# Efficient Electromagnetic Scattering Simulation Approach of the Rotating Moving Complex Targets

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**Abstract**— The detection and recognition of moving target is focused by lots of research scholars greatly. However, the algorithms for detection and recognition have to be tested and verified by a great deal of radar echo data. Efficient electromagnetic scattering simulation becomes an effective and economic method for achieving it. The design of appropriate moving target electromagnetic scattering simulation for computer-generated bots poses serious challenges as they have to satisfy stringent requirements that include computation and execution efficiency. This paper discusses a novel efficient high-frequency electromagnetic scattering simulation approach of the rotating moving complex targets. Based on the wide-adopted high-frequency asymptotic methods, such as Physical Optics (PO), Equivalent Edge Current (EEC) and Shooting Bouncing Ray (SBR), a novel efficient approach is proposed by employing the adaptable NVIDIA OptiX ray-tracing engine to solve scattering problems of rotating moving complex targets. High accuracy and efficiency of the hidden-surface-removal (HSR) in PO/EEC and the ray-tracing in SBR are realized at the same time with the state-of-art GPU computation technology. The precise scattering modulation effects of rotating moving target are therefore achieved. Experiments show the effectiveness of the approach.

## 1. INTRODUCTION

With the development of radar technology, the information of observation target is expanded. Various moving styles such as translation, spin, roll, precession and so on exist in realistic situations. Signatures result from those moving styles are focused by research scholars who are interested in radar detection and recognition, including moving target detection (MTD), moving target indication (MTI), synthetic aperture radar (SAR) imaging and SAR identification, etc.. Above all things, obtaining radar echo data is the most important procedure.

Electromagnetic simulation and electromagnetic measurement are two major approaches for obtaining radar echo data. Compared to the second one, Electromagnetic simulation has more advantage in aspect of cost and convenient. In high frequency, quasi-static electromagnetic simulation which based on high-frequency asymptotic theory is an effective method for obtaining wide band electromagnetic scattering echo data of moving targets. When the targets' rotational frequency is far smaller than the frequency of incidence electromagnetic wave, and the maximum linear velocity of moving targets is far smaller than light speed. It assumes that scattered field generating from moving targets at a moment is similar to the ones that generating from the motionless targets which dwell at its trajectory. Therefore, the simulation radar echo generating from moving targets is equal with a series of the same motionless targets which dwell at its trajectory.

In practically, radar band becomes wider continuously, the modulation action of electromagnetic wave which produced from moving targets turn out to be more conspicuous. In order to obtain radar echo simulation data accurately and efficiently, this paper discusses a novel efficient high-frequency electromagnetic scattering simulation approach of the rotating moving complex targets. Based on the wide-adopted high-frequency asymptotic methods, such as Physical Optics (PO) [2], Equivalent Edge Current (EEC) [1] and Shooting Bouncing Ray (SBR) [6], the approach is proposed by employing the adaptable NVIDIA OptiX ray-tracing engine to solve scattering problems of rotating moving complex targets.

## 2. SIMULATION PROGRAM

The approach proposed in this paper possesses three main steps. Firstly, moving complex targets model building; secondly, utilize NVIDIA OptiX for ray tracing and shading; thirdly, high-frequency electromagnetic scattering calculation.

### 2.1. Step 1: Moving Complex Targets Model Building

A complex target consists of several components; each component has its motion style. In order to describe target's motion, transformation matrix $T$ is introduced, the $T$ has the forms as follow:

$$\mathbf{T} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \tag{1}$$

where, $\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}$ represented the transformation of scaling, rotating and dislocation; $\begin{bmatrix} a_{14} \\ a_{24} \\ a_{34} \end{bmatrix}$ represented the transformation of translation; $[a_{41} \quad a_{42} \quad a_{43}]$ represented the transformation of projection; $[a_{44}]$ represented the transformation of entire scaling.

### 2.2. Step 2: Utilize NVIDIA OptiX for Ray Tracing and Shading

The NVIDIA OptiX ray tracing engine is a programmable system designed for NVIDIA GPUs and other highly parallel architectures. The OptiX engine builds on the key observation that most ray tracing algorithms can be implemented using a small set of programmable operations. Consequently, the core of OptiX is a domain-specific just-in-time compiler that generates custom ray tracing kernels by combining user-supplied programs for ray generation, material shading, object intersection, and scene traversal. This enables the implementation of a highly diverse set of ray tracing-based algorithms and applications, including interactive rendering, offline rendering, collision detection systems, artificial intelligence queries, and scientific simulations such as sound propagation. OptiX achieves high performance through a compact object model and application of several ray tracing-specific compiler optimizations.

There are seven different types of programs in OptiX, each of which operates on a single ray at a time. In addition, a bounding box program operates on geometry to determine primitive bounds for acceleration structure construction. The combination of user programs and hardcoded OptiX kernel code forms the ray tracing pipeline which is outlined in Figure 1. For more information please refer to [8].

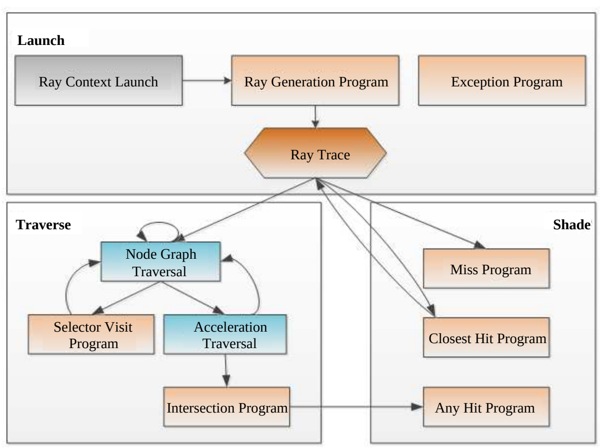


Figure 1: A flow chart of the ray tracing pipeline which based on NVIDIA OptiX.

### 2.3. Step 3: High-frequency Electromagnetic Scattering Calculation

In the situation of plane wave incidence and ignore time-harmonic factor $e^{jwt}$, according to Stratton-Chu equation, the surface scattered far-field could be written as follow [3]:

$$\mathbf{E}_s(\mathbf{r}) = \frac{jk}{4\pi}\frac{e^{-jkr}}{r}\int_S \hat{\mathbf{s}} \times \left(\mathbf{M}_s(\mathbf{r}') + Z_0\hat{\mathbf{s}} \times \mathbf{J}_s(\mathbf{r}')\right) \exp\left(jk\mathbf{r}' \cdot \hat{\mathbf{s}}\right) ds' \tag{2}$$

The above formula can only calculate the targets' surface far-region radiation field, it's not suit for calculating the edge diffraction. Usually, the edge diffraction is often calculated by the method of EEC. According to the concept of EEC which raised by Michaeli, the edge diffraction far-field could be written as follow [4]:

$$\mathbf{E}^d = \frac{jk}{4\pi}\frac{e^{-jkr}}{r}\int_C \left\{Z_0\hat{\mathbf{s}}\times[\hat{s}\times\mathbf{J}(\mathbf{r}')]+\hat{\mathbf{s}}\times\mathbf{M}(\mathbf{r}')\right\}e^{jk\hat{\mathbf{s}}\cdot\mathbf{r}'}dl \tag{3}$$

For more calculation details, please refer to interrelated literature.

## 3. SIMULATION RESULTS

### 3.1. Sample 1: Accuracy Analysis

In order to test and verify the correctness and accuracy of proposed method, a propeller model is introduced as show in Figure 2. Because the motion style of propeller is simple, namely propeller blades rotate around its symmetry axis. Under these circumstances, the RCS data generated from motionless propeller while incidence of electromagnetic wave rotating one cycle corresponds with the RCS data generated from rotating propeller while incidence of electromagnetic wave changeless. Under this precondition, two RCS data simulated by proposed method and Method of Moment (MoM) respectively are show in Figure 3. The simulation condition of MoM is listed as follow: $HH$ polarization, radar frequency $f = 10\,\text{GHz}$, pitch angle $\theta = 45^\circ$, azimuth angle $\phi = 0\sim360^\circ$and step is 0.2°. The simulation condition of proposed method is list as follow: $HH$ polarization, radar frequency $f = 10\,\text{GHz}$, pitch angle $\theta = 45^\circ$, azimuth angle $\phi = 0^\circ$, rotating velocity $\omega = 333.33\,\text{r/s}$, time sampling rate is 400 Hz.

From Figure 4, the consistency of simulation results is quite obvious while some differences still exist. These differences are caused by high-order scattering mechanism on analysis. In order to analyze moving targets have modulation effect on electromagnetic wave, the propeller model is utilized once more. The simulation condition is listed as follow: $HH$ polarization, radar frequency $f = 10\,\text{GHz}$, pitch angle $\theta = 45^\circ$, azimuth angle $\phi = 0^\circ$, rotating velocity $\omega = 20\,\text{r/s}$, time sampling rate is 4 kHz. Analysis of Simulation RCS data are show in Figure 4 and Figure 5.

From Figure 5, we could know that the space of modulation spectrum $\Delta f$ is 60 Hz, and the width of modulation spectrum $\Delta B$ is 3.96 kHz. We also could get the theoretical result by calculate the

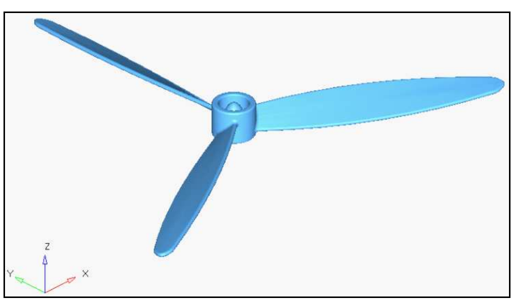


Figure 2: The propeller model.

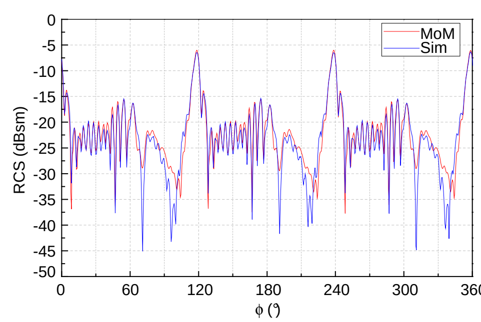


Figure 3: Simulation results comparison between MoM and proposed method.

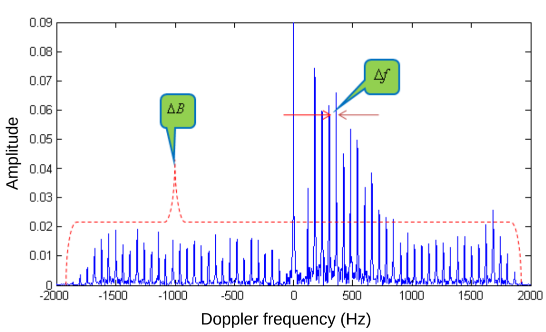


Figure 4: Doppler frequency characteristics of dynamic propeller model.

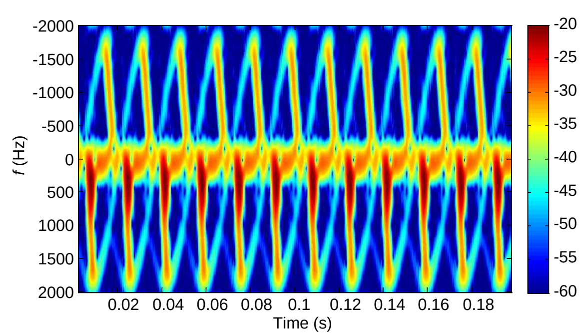


Figure 5: Time-frequency graph of dynamic propeller model.

simulation parameters, where

$$\Delta f = Nf_T = 3 \times 20 = 60\,\text{Hz}$$
$$\Delta B = \frac{8\pi f_T L \cos\theta}{\lambda} = \frac{8\pi \times 20 \times 0.34 \times \cos 45^\circ}{0.03} = 4.02\,\text{kHz}$$

From Figure 6, we could get the time-frequency repetition period is about 0.0167 s, while the propeller owns three blades. Therefore, the rotating period of propeller is 0.0501 s, which agrees with the simulation parameters.

### 3.2. Sample 2: Efficiency Analysis

In order to test the efficiency of proposed method whether NVIDIA OptiX is utilized, a well-known complex target namely Apache-64 model is introduced. Apache-64 model is meshed in different element size, and the geometry is dispersed by triangular element in different numbers. We set ten as the maximum ray tracing times, and the simulation platform is GTX 560 Ti. As a result, statistical results are show in Table 1.

Table 1: Statistical results of dynamic ray tracing for Apache-64 model.

| Element size (mm) | Element number | Memory (MB) | Tree-building time (ms) | Ray-tracing time (ms) | Total time (ms) | Total time without NVIDIA OptiX (ms) |
|---|---|---|---|---|---|---|
| 100 | 75 K | 5 | 109 | 206 | 315 | 2803 |
| 35 | 251 K | 18 | 125 | 257 | 382 | 2875 |
| 25 | 530 K | 38 | 125 | 292 | 417 | 2904 |
| 15 | 1.02 M | 74 | 171 | 312 | 483 | 2975 |
| 10 | 2.06 M | 149 | 219 | 328 | 547 | 3108 |

From Table 1, the efficiency of ray tracing that utilizing NVIDIA OptiX is improved greatly. It's nearly ten times speed than the one without utilizing NVIDIA OptiX in present simulation platform. What's more, the efficiency of ray tracing is subject to the number of flow-processor in GPU. There are 384 flow-processors in GTX 560 Ti merely. With the development of GPU hardware technology, the number of flow-processor is growing in geometric progression. Take GTX 680 for example, there are 1536 flow-processors. Therefore, ray tracing time will be reduced greatly in the offing.

## 4. CONCLUSIONS

A novel efficient high-frequency electromagnetic scattering simulation approach of the rotating moving complex targets is proposed in this paper. It utilizes transformation matrix to describe the moving attributes of the complex target, and NVIDIA OptiX ray tracing engine is introduced to accelerate ray tracing in high-frequency electromagnetic scattering simulation. Simulation results and theoretical analysis indicate the feasibility of the approach.

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