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A Practical and Precise Algorithm for Detecting and Locating Human Movement Behind Walls

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Abstract

In this study, we have proposed a novel localization algorithm to detect a moving object or person behind the wall. Algorithm is based on one-transmitter and two-receiver arrangement and make use of the phases of the received signals. By taking the in-phase and conjugate-phase components of the two-receiving signals, it is shown that it is possible to precisely locate the object's and/or person's exact location in cylindrical coordinate system. A simulation work in Matlab was carried out to assess the performance of the algorithm.

Keywords: Through-the-wall radar (TWR), localization algorithm, moving target detection, radar signal processing.

1. INTRODUCTION

Recently, through wall radar is a critical technology for military and civil applications such as eliminating terrorist acts, search and rescue operations or natural disasters (earthquake, fire, avalanche, etc) [1-2]. Knowing about locations of moving person behind wall can be vital for these applications since it may lead to save lives. We have previously introduced some studies on applying different focusing/imaging algorithms for the detection/imaging of objects behind opaque medium [3-5]. In this study, we have developed a novel algorithm that is depended on one-transmitter and two-receiver configuration for determining the locations of a moving person on the other side of an opaque medium. As the calculation of algorithm provide a fast implementation, it also produces highly effective results in the frequency domain.

The organization of the paper is as follows: In the next section, the steps of proposed algorithm are given in detail. In the third section, the algorithm was implemented on a synthetic data that was developed in Matlab programming language environment [6] to emulate the movement of a point target. Precision and reliability of the algorithm was tested with the result of simulation. Resultant estimated locations after applying our detection algorithm proves the validity of the proposed routine. The last section is dedicated to conclusion.

2. PROPOSED ALGORITHM FOR DETECTION

The principle of the algorithm is based on one-transmitter and two-receiver system configuration. The transmitter () and the receivers (and) are placed on the cross-range axis (y) in such that as equally distance () between the and one of the receivers. In Figure 1, a perfect point scatter is assumed to be located at in the range axis (. The distance between the point scatter and the transmitter; is denoted as a radial distance of target. Also, the distances between the point scatter and the receivers () are represented as and respectively.

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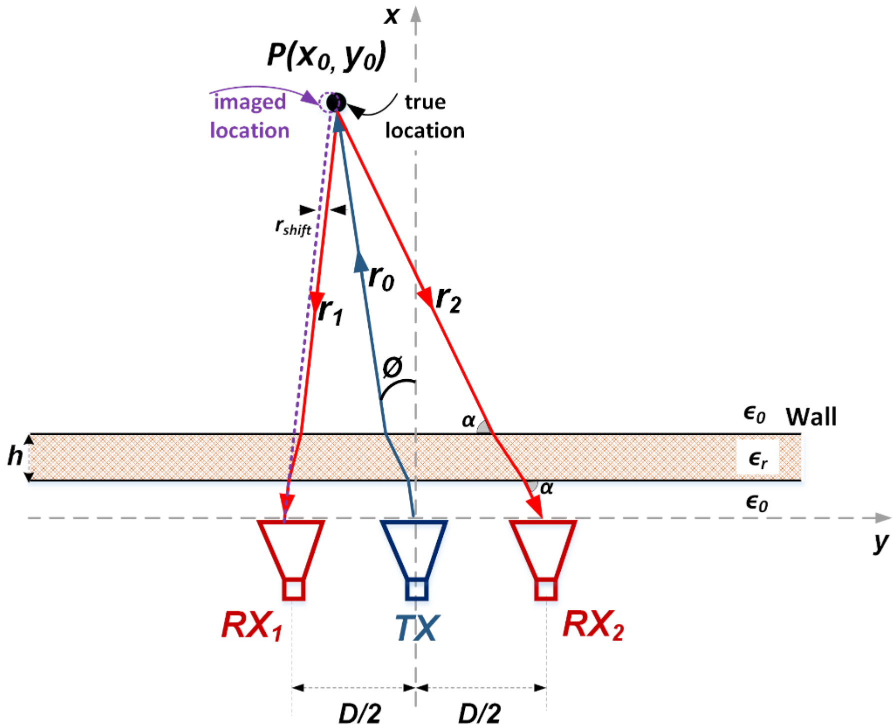

Figure 1: TWR geometry for proposed algorithm.

In the algorithm, two approximations are employed. The first approach in the algorithm is that is quite larger than the distance . In the algorithm, theand distances depend on and which is the angle of point in cylindrical coordinates. Therefore, these distances can be nearly expressed as

$$r_1 \cong r_0 + \frac{D}{2}\sin\phi$$
$$r_2 \cong r_0 - \frac{D}{2}\sin\phi \tag{1}$$

As the second approach in the algorithm; the wall thickness is significantly smaller than the and distances especially for walls with low dielectric constant. Thus, imaged location of target is obtained with a very small shift amount; from true location of target in cross-range axis. This phenomenon is also shown in Figure 1. Provided that the wall thickness is not too much (around 15 cm to 40 cm) and the dielectric constant of the wall material is on the order of 1.5 to 6, the amount of shift, can be readily neglected in the algorithm. The scattered electric field data from target at point are collected by the help of receivers as

$$E_S^1(\boldsymbol{k}) \cong a_1 e^{-j\boldsymbol{k}(r_0+r_1)}$$
$$E_S^2(\boldsymbol{k}) \cong a_2 e^{-j\boldsymbol{k}(r_0+r_2)} \tag{2}$$

Where and are the reflectivity amplitude of target collected by and , respectively. Also is the wavenumber vector. When the expression at (1) is replaced in equation (2), the scattered electric field data can be reorganized as

$$E_S^1(\boldsymbol{k}) \cong a_1 e^{-jk\boldsymbol{k}(r_0+r_0+\frac{D}{2}\sin\phi)} = a_1 e^{-j2\boldsymbol{k}r_0} e^{-j\boldsymbol{k}\frac{D}{2}\sin\phi}$$
$$E_S^2(\boldsymbol{k}) \cong a_2 e^{-j\boldsymbol{k}(r_0+r_0-\frac{D}{2}\sin\phi)} = a_2 e^{-j2\boldsymbol{k}r_0} e^{j\boldsymbol{k}\frac{D}{2}\sin\phi} \tag{3}$$

We can get two new data sets using and vectors as follows;

$$InP(\boldsymbol{k}) \triangleq E_S^1(\boldsymbol{k}) \cdot E_S^2(\boldsymbol{k})$$
$$CrP(\boldsymbol{k}) \triangleq E_S^1(\boldsymbol{k}) \cdot \left[E_S^2(\boldsymbol{k})\right]^* \tag{4}$$

By taking the of and with respect to and to obtain the collected electric field vector in range and domain respectively. Here $\boldsymbol{f}$ is the frequency and v is the velocity of the electromagnetic wave. Thus, point is estimated. Firstly, this point is simply transferred point in the cylindrical coordinates then transformed to Cartesian coordinates by using equation (5) as

$$x_0 = r_0 \cdot \cos\phi$$
$$y_0 = r_0 \cdot \sin\phi \tag{5}$$

3. NUMERICAL RESUŞTS

A simulation study in Matlab was carried out to assess the performance of the proposed algorithm. For this goal, a moving perfect reflecting scattering point has been thought to be moving in a piece-wise linear path as illustrated in Figure 2. The antennas were considered to be put behind the wall as the shown in the figure. The radar was considered to be used in the stepped-frequency set-up with frequencies ranging from 1 to 6 GHz for 620 stepped discrete frequency points.

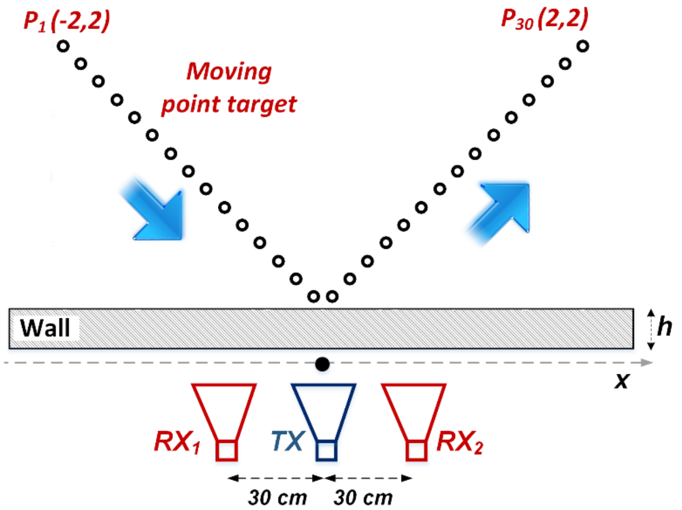

Figure 2: TWR synthetic data geometry for proposed algorithm

Then, we have applied our proposed technique by collecting the electric field data; and   from and , respectively. Bistatic range profiles obtained by taking one dimensional inverse Fourier transforming the frequency diverse A-scan data for the two receivers are shown in Figure 3.

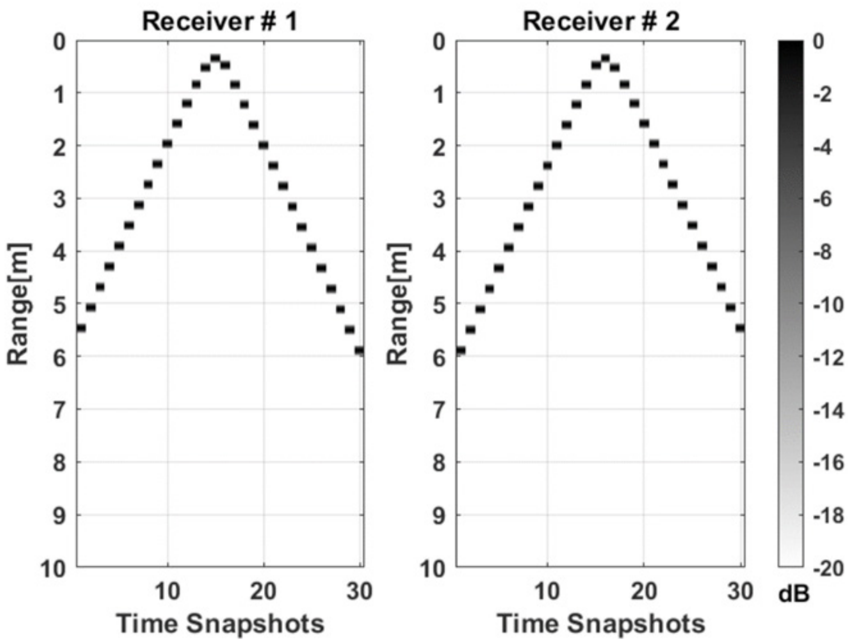

Figure 3: Bistatic range profiles for two receivers.

Afterwards, we have taken the in-phase component as and the conjugate phase component as . Consequently, the range parameter; is found by taking the inverse Fourier transform (IFT) of the in-phase component as ; whereas, the cylindrical angle variable; can also be get by taking taking the IFT of conjugate phase component as . In Figure

4, the range profiles vs. time snapshots obtained by and corresponding angle values of target with respect to time are shown. Lastly, the exact and the estimated locations of the target with the proposed method have been shown in Figure 5. It is clear from the figure that the algorithm has the ability to detect and localize the target with high fidelity. As the target approaches to the wall, the sharpness in the detection of the position of the target degrades. This result is expected, since the approximations in eqn. (1) start to weaken for such cases.

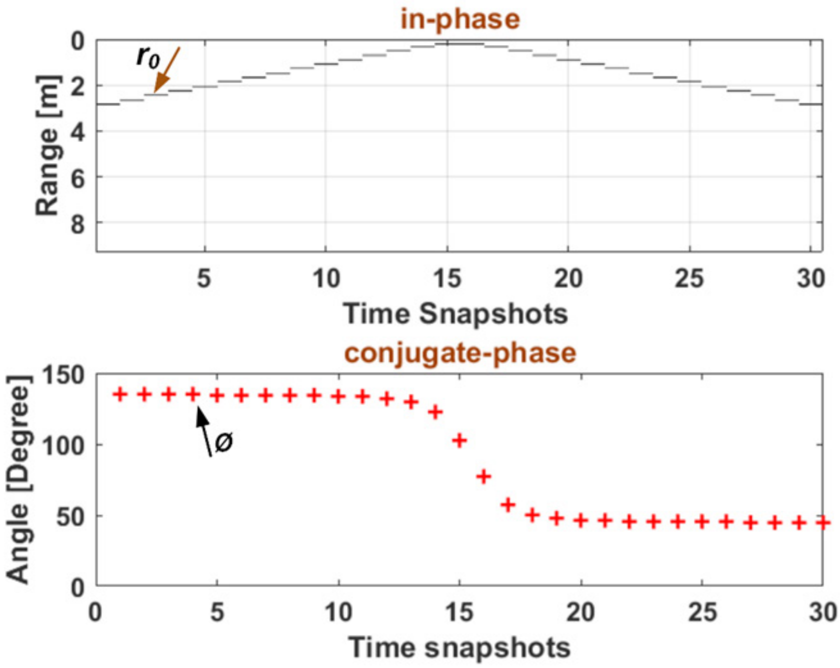

Figure 4: Range () and angle (values versus different time snapshots.

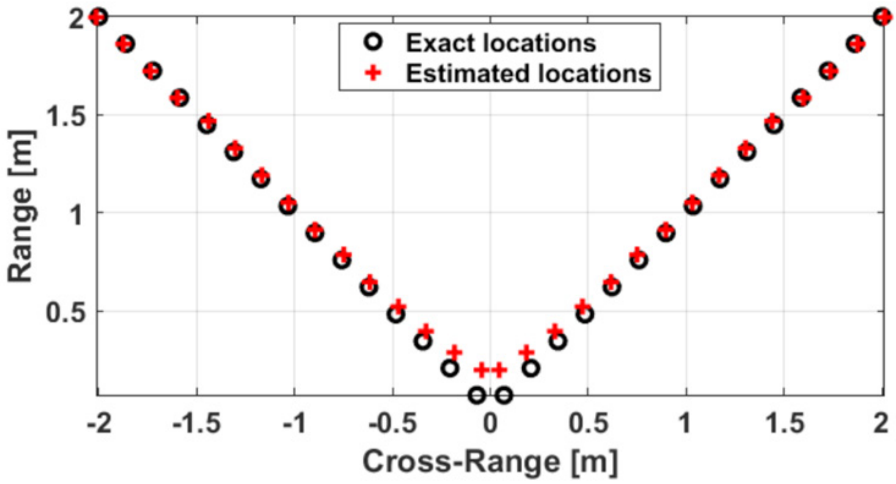

Figure 5: The exact (black circles) and estimated (red crosses) locations of the target.

4. CONCLUSION

In this study, we have introduced a localization algorithm for detecting a moving object or person behind the wall. The proposed algorithm is considerably practical and it can be implemented easily. The performance of the algorithm was tested with a synthetic data in Matlab. The numerical results were demonstrated that the proposed algorithm successfully detects and images the locations of target with good fidelity.

5. ACKNOWLEDGEMENTS

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