

Accuracy Analysis of Propagating-Path Identification Using FDTD Method and Compressive Sensing

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Abstract - In this paper, we propose a propagating path identification method using Finite-Difference Time-Domain (FDTD) method and compressive sensing. In this study, Yee cells are regarded as array antenna, and the compressive sensing is introduced to identify direction-of-arrival of the radio waves. In this method, the signal is alternately transmitted between two antennas, and the DOAs are estimated for each case. By using estimated DOA information for these two cases, the propagating paths can be identified. Also, we evaluated the impact of the number of the array antenna elements and element separation on the accuracy in estimating the propagating paths.

Index Terms — FDTD, DOA, Compressive Sensing

1. Introduction

Up to the present, the studies on the radio wave propagation have been pursued for long time. The radio wave cannot be seen directly, and the mechanism of the propagation is quite complicated since the signals are transferred via a number of the propagating paths. This makes difficult to understand the propagation mechanism. Identifying the propagating path is one of the ways to understand the propagation mechanism. This can be evaluated by the simulations, such as a ray-tracing method and Finite-Difference Time-Domain (FDTD) method [1]. The ray-tracing regards an electromagnetic wave between the Tx and Rx as a ray, and calculates the propagation characteristics through estimating the propagating-path. However, this method loses the accuracy due to the geometrical optics approximation. In contrast, the FDTD method can calculate them without the above mentioned error even when the model has a complicated structure, but this method cannot calculate the propagating path directly.

The authors have presented the path identification method for FDTD simulations [2]. In the previously proposed method, the Yee cells are regarded as array antennas and direction-of-arrival (DOA) is estimated by using compressive sensing [3]. The key idea in this method is visualization of the propagating path by using the estimated DOA information. The signal is transmitted alternately back and forth between a two locations, and DOAs are calculated for both cases. By considering the reciprocity theorem, the signals must propagate on the same paths for both cases. Therefore, the paths contributing to the propagation between two locations can be identified. However, we have shown only that the previous proposed method can identify the propagating path, and we have not yet examined the accuracy analysis of it.

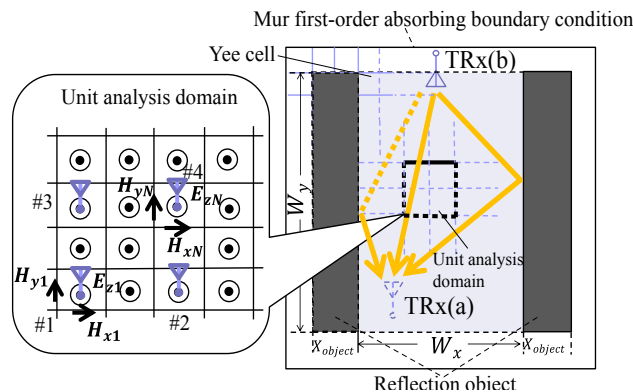


Fig.1 Concept of DOA estimation in FDTD

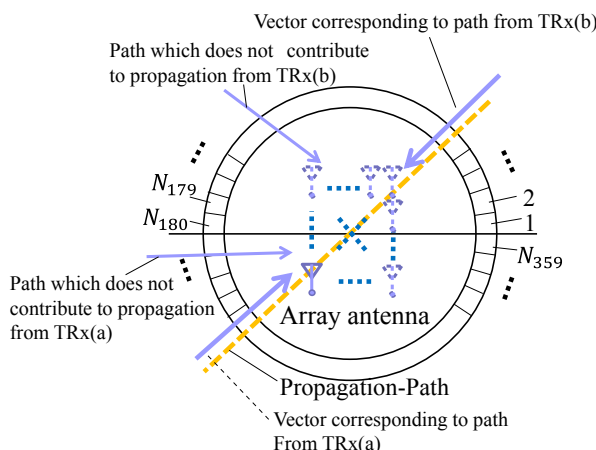


Fig.2 Identification method of the propagating-path by the compressive sensing

In this paper, we evaluate the accuracy of the path identification method when the multiple paths more than two exist. Since this method relies on the DOA information, the accuracy of the path identification is significantly affected by the accuracy of DOAs, which is determined by the array aperture, and element separation. In this study, we evaluated the influence of these parameters on the path identification performance.

2. Review of Path Identification Algorithm

Fig. 1 depicts the way to introduce the array signal processing to FDTD analysis. TRx(a) and TRx(b) represent two transmitters dealt with in this analysis. The whole FDTD analysis region is divided into small regions. Each of them is defined as a unit analysis region, and the

responses of the electric field in this region are treated as the observed signal responses in an array antenna.

Fig. 2 explains the idea of propagation-path identification using the compressive sensing method. N represents the number of the angular bins around an array antenna. This figure depicts the multiple waves arrive at the array from TRx(a) and (b). For both two cases, the multiple paths are estimated and, they are explained by the unit vectors pointing path directions. The inner products of all combinations of the forward and backward vectors are calculated, and the path can be identified by assessing the inner product becomes -1 because the forward and backward signals must direct oppositely on the right paths.

Furthermore, the higher accuracy can be obtained by using the frequency characteristics of the electric fields since the inner product is always -1 independently to the frequency if the unit analysis region is right on the path. By applying this calculation to all over the analysis fields, the path distribution can be revealed.

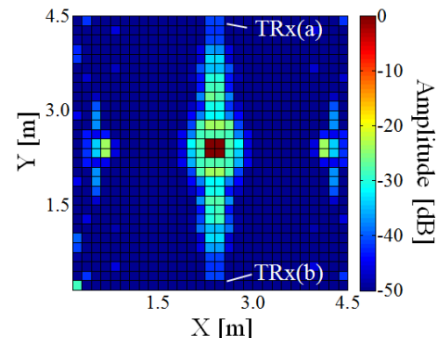
3. Simulation

A. Simulation Conditions

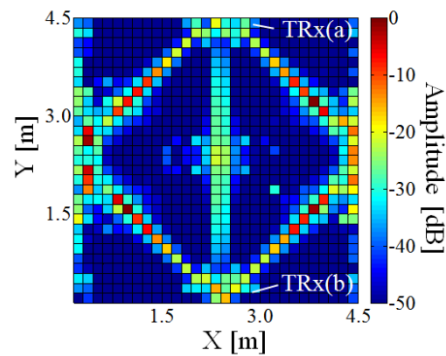
In this simulation, the analysis is performed by two-dimensional TM-FDTD method. The cell size is $\Delta x = \Delta y = 5\text{mm}$, the time step is $\Delta t = 1.178 \times 10^{-11}$ s, the number of the time steps is 3400, the absorbing boundary condition is Mur first-order, and the source excitation waveform is Gaussian. The center frequency is 2 GHz, and the frequency band width is 400MHz. The analysis model has the concrete walls at both sides of the region, where the thickness is $X_{object} = 5$ m, the relative permittivity is $\epsilon_r = 5.5$, and the conductivity is $\delta = 0.023$ S/m. Also, the width of the square unit analysis region is set to 1λ .

B. Simulation Results

Fig. 3 shows the estimated propagating paths, where two different resolutions in the same size of the unit analysis region is used. The color of each unit analysis region represents the likelihood of the path existence, which is determined by the similarity of the inner product to -1 . Fig.3 (i) shows the estimated path distribution when the number of array is 4×4 per each unit analysis region, i.e. the element separation is 0.33λ . Fig.3 (ii) shows the path distributions when the number of array is 8×8 , i.e. the element separation is 0.13λ . The direct wave between TRx(a) and TRx(b) is clearly seen in both Fig. 3(i) and (ii). On the other hand, the reflection wave by the concrete wall at $X = 0, 3$ m is seen only in Fig.3 (ii) but, it is not seen in Fig.3 (i). From this result, it is found that the identification of the propagating path works well estimated when the sampling resolution per unit analysis region is adequately fine. This is because that estimation accuracy of the compressive sensing depends on the element separation. Therefore the analysis accuracy analysis is improved when the number of element per unit analysis region increases. Nevertheless, the twice reflections by the concrete walls are not seen in Fig.3 (i) and (ii). It is suspected that the compressive sensing cannot estimate them because the



(i) The propagating path with 4×4 array per unit analysis region



(ii) The propagating path with 8×8 array per unit analysis region

Fig.3 The propagation path identification results

signals on these paths are significantly attenuated by the concrete. To solve this problem, the sensitivity of the DOA estimation algorithm needs to be improved to be able to distinguish two signals even with a significant power difference.

4. Conclusion

This paper has presented the performance of the path identification technique using two-dimensional TM-FDTD method and compressive sensing. According to the analysis result, it is found that the propagating path can be well estimated when the element separation is sufficiently narrow. Also, it is difficult to estimate the twice reflection paths due to the excessive attenuations. This problem will be resolved in our future work.

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