A Method for Parallel Calculation of Radar Detection Capability Based on 3D Subdivision Grid

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Abstract

In the field of electromagnetic computation, the expression ability of two-dimensional spatial calculation methods is limited, and the three-dimensional spatial calculation methods are complex. The existing radar detection capability calculation methods cannot calculate the power density distribution of radars in space position, comprehensively, quickly enough to depict the real-time capabilities of radars. In order to improve computing performance (To solve these problems), this paper proposes a multi-level fast calculation method of radar detection capability based on three-dimensional (3D) subdivision grid. The algorithm uses a unified encoding method to divide the space at different levels. After that, a parallel computing model is established to quickly calculate the radar power density corresponding to its spatial position and bearing. The experimental results show that the algorithm can provide an efficient calculation method for the power density distribution of various actual radars at different particle sizes.

Keywords

Radar power density distribution, 3D Subdivision Grid, parallel computing

1. Introduction

Radar detection is an important part of reconnaissance and early warning capabilities. Accurately and quickly calculating the power density of radar at spatial sites can help users make decisions and adjust the deployment of reconnaissance platforms. In the military field, accurate description of the radar electromagnetic environment is a key process to implementing accurate and efficient decision-making for military commanders[1].

Current research on radar detection capabilities mainly includes the following two aspects:

Scholars in the field of Radio-wave communications mainly pay attention to the value calculation of the radar equation, focus on research in two -dimensional conditions, or the numerical calculation of a small range of three-dimensional positions:

Awadallah et al. used the boundary integral equation to speed up the value calculation efficiency of electromagnetic three-dimensional communication, but it is difficult to apply when the range is large [2]. Feng Qi et al. introduced the three-dimensional data generating method based on the planar radar detecting area calculating method and vertical detecting distance calculating method [3]. This method reduces the quantity of data effectively.   Xiaoguang Cheng et al. analyzed the detection capability of radar network by using the radar detection information in altitude direction, and proposed a calculation method for the detection range and distance of radar network at different elevation [4].

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Another aspect of research uses geometric optical principles and electromagnetic propagation characteristics to simulate the electromagnetic space formed by radar:

Yubing Bai et al. realized the processing method of complex terrain based on the principle of geometric optics [5], however, this algorithm is based on space intersection, with high computational cost. Hang Qiu et al. proposed a 3D modeling method for radar range based on the influence of mixed sampling [6], which was sampled under different characteristics in the direction of azimuth and pitch. Xiaoguang Cheng computed the 3D power region of air-defense radar by employing the power diagram obtained via radar flight test and considering the influence of terrain and atmosphere [7]. However, this method has the problem of complex calculation and small computable range.

However, the computational complexity of light propagation is high, making it difficult to handle large amounts of three-dimensional spatial data calculations. In 2017, Yue Yuan et al. proposes a method of calculating the radar detection range based on the space division structure [8], reducing the computational complexity of radar detection ranges under the influence of terrain. This article verifies the feasibility of the space division structure in electromagnetic computing problems.

Based on the above-mentioned research, the radar detection capability modeling has problems such as high computing complexity, small representation range, different This article verifies the feasibility of the space division structure in electromagnetic computing problems.

requirements for calculating accuracy, and low universality.

Aiming at these problems, the multi-level fast calculation method of radar detection capability is proposed in this paper. This method uses a 3D subdivision grid to represent the detection domain of the radar, which reduces the computing complexity and calculates the power density distribution of the radar at a variety of scales. In addition, MPI parallel strategy, pre-cache method, and other acceleration algorithms are introduced in the calculation process, which greatly improve the calculation efficiency.

2. Space Subdivision Based on GeoSOT-3D

Graphic projection maps cannot express three-dimensional data, and the visualization effect is not good. The GeoSOT-3D spatial section method has the characteristics of global scale, different particle sizes, and a supporting three-dimensional spatial section [9], which is very suitable for expressing the range of the radar.

GeoSOT-3D grid originated from the GeoSOT, a 2 -dimensional geographical coordinates Earth Code grid, proposed by Peking University. GeoSOT is a subdivision and encoding method of the Earth's surface using planar dissection in the two-dimensional direction of latitude and longitude. It has the characteristics of non-overlapping boundaries, orthogonal mesh, consistent longitude and latitude, and good compatibility with traditional data specifications.

On the basis of inheriting these characteristics, GeoSOT-3D expands GeoSOT on elevation dimension. It uses the oct-tree space segmentation to divide the three-dimensional space which is from the center of the earth to the space at 50000 km above ground, along with the longitude, latitude, and elevation directions into spatial grids. In order to perform binary integer coding, GeoSOT-3D expands the earth space to 512 ° × 512 ° × 512 °, expands 1 ° to 64 ′, expands 1 ′ to 64 ″, and achieves recursive oct-tree space segmentation.

In this paper, the radar electromagnetic space can be found according to the center point of the radar and the radar detecting range. Then, according to the partition granularity selected by the user, the space is divided into three-dimensional grids. The grids obtained by division are real three-dimensional nodes with longitude, latitude, and elevation position information. Each node corresponds to GeoSOT-3D code one-to-one, encoded sequentially according to the Z-order encoding method, and the coded value is obtained by Morton encoding, which can obtain a unique index of each spatial element. GeoSOT-3D grid multi-level partitioning and the coding diagram are shown in Figure 1: The multi-level partitioning and coding diagram based on GeoSOT-3D:

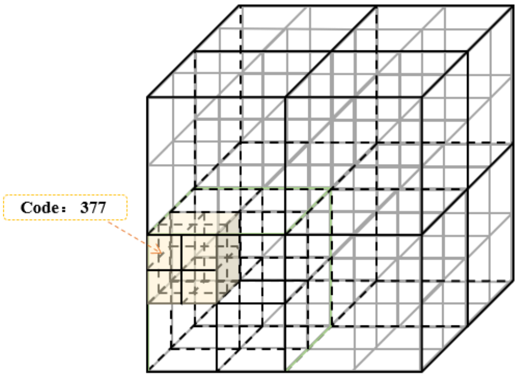

Figure 1: The multi-level partitioning and coding diagram based on GeoSOT-3D

Taking the 3-level division as an example, the current spatial grid corresponds to 64°, and the geographical scale of the grid is 8192km. When continuing to divide the space by oct-tree, the maximum 32-level fractional granularity can reach 1/2048 second, corresponding to the geographical scale of the grid of 1.5cm.

When given a split mesh code, and need to confirm the latitude and longitude, and elevation value (e.g. visualization applications), follow these steps: Firstly, the code is inversely solved according to the rules of Morton code, and the code of each dimension is obtained, then the sequence number of the grid is confirmed according to the encoding rules, finally the longitude and latitude and elevation coordinates can be obtained.

3. Parallel Calculation for Radar Detection Capability Based on MPI

3.1. Radar power density calculation model

First, establish a spherical coordinate system as shown in Figure 2 for radar measurements:

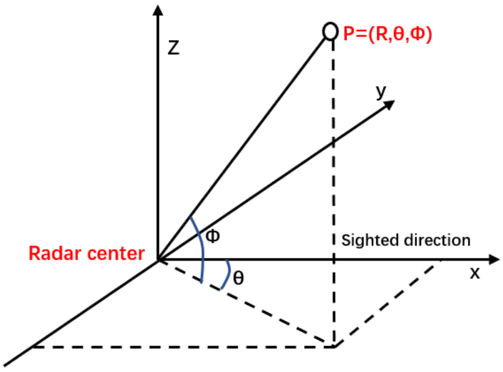

Figure 2: The spherical coordinate system for Radar measurement

The radar power density calculation formula is as follows [10]:

$$Q_t(\theta,\phi)=\frac{P_t\,G(\theta,\phi)}{4\pi R^2 L_a(R)}, \tag{1}$$

In the formula, $G(\theta,\phi)$ is the antenna gain in a particular direction of (θ,φ). Among them, θ is the azimuth angle, $\varphi$is the pitch angle. And R is the distance from the detection point to the center of the radar (unit is meter). $P_t$is the radar's transmitting power (unit is W). $L_a(R)$ is the atmospheric loss at the distance R, and the unit is loss decibels per km. Typically, the antenna's line of sight is the maximum direction of the antenna gain, and the antenna maximum gain is $G_{max}=G(0,0)$.

Consider the formula for calculating $G(\theta,\phi)$:

$$G(\theta,\phi)=G\times E(\theta,\phi), \tag{2}$$

In the formula 2, $E(\theta,\phi)$ is the Directivity coefficient, and,

$$E(\theta,\phi)=E_\theta(\theta)\,E_\phi(\phi), \tag{3}$$

For aperture antennas, the following calculation formula is available:

$$E(\theta) = \frac{sin[\pi(D_y/\lambda)\, sin\, \theta]}{\pi\left(\frac{D_y}{\lambda}\right) sin\, \theta}, \tag{4}$$

D_y is the y-oriented rectangular aperture size.

For array antennas, the formula is slightly different:

$$|E(\theta)| = \left|\frac{sin[\, N(\pi d/\lambda)\, sin\, \theta]}{N sin[\,(\pi d/\lambda)\, sin\, \theta]}\right|, \tag{5}$$

3.2. Calculation model based on precomputation

According to performance analysis, it was found that the most time-consuming part of the calculation process was the calculation of the value of the sin function. Therefore, in order to speed up the calculation efficiency, the calculation of the E(θ) table, etc. is carried out in advance and the results will be saved in memory.

The table is constructed as follows:

According to radar types (seam array radar, phased array radar) and radar parameters (number of array elements, element spacing or y-direction size, working frequency), using different directionality coefficient calculation formulas, the corresponding directionality coefficient of 0° to 360 ° can be calculated (the default accuracy is 10^{-3}degree, adjustable).

Follow the above procedure to calculate the comparison table of angle and directivity coefficients. When calculation needs to use it, look up the table directly. This approach reduces the actual total calculation time.

3.3. Parallel acceleration strategy based on MPI

This article uses the MPI Parallel Computing framework. The advantage of the MPI parallel computing framework is that the process space is independent, which can effectively avoid the competition between memory and cache, and achieve a near-linear acceleration ratio. At the same time, the MPI algorithm can run directly across nodes.

The algorithm takes several measures to avoid the startup overhead of the MPI process and the data interaction between the processes.

1) According to the main use scenarios of the algorithm, the E(θ) table, etc. is calculated in the pre-processing stage, and each process performs the full calculation so that when the position or attitude of the radar vehicle is updated, the update of the calculation result can be realized at the minimum cost.

The computing task is assigned according to the spatial grid, and each node is calculated separately without interaction.

Taking the four processes as an example, the spatial allocation of tasks is shown in Figure 3:

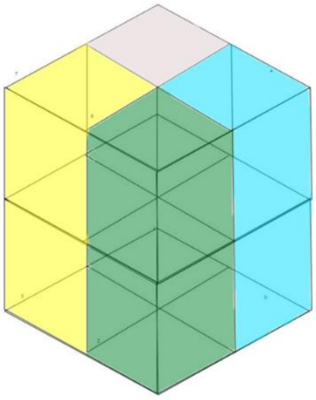

Figure 3: Task assignment in MPI process

Different colors indicate the task area assigned to different processes, and the interior of each space area is divided into a corresponding smaller grid by the level given according to the actual situation.

The calculation of different processes does not interfere with each other, and a confirmation message is sent to process 0 after the process calculation is completed, indicating that the calculation has been completed.

In the selection of data services, considering the huge amount of large-scale electromagnetic field data, it is necessary to consider the global data access efficiency.

The column-oriented database is a column-related storage architecture for a data storage database, mainly suitable for batch data processing and instant query, with a very high loading speed, can quickly query the range, so it is very suitable for the storage of radar field data in this article.

The experimental part of this paper selects ClickHouse[11] as the implementation scheme and takes advantage of ClickHouse's concurrency to write directly after each process is calculated, so as to avoid the communication and synchronization overhead caused by data aggregation.

4. Experimental Results and Analysis

In this paper, four types of radar (including slit array radar and phased array radar) were selected as experimental data. These experiments calculated their power density distribution in different geographical locations and at different levels.

4.1. Experimental setting

The electromagnetic situation analysis of radar direction with vehicle attitude is also carried out in this paper. Taking a certain airborne radar as an example, based on the Angle of the vehicle as a reference, the calculation of the vehicle's periphery is carried out according to the degree of freedom of radar movement. The situation includes:

1) The detection point is in the radar scan area. This is the area that the radar can directly reach through rotation and pitch, and the radar equation for this area can be directly calculated (θ, $\varphi=0$) (the sector area OAB, blue in Figure 4).

2) The detection point is outside the radar scanning area, but within the antenna signal reachable area. Although these areas cannot be directly detected by radar, they still have relatively weak field strength due to the electromagnetic law of the antenna itself. The power density distribution of these areas can be calculated by using the corresponding antenna pattern formula. When the radar rotation Angle is set, the nearest Angle within the radar activity range is selected so that the calculated intensity is the maximum possible intensity (the sector area OAC and OBD, orange area below).

3) Areas where the antenna signal is unreachable. The power density in these areas is zero.

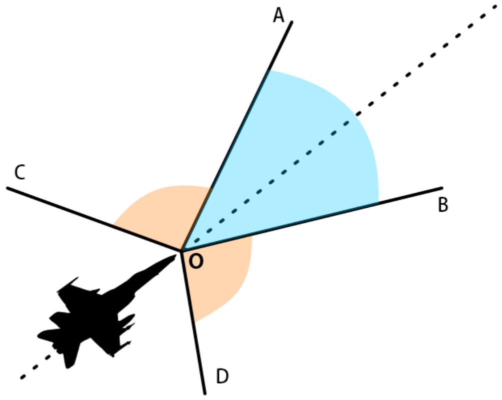

Figure 4: Diagrammatic drawing of airborne radar detection area

4.2. Experimental results and analysis

In this experiment, the segmentation strategies at different levels were selected for comparison. At different levels, the number of obtained meshes shows an increasing trend of about 8 times. As the number of calculations for the grid increases, so does the calculation time. **Table 1** shows the situation in the case of a single process (Take 50000m as the detection distance as an example):

Table 1

Experimental results under a single process

Level	Grid numbers	Calculation time
14	21952	10ms
15	166375	40ms
16	1331000	310ms

Using a multi-process acceleration algorithm, the calculation time is significantly reduced, as shown in **Table 2**:

Table 2

Experimental results under 12 processes

Level	Grid numbers	Calculation time
14	21952	0.5ms
15	166375	4ms
16	1331000	30ms

In the prototype system, the acceleration effect is analyzed as follows. In the experiment, the space was divided and coded at different levels, and the number of partition elements within the scope of radar was obtained from 100,000 to 10 million. The time cost before and after the use of the partition grid parallel model was recorded respectively. Experimental results show that the speed is increased by 4-10 times. In addition, considering that the data calculation between the split meshes does not interfere with each other, parallel computing has a good effect on the radar power density calculation performance of large-scale spatial grid points. Therefore, assigning grid computing tasks to the MPI process can further accelerate the computational efficiency.

The results show that the average total time taken to calculate the radar power density of 1 million grid points is about 40ms when running in parallel with 12 processes, which is about 11 times higher than that of serial computing strategies. The parallel acceleration effect is shown in Figure 5 and Figure 6, which show that the calculation time decreases with the number of processes, and the acceleration ratio is almost the same as the number of processes, which means that a nearly linear acceleration ratio is obtained.

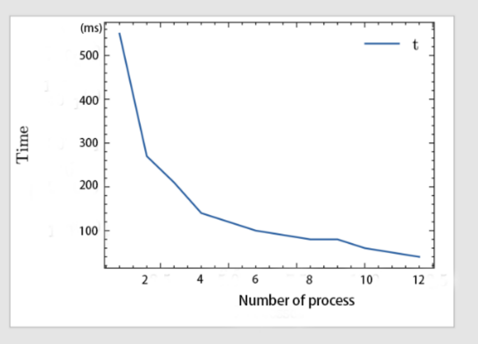

Figure 5: Time-consuming changes of parallel algorithms

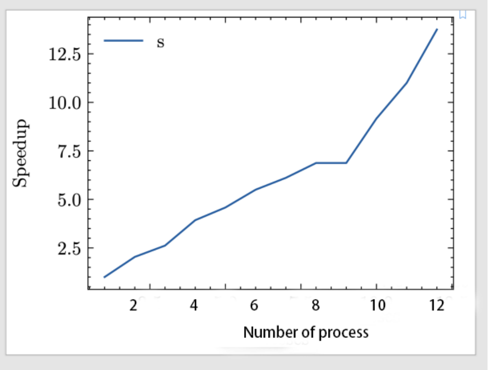

Figure 6: Accelerating effect of parallel algorithm

5. Conclusion

In this paper, different types and models of radars in real scenes are taken as research objects. Aiming at the problems of different granularity of radar detection range and complex and time-consuming calculation of intensity at detection points, a three-dimensional space model based on GeoSOT-3D split mesh integrating radar power density calculation and expression is designed. In addition, this model can respond in time when the position and direction of the radar vehicle change, and quickly calculate the change in power density of the detection point.

All in all, this paper provides a unified, efficient, and fast calculation method for the power density distribution of various radars within their range of action.

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