High Resolution Visualize Technique for Underground Survey Using GPR

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ABSTRACT

In this paper, FMCW (Frequency Modulation Continuous Wave) radar has been proposed for the underground survey. The FFT (Fast Fourier Transform) has high precision of receiving signal level; however, it could not give high resolution. On the other hand, MUSIC (Multiple Signal Classification) algorithm can resolve the super resolution but the precision of receiving signal level is lacking. So, the time domain response of MUSIC processing and IFFT (Inverse FFT) processing has been combined and termed as CPM (Combined Processing Method). The CPM has been implemented for the signal processing and image reconstruction of closely located GPR (Ground Penetrating Radar) targets. In order to support the proposal, a detailed simulation has been performed analyzing SNR (Signal to Noise Ratio). Moreover, a laboratory experiment has also been performed for thorough investigation and support of the proposed method.

Keyword: FFT, GPR, MUSIC Algorithm, FMCW radar, Super Resolution Signal Processing

1. Introduction:

A GPR is a device, which transmits the electromagnetic wave inside the earth and received the echo signal from the earth to detect and characterized the buried targets by its imaging. GPR technology has proved to be very successful in the investigations and detection of buried objects such as water, gas, electric pipes, cables, archaeological objects, voids, landmines, and so on.

High resolution techniques have been developed for years but have not been applied to the ground penetrating radar data successfully due to most of GPR are in time domain using pulse signal, and the sensitivity and maximum detectable depth is usually limited by antenna and natural clutter. So, the frequency domain radar, which is a FMCW radar based on vector network analyzer has been used due to large dynamic range and more convenient calibration. We present an example of the applying the high-resolution MUSIC 2) algorithm to improve the time-domain resolution of the close objects with simulation and experimental data. In addition, we introduces a method of combining the IFFT and MUSIC results to achieve a good tradeoff of absolute magnitude and high resolution at some price of noise sensitivity.

2. Simulation:

The frequency domain spectrum of radar signal has been generated using Band Pass Filter (BPF). The bandwidth was set to 125 MHz, sampling frequency was set to 1 MHz, and the numbers of signals were set to 3 at the interval of 20 ns, 30 ns and 60 ns respectively. The radar signal was processed by IFFT technique. In the mean time, the same radar signal was processed using MUSIC algorithm and the results were comparatively studied. The frequency domain data is converted in to the time domain data in both cases. Combined Processing Method (CPM) of time domain response of IFFT and MUSIC is performed. CPM was carried out using the following expression.

\[ Z(t) = \frac{X \frac{\partial Y}{\partial t} + Y \frac{\partial X}{\partial t}}{\sqrt{\left| \frac{\partial Y}{\partial t} \right|^2 + \left| \frac{\partial X}{\partial t} \right|^2}} \]  

where, \( X(t) \) is the complex time domain data of IFFT response, \( Y(t) \) is the time domain data of MUSIC response and \( Z(t) \) is the complex time domain data of combined result.

![Fig.1 Demonstration of CPM response to resolve the close targets](image-url)

It is observed in Fig.1 that the IFFT response gives correct amplitude. However, resolution is very poor and also suffers from a windowing problem. In addition, the IFFT couldn't well resolve two closely located targets,
i.e. the delay time difference between the successive signal is 10 ns. On the other hand MUSIC could well resolve the same two closely located targets but the precision of signal level is low. Consequently, the proposed method CPM could also well resolve two closely located targets with high precision signal level, which is demonstrated in Fig. 1.

3 Laboratory Experiment:
This research is concentrated to resolve the vertical resolution; further investigation has been performed to check the maximum resolution capacity between two vertically aligned targets. For this, experimental setup in the water medium has been developed in the University of Electro-Communications laboratory with an aquarium of length 40 cm, breadth 40 cm and height 100 cm. Two targets of copper pipe having length 38 cm are fixed at a 10 cm depth from the water surface and vertical separation is 2 cm and while horizontal separation is 4 cm.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Setting</th>
</tr>
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<tbody>
<tr>
<td>Frequency Band</td>
<td>800 MHz</td>
</tr>
<tr>
<td>No. of Points</td>
<td>801</td>
</tr>
<tr>
<td>Sweep time</td>
<td>1 sec</td>
</tr>
<tr>
<td>Small change in frequency</td>
<td>1 MHz</td>
</tr>
<tr>
<td>Water Relative Permittivity</td>
<td>81</td>
</tr>
<tr>
<td>Target Diameter</td>
<td>1 cm</td>
</tr>
<tr>
<td>Vertical Target separation</td>
<td>2 cm</td>
</tr>
</tbody>
</table>

The experimental setup includes the high bandwidth antenna, network analyzer and the signal-processing unit. A register loaded dipole antenna has been used for the experiment. The antenna bandwidth is 600 MHz (500 to 1100 MHz) and antenna size of 4x6 cm. Parameter setting in the network analyzer for experimental purpose is as shown in Table 1.

The antenna is submersed in the water; however, water level and top surface of the antenna is kept at the same level. Antenna is moved from left to right at the increment of 1 cm to scan the target. The image of laboratory experiment data processed by CPM method is shown in Fig. 4, when the radar antenna is just above the first target. The image is represented in linear scale and interpolation process has not been performed as the frequency bandwidth is higher. The CPM response could successfully resolve 2 cm resolution with remarkable reduction of the time side lobe and continuous diffraction pattern.

4. Conclusions:
The laboratory experiment described above demonstrates the proposed CPM could successfully resolve the vertically separated target up to 2 cm at 800 MHz frequency bandwidth in a water medium. In addition the experiment results show the remarkable reduction of time side lobes and natural clutter. The continuous diffraction pattern of the radar signal has also been realized from 3-D images. From the simulation results, it is concluded that CPM has very high resolution than other conventional signal processing method due to the effect of the MUSIC processing and also the precision of receiving signal is high due the effect of the IFFT processing.

5. Reference: