

ELECTROMAGNETIC IMAGING METHOD BASED ON TIME REVERSAL PROCESSING APPLIED TO THROUGH-THE-WALL TARGET LOCALIZATION

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Abstract—A time reversal method is studied and adapted to through-the-wall detection and localization of moving targets. Tests are realised on experimental data in a synthetic aperture radar configuration. The efficiency of the method to extract a moving target from a cluttered environment is proved on experimental data.

1. INTRODUCTION

The detection and localization of persons through obstacles is becoming a great stake in both civil and military fields. One of the most important applications is certainly sensing through the walls which can be very useful in safety, peace-keeping and law enforcement operations. One needs not only to know if there is somebody inside a room but also where this person is. Radar systems are likely to provide an adequate answer to this kind of problem [1] and various processing methods are nowadays studied and considered to reach the final solution [2]. In this paper, we focus on ultra-wideband radar techniques [3, 4] applied to through-the-wall human sensing. In

particular, experimental measurements are performed in a spotlight synthetic aperture radar configuration [5, 6] and then are treated by a signal processing method to obtain an image of the scene. In this radar configuration, an antenna array is used on reception and a fixed one on emission. Many signal processing methods can be considered for target localization. We have chosen to focus on an emerging method in electromagnetic detection field, especially in a cluttered environment [7]: time-reversal adapted here to through-the-wall localization. In this work, in particular, time reversal processing is applied to experimental data to demonstrate the localization of dielectric moving objects behind a 10 cm thick brick wall.

2. TIME REVERSAL METHOD

Time reversal is a method that has proved its efficiency in recent years especially in acoustics [8, 9] but also in UWB communications [10–12]. This method is based on the reciprocity of Maxwell’s equations in a time-invariant medium. It can be used to localize a source of energy in space. In fact, we assume that we have a pulsed UWB source. This emitted signal is recorded by an array of receivers. It has been proved [13] that by reversing in time this data and radiating it from the same array, we focus on the source location. The focusing precision is imposed by the size of the array of transceivers and may even increase in presence of multipaths [14]. In this particular case, there is a source radiating a plane wave. This field is scattered by a collection of targets and the environment which can be considered as secondary sources in the time-reversal processing. Fields are recorded, time reversed and re-radiated from receivers. This last step is achieved computationally. In the observed scene, focusing occurs on all scattering points (target + clutter). However, if we assume that background is stationary so its signature (without the target) may be measured and subtracted to the whole signature (target + clutter). This new signal is then backscattered from receivers into medium. Now focusing only occurs on the target.

Let us consider a single target located in a time-invariant clutter. The single source is located at \vec{r}_s and the N positions of the receiving antenna are denoted as \vec{r}_i ($1 \leq i \leq N$) (see Fig. 1). Here, all the possible interactions between the environment and the target are neglected. When the source emits a pulse of spectrum $P(w)$, the incident field on the target point located at \vec{r}_c is given by:

$$E(\vec{r}_c, w) = P(w)G(\vec{r}_c, \vec{r}_s, w) \quad (1)$$

where $G(\vec{r}_c, \vec{r}_s, w)$ is the Green’s function of the environment. At each

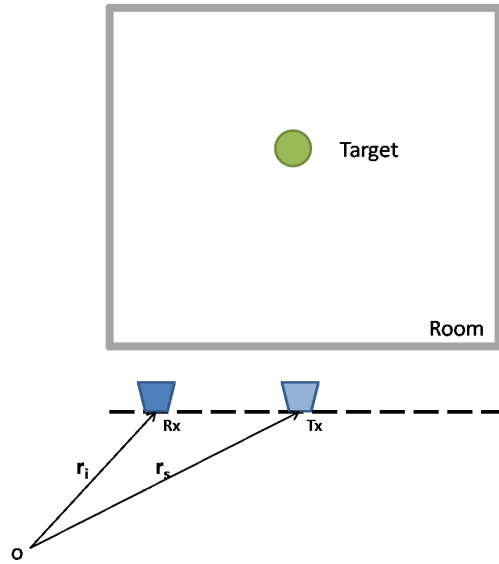


Figure 1. Schematic of through-the-wall time-reversal imaging. The target is located in a room. Sensors are outside.

receiver position i , the scattered field observed is:

$$\begin{aligned}
 E(\vec{r}_i, w) &= R(\vec{r}_c)E(\vec{r}_c, w)G(\vec{r}_i, \vec{r}_c, w) \\
 &= R(\vec{r}_c)P(w)G(\vec{r}_c, \vec{r}_s, w)G(\vec{r}_i, \vec{r}_c, w)
 \end{aligned}
 \tag{2}$$

where $R(\vec{r}_c)$ is the reflexion coefficient. It is important to note that in (2) only the back-scattered field from the target is taken into account. In fact, assuming that the environment is well known, it is possible to remove the part of the signal which corresponds to the back-scattering from the environment. This removal should correspond to differential measurements in which the detection concerns the changes in the observed scene between two close instants. Let us call this process differential mode. As in this particular application, we are looking for moving targets, differential mode is of great interest. Hence, the environment can be removed keeping only the part of the signal which corresponds to moving objects in the observed scene. The next step in time reversal process is to phase conjugate the received field at each receiver position assuming that it comes from a possible source in the scene. Phase conjugation in frequency domain corresponds to time reversal in time domain. The last step in time reversal theory is to re-radiate time reversed signal into the scene. In this work, the coefficient

$\eta(\vec{r})$ is evaluated at each point of the domain:

$$\begin{aligned}\eta(\vec{r}) &= \sum_w \sum_{i=1}^N E^*(\vec{r}_i, w) G(\vec{r}, \vec{r}_i, w) P(w) G(\vec{r}_s, \vec{r}, w) \\ &= \sum_w \sum_{i=1}^N [R(\vec{r}_c) P(w) G(\vec{r}_c, \vec{r}_s, w) G(\vec{r}_i, \vec{r}_c, w)]^* \\ &\quad G(\vec{r}, \vec{r}_i, w) P(w) G(\vec{r}_s, \vec{r}, w)\end{aligned}\quad (3)$$

In this equation, the first group of terms $E^*(\vec{r}_i, w) G(\vec{r}, \vec{r}_i, w)$ corresponds to a classical time reversal process in which the recorded signals are phase conjugated and then re-radiated into the scene. The second group of terms $P(w) G(\vec{r}_s, \vec{r}, w)$ corresponds to a compensation of the fact that the recorded signals don't come from the target it self but are scattered by it. Due to the reciprocity theorem, we have: $G(\vec{r}_c, \vec{r}_s, w) = G(\vec{r}_s, \vec{r}_c, w)$ and $G(\vec{r}_i, \vec{r}_c, w) = G(\vec{r}_c, \vec{r}_i, w)$, thus we obtain, on the equation (3), constructive interferences at $\vec{r} = \vec{r}_c$. The variation of $\eta(\vec{r})$ gives a 2D or 3D image which is a representation of the reflexion coefficient at each point of the scene. It is important to note that, in our case, the calculation of Green's function is performed considering the free-space form and then a supplementary delay due to the propagation on the wall is introduced. The exact calculation of Green's function was done numerically by a finite difference time domain (FDTD) method. Results obtained on our measurements are quite the same probably because of the nature of the wall and the range of frequencies used in this particular case. However, in a more complex medium, the exact calculation of Green's function could become necessary.

3. EXPERIMENTAL SET UP

The experimental set up consists of a vector network analyser and of two ultra-wideband ETSA (exponentially tapered slot antenna) antennas (a transmitter and a receiver). This type of antennas has improved bandwidth and radiation characteristics [15].

The receiving antenna is placed on a moving rail to synthesize an array on reception. Synthetic aperture radar configuration is chosen to improve the crossrange resolution. The size of the array is 1.8 meters and 18 positions are taken with an increment of 10 cm. Receiving antenna is elevated at about 1.2 meters above ground.

The transmitting antenna is fixed at the center of the array and is elevated at about 2 meters above ground. The frequency bandwidth is 500 MHz to 3 GHz. The upper bound of the frequency range is limited

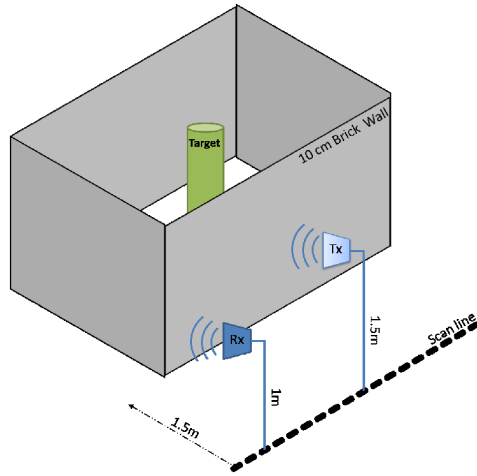


Figure 2. Experimental configuration.

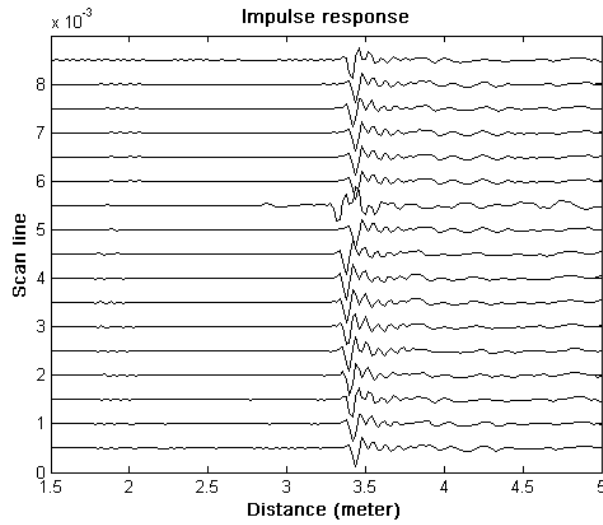


Figure 3. Impulse response at each receiver position for a target placed at (1 m, 3.4 m).

by the attenuation of electromagnetic waves through walls. Fig. 2 shows this experimental configuration.

The processing is not fully experimental. The scene is illuminated by the fixed source and a measurement is performed at each position of

the array of receivers. These measurements are then computationally processed by time reversal method to give an image of the scene. Fig. 3 is a time domain representation of the signals measured at each antenna position when only one target is in the room (environment has been subtracted from the measurements).

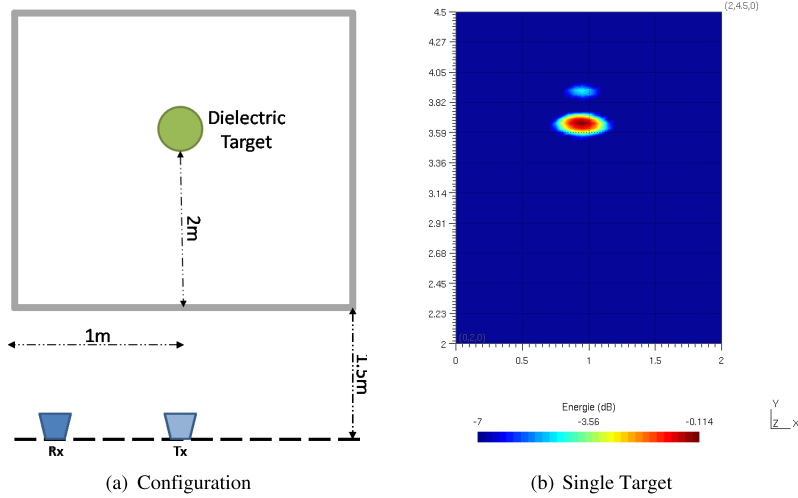


Figure 4. Localization of a single target.

4. RESULTS

To test our method, two different configurations are considered: static target (illustrated by the Fig. 4(a)) and moving target in a cluttered environment (illustrated by the Fig. 5(a)). Fig. 4(b) corresponds to the result obtained for the localization of the target in a room without clutter. This quite simple configuration is considered only to verify the imaging process on real data. The result shows that the target is well localized at (1 m, 3.6 m). In Fig. 5, panel (c) and (d) correspond to the detection of the same target in the room in presence of clutter respectively for a position 1 and for a position 2 (we simulate like this the target motion from 1 to 2). We can note that it is quite difficult to localize the target into the clutter. In order to extract the moving target, two measurements performed at two different instants are subtracted one from another (differential mode). And then, signals resulting from this subtraction are processed with the time reversal algorithm. The image given in Fig. 5(b) gives the exact trajectory of the target from the position 1 to the position 2. The clutter has

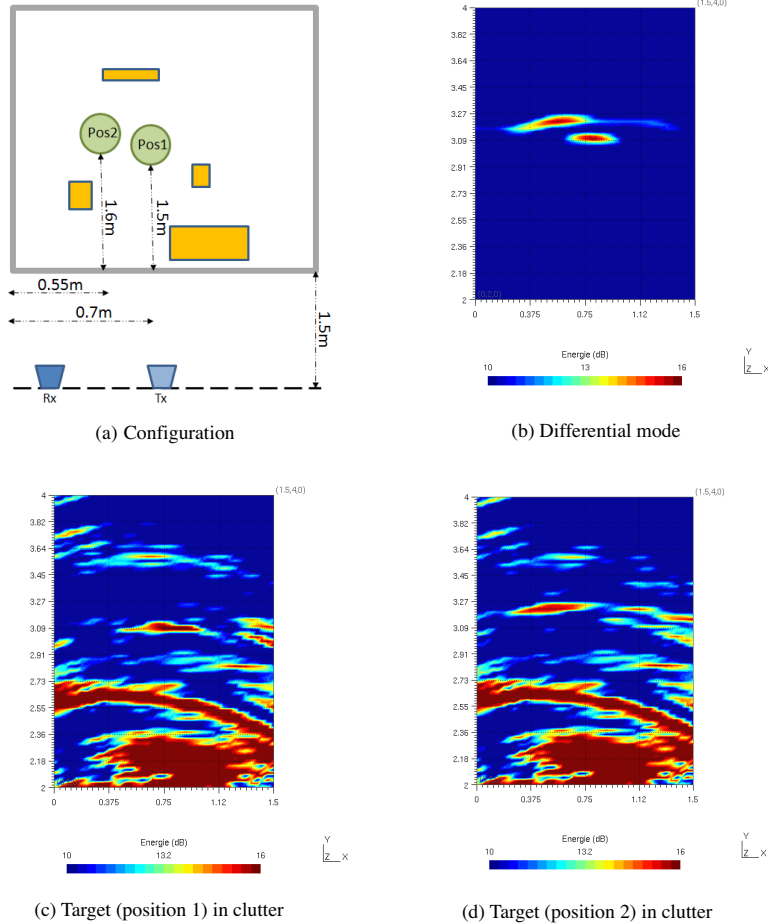


Figure 5. Localization of a moving target in a cluttered environment.

been removed. This result shows the efficiency of our time-reversed imaging processing in the case of through-the-wall localization of a moving target even in presence of clutter.

5. CONCLUSION

In this paper, a through-the-wall imaging processing based on time reversal method has been introduced and its efficiency demonstrated experimentally in the configuration of spotlight synthetic aperture radar. Extraction of a moving target from a cluttered environment

has been performed. Moreover, we notice that, in order to track a target in a room, it is not necessary to perform a first calculation of the environment without the target. Taken advantage from the fact that the human target is necessarily moving, the differential mode would be sufficient. A future challenge would consist in being able to detect a very small movement in a more complex environment (concrete walls, numerous walls, multiple targets...).

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