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• Supplementary File •

Accurate Scattering Centers Modeling for Complex Conducting Targets Based on Induced Currents

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Appendix A The relationship of partitions and scattering mechanisms

The physical scattering mechanisms of the target are determined when the incident field is known. There is a one-to-one relationship between the partition with one scattering mechanism and the corresponding SC model. The different type of current partitions corresponding to physical scattering mechanisms and SC types are presented in Table A1.

Table A1 The relationship of current partitions and physical scattering mechanisms.

The Current Partition	The Physical Mechanism	SC Type
Sharp apex	Spire diffraction	LSC
Small spherical top (The radius of curvature is less than the range resolution)	Specular reflection	LSC
Straight edge	Edge diffraction	DSC
Curved edge	Edge diffraction	SSC
Planar surface	Specular reflection	DSC
Single-curved surface	Specular reflection	DSC and SSC
Double-curved surface	Specular reflection	SSC

To improve the efficiency of the process of determining of SC types, we firstly rank and select partitions that have sufficient contribution on the total fields. Then, we determinate the SC type of the selected partition referring to Table A1. For the quadrotor, the number of DSCs and SSCs are only 3 and 8 respectively therefore this process is not time consuming.

Appendix B The calculation of scattering fields

According to the Maxwell's equations [1], the formulation of the electric field is given as:

$$\mathbf{E} = -jkZ \int \left[\mathbf{J}(\mathbf{r}') + \frac{1}{k^2} \nabla \left(\nabla' \cdot \mathbf{J}(\mathbf{r}') \right) \right] G ds'. \tag{B1}$$

where k and Z are the wave number and the wave impedance in the free space; $\mathbf{J}$ are the induced currents on the target and $G = \frac{e^{-jk|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|}$ is the green function in the free space; $\mathbf{r}$ and $\mathbf{r}'$ are the field point and source point respectively. If induced currents on the target are known, based on the far-field conditions formulation B1 can be approximated as:

$$\mathbf{E}^s = -jkZ \frac{e^{-jkr}}{4\pi r} \int \mathbf{J}(\mathbf{r}') e^{jk\hat{\mathbf{r}}_{\mathbf{los}} \cdot \mathbf{r}'} ds'. \tag{B2}$$

where $\mathbf{E}^s$ is the scattering fields of the region s' and $\hat{\mathbf{r}}_{\mathbf{los}}$ is the direction of the LOS.

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The induced currents **J** which are solved by the electric field integral equation (EFIE) [1] using the method of moments (MoM) [2] with the Rao-Wilton-Glisson (RWG) basic functions [3], are the input for SC modeling. When the calculating frequency is too low or the mesh elements are much smaller than the wavelength λ, the matrix system of MoM is ill-conditioned and even breaks down, which is called the low-frequency breakdown problem [4]. The size of the quadrotor is 105λ and the mesh size is set as $\lambda/10$. Therefore, there is no low-frequency breakdown problem in this case.

Appendix C The procedure and result of partition

More specifically, based on the degree of deviation between the normal directions of adjacent facets, the partition of the target is accomplished. The degree of normal deviation is expressed by the value of the dot-product of two normal directions. The sudden change points in the dot-product values indicate the merges of different regions.Therefore, a threshold t is used to judge whether the two facets can be assigned to the same partition. If the dot-product value of two adjacent facets is less than the threshold t, they are assigned to the same region; otherwise, they should be divided into different regions.

Owing to the complex curved surface like blades on the quadrotor, the dot-product value of the normal directions undoubtedly varies greatly. Hence, the threshold $t = 0$ is adopted here, that is, if the angle of the two adjacent faces is acute, we consider that they are in the same region. The partition of the small-scale structure of the quadrotor is shown in Figure C1(a) and (b).

Under the incidence of a uniform plane wave (i.e., the amplitude of the electric field $|E| = 1V/m$), if the maximum amplitude of the electric fields $|E_s^{max}|$ in a region exceeds a predefined threshold, it is considered that the contribution of the region to the radar image is sufficient. For the model of the quadrotor in this paper, the threshold is set as $|E_t| = -40$ dBV/m which is 1% of the amplitude of the incident wave. We first rank all the maximal amplitude of electric fields among 53 regions, and then select 21 regions above the threshold. The selected 21 regions are shown in Figure C1(c).

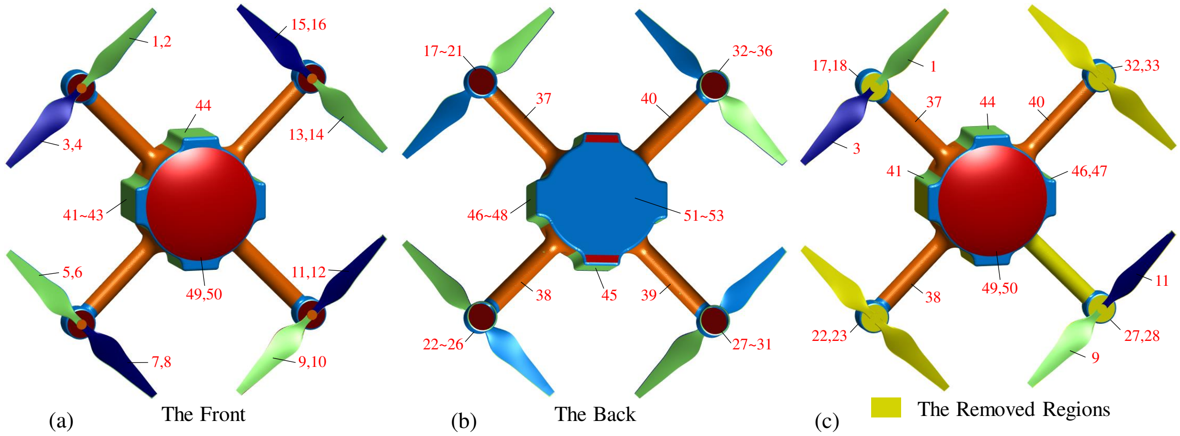

Figure C1 (a) The partitioning result on the front of the quadrotor; (b) The partitioning result on the back of the quadrotor; (c) The partitioning result with 21 regions after refining.

Appendix D Extraction of SSC positions

To determine the SC position, the geometrical center of the region can be simply selected for LSCs and DSCs. For LSC, because the corresponding regions is are usually small compared to the range resolution, we use the geometrical center approximately. For DSC, its equivalent position can be set as the geometrical center of the region, and its distribution length is included in the aspect dependent function. For SSC, the SC position changes with the radar LOS. Therefore, according to the variation of the LOS, the center of the facets in the corresponding region which shows the highest degree of parallelism with the LOS (i.e., the dot-product value of the LOS and the normal direction is closest to 1) is chosen as the SSC position under the corresponding LOS.

The result of the extracted SSC position on the top surface is shown (as red points) in Figure D1 for an instance. According to the variation in the normal directions of the facets and the TFR, the blade structure can be clearly observed in the range of $\theta = 40^\circ \sim 90^\circ$. Therefore, the window function is added to filter the part $\theta < 40^\circ$ after the complete parameter model is obtained.

As described above, the position of SSC on the top surface is expressed as $\mathbf{r}_{50}(\theta) = [r_x(\theta), 0.054, r_z(\theta)]$. The Curve Fitting Tool of MATLAB is used in parameter estimation. $r_x(\theta)$ and $r_z(\theta)$ are described by a polynomial function. Their coefficient vectors (N=5) are

$$\begin{aligned}\mathbf{P}_{rx} &= [-0.1801, 0.7644, -1.065, 0.7219, -0.179],\\ \mathbf{P}_{rz} &= [0.2665, -0.6495, 0.9191, -0.5716, 0.1153].\end{aligned} \tag{D1}$$

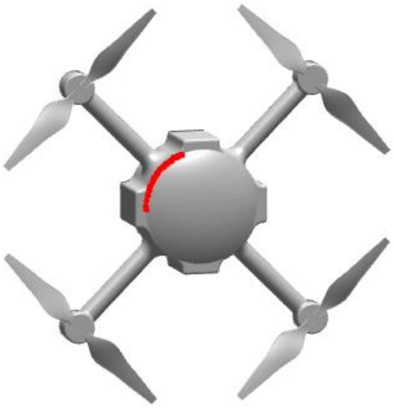

Figure D1 The variation of the SSC positions with the aspect angle on the quadrotor.

And the coefficient vector (N=9) for the amplitude function in region 50 is

$$\mathbf{P}_{50} = [0.001081, 0.01827, -0.2142, 1.115, -2.879, 4.055, -3.175, 1.305, -0.2195]. \tag{D2}$$

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