axis and y axis to reconstruct the B-scan and three dimension image of the target. We moved the GPR antenna 40 cm in y axis 10 cm in x axis at the increment of 1 cm in each axis. The number of data point in each measurement is 128.

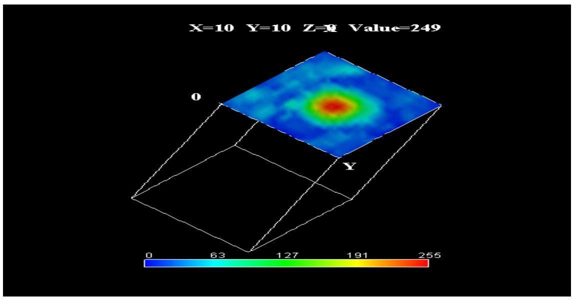

Fig. 4 The B-scan image processed by SAR

The data collected from this measurement was processed by SAR method. The B-scan image of TYPE-72 landmine is shown in the Fig. 4. We get the clear circle of image of the landmine. We can also get the slice view of the target in the different depth. Thus, we could identify and discriminate the target and clutter.

4. Conclusions

From the experiment, we found that the GPR could successfully detect the metallic and the non-metallic landmine. In addition, we found the attractive features and limitations of both SFCW radar and impulse radar. Analyzing of the advantages and limitations, proper utilization of the both SFCW and Impulse radar could be the best solution for the detection and discrimination of AP landmine. From the SFCW radar result, time domain image with high vertical resolution can be achieved due to the application of MUSIC processing method and we can get the precise depth of the target by calculating PMUSIC (Peak MUSIC). However, the data acquisition time by SFCW radar and signal processing time by MUSIC is excessively high. Moreover, the hardware configuration of SFCW radar is heavier and complicated than impulse radar. In contrast, the data acquisition time and signal processing time by SAR is very fast and it can be done in real time speed if an array of antennas is used. Moreover, the hardware configuration is light and compact. However, accurate depth can not be measured by this method. The dynamic range of pulse radar is lower than the SFCW radar; in consequence, the computational facility is limited and could not enjoy the super resolution image. Therefore, it is recommended to do initial scanning by pulse radar and if the target is detected, detailed investigation should be done by SFCW radar to get more information. In this way, time, energy, and money can be saved as well as target can be detected and discriminated reducing the false alarm.

Acknowledgement

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