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The impact of stretching of the reference signal at determining coordinates of the objects with 1Tx + 4Rx antenna system

Vadym Ruban
Radiophysical Introscopy Department
O.Ya. Usikov IRE NASU
Kharkiv, Ukraine
ruban@ire.kharkov.ua

Gennadiy Pochanin
Radiophysical Introscopy Department
O.Ya. Usikov IRE NASU
Kharkiv, Ukraine
gpp_15@ukr.net

Lorenzo Capineri
DINFO
University of Florence
Florence, Italy
lorenzo.capineri@unifi.it

Timothy Bechtel
Dept. of Earth & Environment
Franklin & Marshall College
Lancaster, PA, USA
tbechtel@fandm.edu

Tetiana Ogurtsova
Radiophysical Introscopy Department
O.Ya. Usikov IRE NASU
Kharkiv, Ukraine
otn_tati@ukr.net

Oleksandr Orlenko
Radiophysical Introscopy Department
O.Ya. Usikov IRE NASU
Kharkiv, Ukraine
olanorlenko@gmail.com

Pierluigi Falorni
DINFO
University of Florence
Florence, Italy
p.falorni@gmail.com

Fronefield Crawford
Dept. of Physics and Astronomy
Franklin & Marshall College
Lancaster, PA, USA
fcrawfor@fandm.edu

***Abstract*—This paper considers the possibility of improving the probability of detecting objects using a UWB radar with 1 transmitter and 4 receivers antenna system. The influence of "stretching" of the reference signal on the level of the Pearson coefficient for signals reflected from objects and determination of the times of flight is investigated.**

Keywords—GPR, TOF, Pearson correlation coefficient, data processing, subsurface object detection.

I. Introduction

During the implementation of Project #G5014; "Holographic and Impulse Subsurface Radar for Landmine and IED Detection" [1] of the NATO Science for Peace and Security (SPS) Program [2], an algorithm for the detection of buried objects was developed using the times of flight (TOFs) from the transmitter to the object and back to each of 4 receivers [3-5]. In this algorithm, TOFs were determined by the maximums of the Pearson correlation coefficients. We determined correlation between signals reflected from the object and the pre-selected reference signal. Reflection from a metal disk 10 cm in size was used as a reference signal [3].

However, in reality, the waveform of the reflected signals changes depending on the distance from the antenna to the object. For example, Fig. 1 shows how the shape (width) of the pulse reflected from the metal disk changes, depending on the distance to it. Accordingly, the level of the Pearson coefficient also changes while approaching the object.

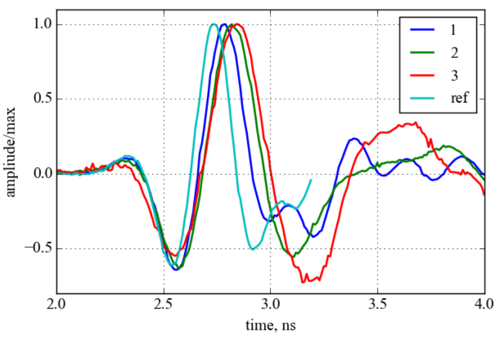


Fig. 1. Example of reflected signals. 1 – Object under transmitting antenna, 2 – Object 10 cm behind transmitting antenna, 3 – Object 20 cm behind transmitting antenna, ref – reference signal

Therefore, it is important to study how the expansion of the reference signal affects the determination of the Pearson correlation coefficient and the determination of the coordinates of objects.

II. Methodology Description

The first stage of the research was done in laboratory conditions with target objects in the air.

Experiments were carried out with a 4-channel radar using the setup shown in Fig. 2.

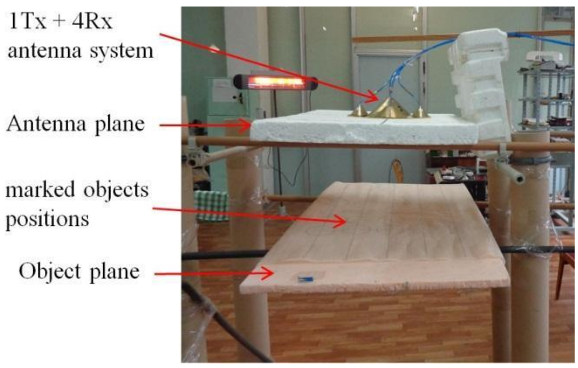


Fig. 2. Experimental setup

An object was placed on a block of foam extending 1.5 m above the floor. The distance from the plane of the antenna system to the plane of the object was 34 cm. During the experiments, the object under investigation was positioned in a grid consisting of 5 by 5 nodes with a step of 10 cm in both coordinates. Fig. 3 shows the numbering of the positions of the object during measurements.

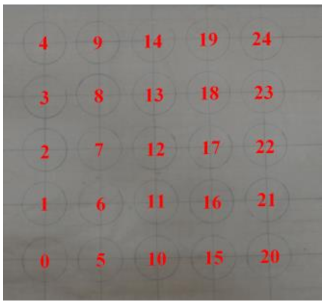


Fig. 3. The numbering of the positions of the object

Fig. 4 shows the position of the antenna system with respect to the target grid.

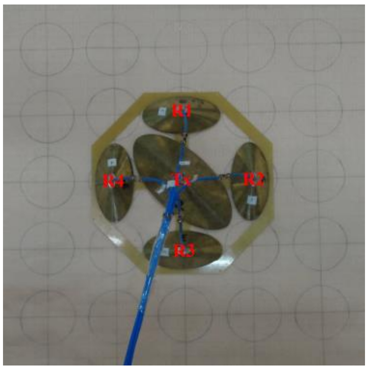


Fig. 4. The antenna system in the center of the grid

The set of objects used in the experiments is shown in Fig. 5.

Fig. 5. A metallic disk, a tin can, and a PMN-2 simulant (left to right) were used as test targets.

During the experiments, each of the objects was placed sequentially at the grid nodes. Signals reflected from the object at each position (from 0 to 24) were recorded. So the sequence of actions was as follows:

1. Set object in position;
2. Record data;
3. Calculate the Pearson coefficients for the reference signal;
4. Select “minima of maxima” or “maxima of minima” for positions at different reference stretching;
5. Calculate probable object coordinates with “optimal” reference stretching.

Fig. 6 shows the correlation curves for the reflection from the disk at position 0. It also shows the maxima that are taken into consideration for each of the receiving channels.

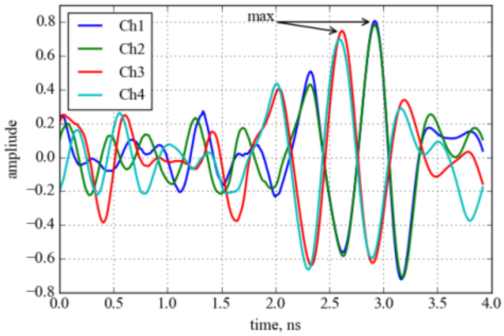


Fig. 6. The correlation curves for the reflection from the disk at position 0

We can determine the correlation curves maxima values for each object position and each channel for the given reference signal shape. Shown in Fig. 7 are the dependences of the maxima of the correlation curves on the object position.

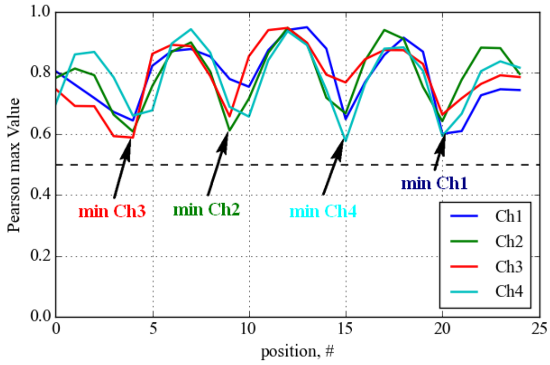


Fig. 7. Maxima of Pearson's correlation coefficients versus the number of object position for all four channels

Here, arrows indicate the minimum values of the correlation coefficients from all positions. We will call them "minima of the maxima" and will use them to estimate Pearson coefficient threshold level for the TOFs selection process.

According to this methodology, the Reference signals were "stretched" in time by factors from 1.0 to 1.8. The "minima of the maxima" values of the correlation curves were calculated for each of them. Fig. 8 shows the relationship of these values for the "stretch" factor of the reference signal.

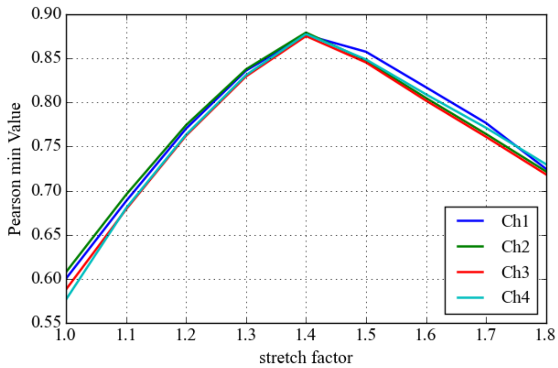
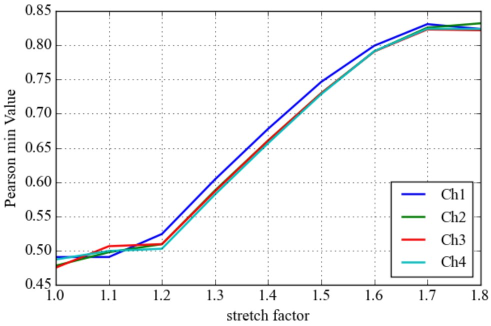


Fig. 8. "Minima of the maxima" values for stretched reference signals. Metal disk example

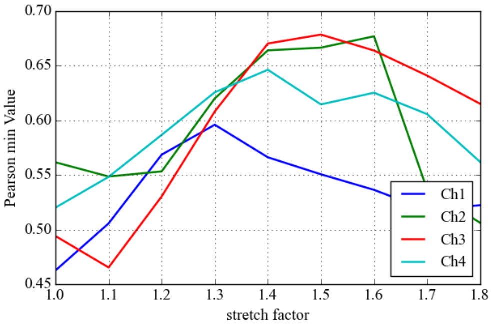
It can be seen that this dependence has a maximum at the "stretch" factor of 1.4. This means that with the stretched reference signal, the highest threshold level for choosing TOFs can be set. The impact of "optimal" reference signal on the object detection and positioning is discussed in the next section.

III. Experiments; Results and Discussion

In addition to considering a metal disk, we studied the effect of stretching the reference signal for two other objects - a tin can and a PMN-2 landmine simulant. Fig. 9 shows the dependence of the "minima of the maxima" of the correlation curves on the "stretching" factor of the reference signal for both objects.



a)



b)

Fig. 9. The "minima of the maxima" versus the stretch factor for a) the tin can and 2) the PMN-2 simulant

It can be seen from the figures that for the tin can, a reference signal "stretching" factor of 1.7 is optimal, while the threshold level for the Pearson's coefficient selection can be raised to 0.8. At the same time, for the PMN-2, the dependences of the “minima of the maxima” on the shape of the reference signal differ in the receiving channels. This is due to the fact that the PMN-2 simulant has relief on its surface (non-flat). Therefore, the reflected signal waveform for each receiver is different. If we consider the “worst” variant (for channel 1), then the optimal “stretching” of the reference signal is 1.3, while the threshold level for selection of coefficients can be set above 0.55.

Using the "optimal" reference signal, we determined the positions of the objects. Fig. 10 shows the calculated coordinates of the object (metal disk) if the threshold level equals 0.8. The color of the points changes with the distance from the plane of the antennas to the object. The color scale to the right of the figure can be used to estimate this distance in cm.

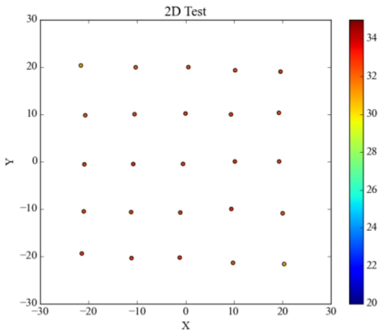
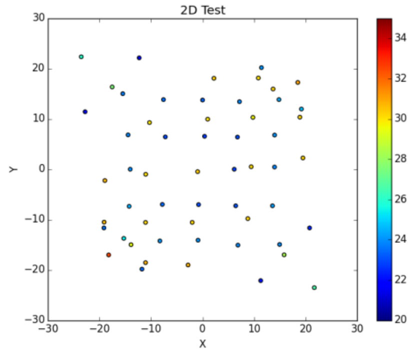


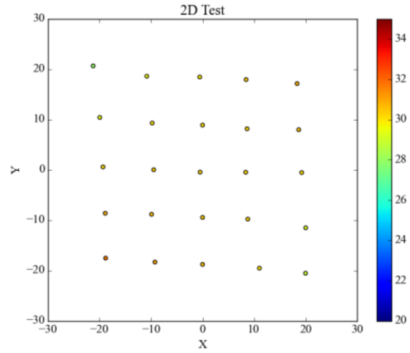
Fig. 10. Calculated coordinates of the metal disk

It can be seen that all positions are determined quite accurately.

Let us compare the possibilities of determining the coordinates of an object with optimally and non-optimally "stretched" reference signals. Fig. 11 shows the calculated coordinates of the tin can when using a reference signal without "stretching" (stretch factor is 1) and the same ones using the optimal reference signal (stretch factor is 1.7).



a)

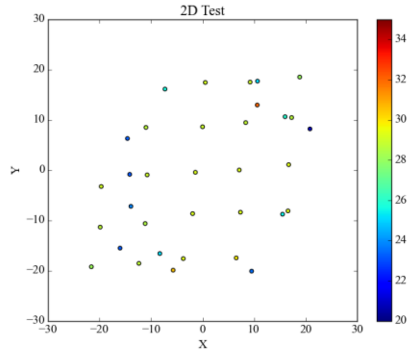


b)

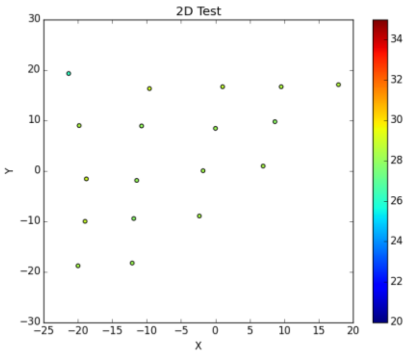
Fig. 11. Calculated coordinates of the tin can. a) reference signal without "stretching", the threshold level is 0.4, b) "stretching" of reference signal is 1.7, the threshold level is 0.8

When using a "sub-optimal" reference signal to calculate the tin coordinates, there are many inconsistent or false additional coordinates. When using the "optimal" reference signal, all coordinates of the object positions are determined and there are no false or additional detections.

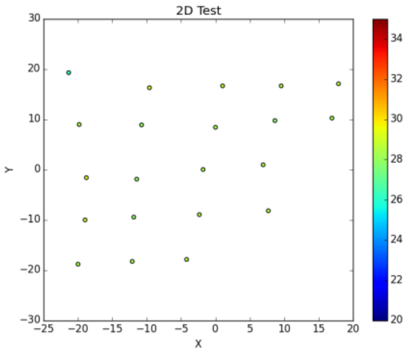
Fig. 12 shows the calculated coordinates of the PMN-2 simulant.



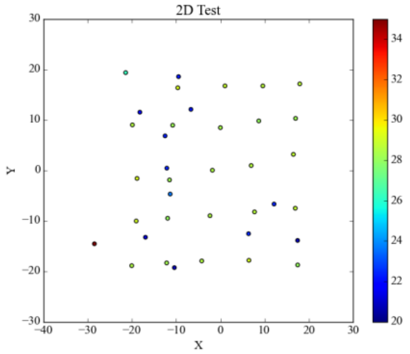
a)



b)



c)



d)

Fig. 12. Calculated coordinates of the PMN-2 simulant. a) reference signal without "stretching", the threshold level is 0.45, b) "stretching" of reference signal is 1.3, the threshold level is 0.5, c) "stretching" of reference signal is 1.3, the threshold level is 0.4, d) "stretching" of reference signal is 1.3, the threshold level is 0.3

As can be seen from the figures, if we use a reference signal without "stretching" to determine the PMN-2 coordinates, then only 22 out of 25 object positions are detected. There are also false targets (Fig. 12a). At the same time, when an object is detected with an "optimal" reference signal and a high threshold level for coefficient selection (Fig. 12b), false targets disappear, but the detection of the object also worsens (only 18 out of 25 positions are detected). Lowering the threshold level to 0.4 improves detection (in Fig. 12c, 21 out of 25 positions are detected). With a further decrease in the threshold level to 0.3, all positions of the object are detected, but false targets also appear (Fig. 12d).

IV. CONCLUSIONS

Analyzing object detection results with experimental data, we noted that the shape of a signal scattered by an object changes depending on its position with respect to the antenna array. Pearson's correlation algorithm gives better results if we use a stretched reference signal for correlation. For the PMN-2 plastic mine with surface relief, there is a trade-off between probability of detection and appearance of false positives; a universal problem in detection of landmines and nearly any other targets.

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