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Abstract

The preliminary results of application of Adaptive Polarization-Imaging Algorithm for Through-the-Wall Microwave Imaging problems are presented. Use of complete polarization information in the scattered field from the object together with the adaptation technique provides enhancement in detection of target movement.

Comments

Adaptive Polarization-Difference Imaging Algorithms for Through-the-Wall Microwave Imaging Scenarios

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Introduction

The Polarization-Difference Imaging (PDI) is a bio-inspired technique originally developed for optical imaging (see e.g., [1],[2]) which provided significant enhancements in target detection and feature extraction over the conventional methods. The Adaptive Polarization-Difference Imaging (APDI) algorithm is a further step in the development of the PDI technique. The idea of an adaptation mechanism in polarization vision was inspired from the nature [3] and was successfully implemented in optical imaging [4]. In APDI, using the well-known Principal Component Analysis (PCA) technique on statistical scene data, we developed a method to adaptively determine the two/three optimum information channels that can be composed as linear combinations (with unequal weighting coefficients) of the two original polarization signal channels. In addition, we determined the optimal orientations of polarization filters that can achieve the optimum target-to-background separation, where the target is defined as an area with distinct polarization characteristics compared to the background. We use criteria such as maximum multiplicative coefficients in the principal component outputs and the maximum variances for the second and/or third PC components to determine the optimal channels. Simulation and experimental results in the visible spectrum confirmed that the new APDI technique outperforms the original non-adaptive PDI technique in most situations [1]. Here, we utilize this new technique for the Through-the-Wall Microwave Imaging (TMWI) project. The main goal of the project is to have a system that would be able to sense and identify objects behind a wall. In this paper, we use the APDI technique to improve target detection, particularly detection of human presence and movement inside the room.

General Description of APDI algorithm

In this section we present a short overview of the algorithm, emphasizing the points relevant to TMWI project. The main initial assumption considered in this technique is that prior to a certain moment of time the scene being observed by a polarization-sensing imaging system is considered as a *non-target* or a *background* scene. After such a moment the scene is supposed to become a *target* scene due to the change in the room (adding or removing an object or having a moving object). The general idea of the technique is that based on the analysis of the polarization statistics of the non-target scene, we *adapt* our imaging system in such a way that any change in the scene, such as appearance of the new object (i.e., target) or change in the layout of existing objects, become more pronounced to the observer. The non-target scene is analyzed with the

well-known Principal Component Analysis (PCA) technique. Providing the polarization information of the scene is known, image of the scene for any orientation of the polarization analyzer can be simulated. First, a set of input signals for orientations of the polarizer ranging from 0 to 180 degrees was simulated. We then applied the PCA to all possible pairs of images (2-channel APDI algorithm) and determined a pair of optimal angles at which the polarizers must be installed and a pair of corresponding weighting coefficients to form the transformation matrix. Finally, the principal components (PCs) were obtained by multiplying the transformation matrix by a pair of *target* images corresponding to the optimal pair of angles already known from the *non-target* scene. Mathematical formulation is the following:
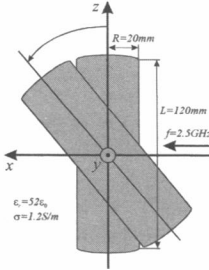
Figure 1. Geometry of the problem

$$\begin{pmatrix} PC_1 \\ PC_2 \end{pmatrix} = \begin{bmatrix} -\beta & \alpha \\ \alpha & \beta \end{bmatrix} \begin{pmatrix} I\left(\theta_1^{opt}\right) \\ I\left(\theta_2^{opt}\right) \end{pmatrix}, \tag{1}$$

where α, β are the weighing coefficients ($\alpha \neq \beta$) and θ_1^{opt}, θ_2^{opt} form the optimal pair of angles. As is well known, second principal component (i.e., PC2) has a smaller variance than the first PC and thus it reveals better the target against the background scene.

Here, we are applying the APDI technique in the microwave band for the TWMI scenarios. Unlike the case of optical imaging where the phase difference was not measured due to the intrinsic features of the optical imaging system, here we can utilize all four Stokes parameters, i.e. we can take into consideration the phase difference between the components of scattered field.

Application of APDI to TMWI problem

In order to examine this concept, we consider a case of plane wave scattering from a finite-length dielectric cylinder with similar dielectric properties as those of the human body. As a "non-target" scene, we take a vertical dielectric cylinder. As a scene with both background and target information, we consider two dielectric cylinders, one being vertical, and the other being rotated at a certain angle with respect to the first. The permittivity of both cylinders is $\varepsilon_r = 53\varepsilon_o$ and the conductivity is $\sigma = 1.2 S/m$. The incident plane wave with frequency $f = 2.5GHz$ propagates along the direction of x axis. The frequency of the plane wave corresponds to the center frequency of the TMWI receiving antenna array. Geometry of the problem is shown in Figure 1.

We consider the two cases, when the incident wave was polarized in θ and φ planes, i.e., either E_θ or E_φ component in the incident field. The scattered fields in the far zone are computed using REMCOM® XFDTD™ software package. The output of the simulation is the distribution of amplitudes and phases of scattered electric field in the sector of $\pm 10°$ around the horizon (i.e., $80° \leq \theta \leq 100°$) for all azimuthal angles, i.e., $0° \leq \varphi \leq 360°$. Based on the information obtained, Stokes parameters are computed. Due to the limited space, here we present the results only for E_θ incident plane wave.

In the optical imaging scenarios, PCA was performed on a pair of images corresponding to different orientations of the polarization analyzer. In TMWI problem here, similarly we perform PCA on the outputs of two "channels" (or "receiving antennas") that are

115

oriented at angles ψ_1, ψ_2. The outputs of these channels are given as, $Channel_1$ and $Channel_2$:

$$Channel_1 = \left| E_\varphi e^{j\Phi_\varphi} \cos\psi_1 + E_\theta e^{j\Phi_\theta} \sin\psi_1 \right|,$$
$$Channel_2 = \left| E_\varphi e^{j\Phi_\varphi} \cos\psi_2 + E_\theta e^{j\Phi_\theta} \sin\psi_2 \right|,$$

(2)

where E_θ, Φ_θ are the amplitude and the phase of θ component of the scattered electric field and E_φ, Φ_φ are the amplitude and the phase of φ component of the scattered field with $0 \le \psi_1, \psi_2 \le 180$. The PCA is performed on signals, corresponding to all possible combinations of angle of orientation of receiving antenna (i.e., ψ_1 and ψ_2). From the PCA, we find four parameters, i.e. two weighting coefficients α, β (also can be called "adaptive" coefficients) and two eigenvalues, which are all functions of ψ_1, and ψ_2. As an *"optimal"* pair of angles, we select a pair that corresponds to peak values of the weighting coefficient α. The issue of selecting the optimal coefficients in context of optical imaging is discussed in details in [4]. As object (or "target") scenes, we consider the presence of an additional cylinder rotated relative to the original cylinder by a certain angle. We study the cases when the angle between cylinders is 30° and 60°. For both orientations of the additional cylinder, we simulate a pair of signals according to Eq. (2), where ψ_1, ψ_2 are taken to be the optimal pair of angles found from the statistics of the "background" object. Then the PC signals are computed according to (1).

In order to estimate the advantage of using the principal component analysis in this problem, we compare changes in the first and second principal components values (i.e., PC$_1$ and PC$_2$) for the two cases of rotated second cylinder. The results are shown in Figure 2. As a benchmark case, we include the PC signals obtained when we apply the same pair of adaptive coefficients to the signal produced by a vertical cylinder itself (refer to the first column in Figure 2). The variation in the first PC, corresponding to the largest eigenvalues, is approximately the same for all cases, while the variation in the second PC changes significantly when the "target" cylinders are presented. An important issue we need to address here is whether the use of just Stokes parameters is good enough to identify changes in the scene. In Figure 3 we show the variation of the Stokes parameters with changes in mutual orientation of the cylinders. Although changes in the distribution of Stokes parameters do take place, it is less significant than that in the ones in the principal components signals (compare Figure 2 and Figure 3). These results provide some evidence that a simple use of Stokes parameters may not surpass the advantages provided by the APDI algorithm.

Conclusions

The results presented in the paper show a significant potential of APDI algorithm for TMWI applications. As a future work, we plan to apply the proposed method to real images of inside-the-room scene, which will be obtained using the beam-forming techniques.

Acknowledgments

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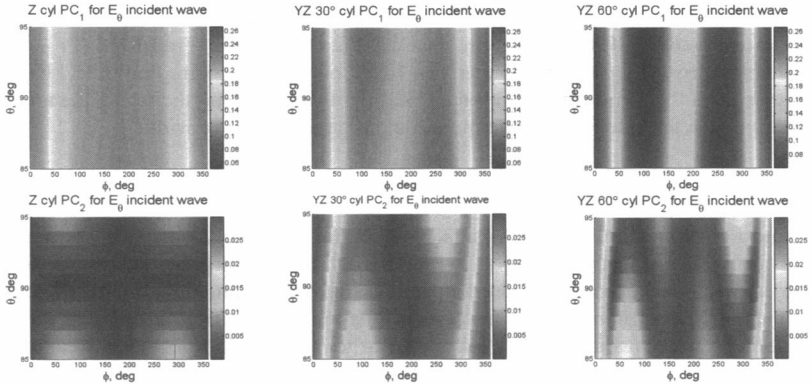
Figure 2. Variations in principal components (PCs) with changing in orientation of the second cylinder. First column corresponds to a single vertical cylinder itself (i.e., the non-target case). The first row shows PC_1 signals and the second shows PC_2. All images are shown in the same scale.
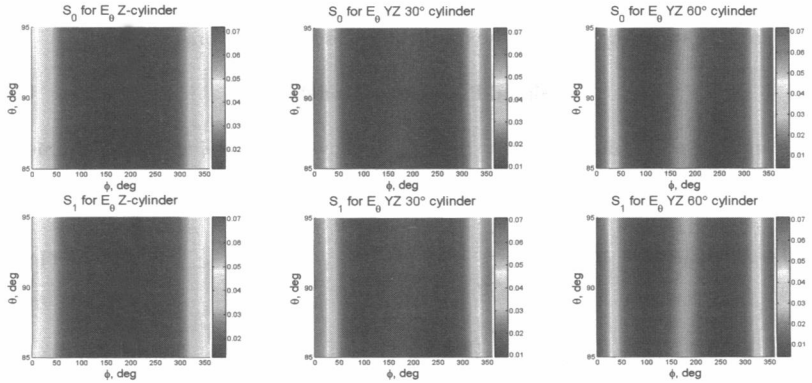

Figure 3. Variations in first two Stokes parameters, i.e., S_0 and S_1, with changing in orientation of the second cylinder. First column corresponds to a single vertical cylinder itself (i.e., the non-target case). The first row corresponds to S_0, and the second to S_1. All images are shown in the same scale.