



HAL
open science

Uncertainty Analysis on Wall and Radar's Characteristics in Through-the-Wall Context

Yanisse Boudrouz, Israel Hinostroza, Mohammed Serhir, Christelle Eyraud

► **To cite this version:**

Yanisse Boudrouz, Israel Hinostroza, Mohammed Serhir, Christelle Eyraud. Uncertainty Analysis on Wall and Radar's Characteristics in Through-the-Wall Context. 2023 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (USNC-URSI), Jul 2023, Portland, United States. pp.1803-1804, 10.1109/USNC-URSI52151.2023.10237953 . hal-04490761

HAL Id: hal-04490761

<https://hal.science/hal-04490761>

Submitted on 5 Mar 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Uncertainty Analysis on Wall and Radar's characteristics in Through-the-Wall context

Yanisse Boudrouz⁽¹⁾, Israel Hinostroza⁽¹⁾, Mohammed Serhir⁽¹⁾, and Christelle Eyraud⁽²⁾

⁽¹⁾ Paris-Saclay Univ., CentraleSupélec, SONDRRA, Gif-sur-Yvette, France.

⁽²⁾ Aix-Marseille Univ., CNRS, Centrale Marseille, Institut Fresnel, Marseille, France.

Abstract—Through-the-wall radar imaging (TTWRI) detects concealed objects behind barriers using radar. It is a promising research area for civilian and military applications, including rescuing, surveillance, and target identification. This study evaluates the impact of miss-evaluating wall and radar characteristics on TTWRI results.

Index Terms—synthetic aperture radar, point spread function, Snell-Descartes laws, backprojection, uncertainty analysis.

I. INTRODUCTION

Through-the-wall synthetic aperture radar (SAR) imaging is a technique that enables the detection of hidden objects behind walls or barriers. This technique relies on the Snell-Descartes laws and the Backprojection (BP) algorithm to locate the target. However, inaccuracies in the characteristics of the wall can negatively affect the quality of the imaging results. To address these issues, it is essential to quantify the quality of the radar image and the resulting uncertainties by accurately assessing the scene characteristics. While previous studies have investigated inaccuracies in wall parameters [1], this one aims to extend the analysis to include the impact of errors in radar parameters as well.

The second section of this paper provides an explanation of the physics involved in the problem and the used imaging technique. To provide context for the following section, a detailed discussion of the wall and radar system relevant to the study is included. The third section focuses on the consequences of misjudging the characteristics of the wall and radar and presents the results of an uncertainty study.

II. PROBLEM FORMULATION

A. Uncertainty on the Point Spread Function

For TTWRI, we use the BP algorithm [2] to image the scene. First, we need to express the propagation time of the wave between the transmitting antenna, the target point, and the receiving antenna. Using Snell-Descartes laws we can estimate the exact path of the wave. Then, by dividing the traveled distance by the phase velocity of the wave in the medium, we can obtain the propagation time τ_{mn} [3]. Finally, we need to calculate the intensity associated with each pixel, and to do so, we use the Point Spread Function (PSF) associated with each pixel in the image [4]:

$$I(x_p, y_p) = \sum_{m=1}^M \sum_{n=1}^N [s_{mn}(t + \hat{\tau}_{mn}(x_p, y_p)) * h(t)]_{t=0} \quad (1)$$

where x_p, y_p are the pixel coordinates, M the number of emitters, N the number of receivers, s_{mn} the point target return for each receiver (Rx) and transmitter (Tx), τ_{mn} the delay of the signal traveling from the m^{th} receiver to the imaging point, and then back to the n^{th} receiver and $h(t)$ the impulse response of the matched filter.

However, the expression of this propagation time and the PSF under these conditions is absolute and does not depend on the uncertainties associated with the walls and the positions of the radar antennas.

By expanding the expression of the PSF using the same linearization technique as [1] and taking into account the positional parameters of the radar antennas (i.e. their position along x and y), we obtain a new form of the PSF:

$$\begin{aligned} \tilde{I}(x_q, y_q) &\simeq I(x_q, y_q) + \delta_\varepsilon \sum_{l=1}^N \left(\left(\frac{2d_w}{c} - \frac{x_l \theta_q}{c} + \frac{y_l \theta_q^2}{c} \right) \frac{\partial s}{\partial t} \right) \\ &+ \delta_d \sum_{l=1}^N \left(\frac{2(\sqrt{\varepsilon_w} - 1)}{c} \frac{\partial s}{\partial t} \right) + \delta_{x_{tm}} \sum_{l=1}^N \left(\frac{\sqrt{\varepsilon_w} \theta_q}{c} \frac{\partial s}{\partial t} \right) \\ &+ \delta_{x_{rn}} \sum_{l=1}^N \left(\frac{\sqrt{\varepsilon_w} \theta_q}{c} \frac{\partial s}{\partial t} \right) + \delta_{y_{tm}} \sum_{l=1}^N \left(\frac{\varepsilon_w \theta_q^2}{c} \frac{\partial s}{\partial t} \right) + \delta_{y_{rn}} \sum_{l=1}^N \left(\frac{\varepsilon_w \theta_q^2}{c} \frac{\partial s}{\partial t} \right) \end{aligned} \quad (2)$$

with c the free space light celerity, d_w the wall thickness, ε_w the wall permittivity, θ_q the incident angle relative to the normal of the wall surface, s the Tx signal, x_l the position of the Tx/Rx antennas located at the l^{th} position along the wall, (x_{tm}, y_{tm}) and (x_{rn}, y_{rn}) the positions of the Tx/Rx antennas.

B. Scene characteristics

The data are generated using an FDTD solver named gprMax. The scene comprises a homogeneous wall that measures 2.5m by 0.2m. The radar has a monostatic configuration composed of one Rx and one Tx which emits Gaussian pulses with the center frequency of 2GHz. The radar travels along the 2.5m of the wall with a step of 0.025m. The target is a perfect electrical conductor (PEC) cylinder with a diameter of 0.04m, located at $x_t = 1.2m$ and $y_t = 1.8m$.

III. UNCERTAINTY ANALYSIS

A. Wall parameters

We examine the wall and the radar effects separately. To achieve this, we first present a scheme of the scene with the

parameters, followed by the imaging results, and finally, the -3 dB shapes for different errors, as it defines an area that contains the most of the intensity.

In the case of the wall, we vary its thickness and relative permittivity (i.e. its index). As shown in Fig.1, thickness and permittivity variations result in a shift in the range of the target position and cause a spread of the spot shape at -3 dB. However, the thickness and permittivity of the wall are related by $d_w = \frac{ct}{\sqrt{\epsilon_{r,wall}}}$, where c is the celerity and t the propagation time inside the wall. So there are certain parameter combinations where errors in the wall parameters cancel each other out, resulting in accurate image formation (see Fig.1.c).

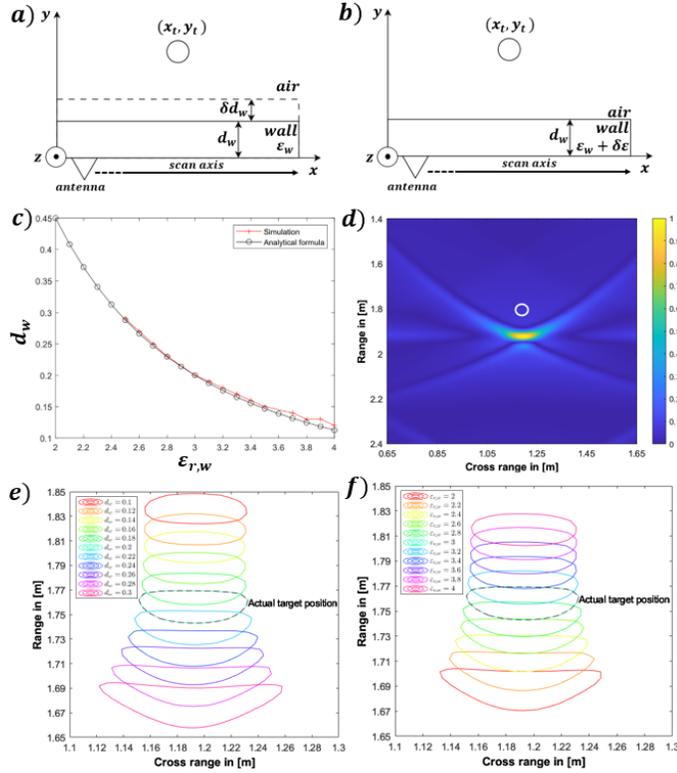


Fig. 1. Imaging with wrong wall parameters a) scheme of the error on wall thickness, b) scheme of the error on wall permittivity, c) pairs of parameters d_w and $\epsilon_{r,wall}$ where the target position error is equal to 0, d) BP imaging for $d_w = 0.24$ and $\epsilon_{r,w} = 3.8$ e) shapes at -3 dB for several different errors draws of d_w at $\epsilon_{r,wall} = 3$ and f) shapes at -3 dB for several different errors draws of ϵ at $d_w = 0.2$.

B. Radar parameters

Errors in the antennas positions in the x and y axis result in a shift in the position of the target (see Fig.2). For the simulations, we made a random draw following a uniform law on each antenna position for the x -axis and y -axis separately.

As it can be seen, errors in the radar antenna positions lead to a shift in the target position in range and cross-range. This is not the case when only the wall parameters are wrong. However, the error of y depends on ϵ_w while the error of x depends on $\sqrt{\epsilon_w}$, and this implies that it has a greater impact. As seen in Fig.2.e and Fig.2.f, the -3 dB shapes resulting from

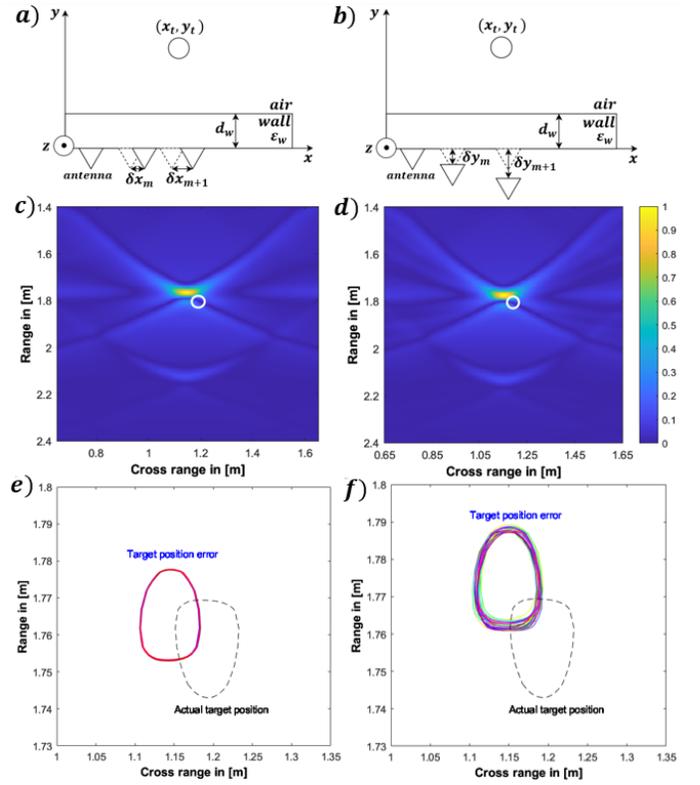


Fig. 2. Imaging with wrong radar position parameters a) scheme of the error on x , b) scheme of the error on y , c) and d) BP imaging, e) shapes at -3 dB for several different errors draw of $x_{t,r}$ and $\delta_y = 0$ and f) shapes at -3 dB for several different errors draw of $y_{t,r}$ and $\delta_x = 0$.

an error on y position have a larger spread compared to those resulting from an error on x position.

IV. CONCLUSION

An error in the wall and radar parameters can lead to displacements of the actual target position and distortions in the imagery. By quantifying these uncertainties, we found that an error in the thickness of the wall has a greater impact than an error in its permittivity, and an error in the distance of the radar system from the wall has a greater impact than an error in its position along the wall.

The analytical formulation of the point spread function enables us to conduct a sensitivity analysis using Sobol indices. Additionally, we can conduct this study in 3D, in line with our ongoing research on 3D imaging.

REFERENCES

- [1] F. Ahmad M. G. Amin and G. Mandapati, "Autofocusing of Through-the-Wall Radar Imagery Under Unknown Wall Characteristics", *IEEE Transactions on Imaging Processing*, vol. 16, no 7, p. 1780-1795, 2007.
- [2] M. Soumekh, "Synthetic Aperture Radar Signal Processing", *New-York: Wiley*, 1999.
- [3] F. Ahmad and S. A. Kassam, "Synthetic Aperture Beamformer for Imaging Through a Dielectric Wall", *IEEE Transactions on Aerospace and Electronic Systems*, vol. 41, no 1, p. 271-283, 2005.
- [4] M. G. Amin, "Through-the-Wall Radar Imaging", *CRC Press*, 2011.