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Best Viewpoint Selection for 3D Visualization Using Particle Swarm Optimization

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Keywords

3D visualization, viewpoint selection, Particle Swarm Optimization, multi-objective optimization

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Keywords: 3D visualization; viewpoint selection; Particle Swarm Optimization; multi-objective optimization

粒子群优化算法的三维可视化最佳视点选取

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摘要：视点选取为了提供给用户较好的观察位置，涉及到视点质量好坏的评估。提出了粒子群优化算法的三维可视化最佳视点选取方法。*通过采用图像信息熵与图像边缘熵进行视点质量的评估，通过多目标智能优化方法选取视点。基本流程是由初始视点集开始，通过编码、粒子评价和粒子更新等操作寻找最佳视点，这是一个多次迭代的过程，直至找到满意的视点或者达到迭代最大代数。*实验表明，该方法可行有效，能自动完成最佳视点的选取，有效地减少了人工试探选取次数。

关键词：三维可视化；视点选取；粒子群优化算法；多目标优化
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Introduction

With the data source increase in 3D visualization, such as the 3D entity, special effect, and virtual environment, problems of melting and integrated display of various types of data sources become more and more serious. Information obtained by viewers from different viewpoints at the time when observing the virtual scene formed by visualization is differed, which results in quality difference of image rendering

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based on different viewpoints, and further results in problem of viewpoint quality: in aspect of observing mechanism, the viewpoint quality is determined by scene viewpoint attribute and rendering pipeline. Visibility culling [1] is one of the types. It includes view-frustum culling, backface culling, and occlusion culling, which make the viewer unable to observe some certain parts of 3D scene information from 2D views; in aspect of spatial dimension method, the virtual observation is a dimensionality reduction process from 3D to 2D, which would surely result in information loss. During the observation process, selection of different viewpoints of viewers results in different dimensionality reduction paths, and therefore, further results in different information losses. Because of this, developers often need to manually perform iteration to select viewpoints. This would surely make the iteration times increase and make the design efficiency reduce. So it is a very exhausting item of work.

How to select a most optimized viewpoint according to certain criterion is a kind of effective optimization method for virtual scene melting rendering. Among the basis for viewpoint selection, people propose lots of viewpoint metric functions. And Reference [2] firstly proposes the method of using information entropy theory to measure information for viewpoint selection. Reference [3] proposes the method of taking the viewpoint information entropy theory and human-being eye visual perception theory as the basis to realize automatic selection of viewpoints in 3D model browser system. Reference [4] proposes the method of using viewpoint entropy theory to measure the information amount of the rendering scene under the fixed viewpoint. The information entropy is introduced in and obtained good applying effect [5-6]. Therefore, this paper proposes a kind of method for 3D visualization viewpoint optimization based on particle swarm to represent viewpoints by multiple resolution levels and introduce image information entropy function in as the target function for optimization[7]. Besides, compared with other intelligent optimization algorithms, particle swarm optimization is better in aspects of solving the real number, simple arithmetic, convenient computing, and fast solving speed [8-9]. Therefore, this paper uses PSO for realizing rapid selection of best viewpoint.

1 Evaluation method on viewpoints

1.1 Representation of viewpoints by multiple resolution levels

In the 3D virtual scene, each type of data source can represent different rendering effects under different viewpoints. Suppose that the central point of the data source locates in the origin O, limit the viewpoint distance within the fixed distance of R away from the origin. Then, it can use the region of Ω, which is composed by all points on the spherical surface which takes R as the semi-diameter and O as the center of the circle, to represent the range of all candidate viewpoints. By doing so, all viewpoints' directions can be covered [10]. Just as shown in Figure 1 that, Q is an arbitrary point on spherical surface Ω, then its spatial coordinates are (x_i,y_i,z_i) and its corresponding polar coordinates are (R,δ_i,θ_i).

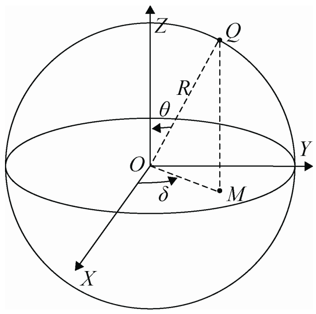

Fig. 1　Selection range of candidate viewpoints

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Among the above, R represents the distance from origin O and point Q, namely the semi-diameter of the spherical surface; θ_i is the positive included angle of the directed line segment QO and the Axes-Z; δ_i is the angle formed by method as follow: viewing from positive Axes-Z, rotating from Axes-X to directed line segment QO according to counter-clockwise direction; M is the projection of point Q on XOY plane. Then, the relation between the spatial coordinates and polar coordinates can be obtained as follow:

$$\begin{aligned} x_i &= R\sin\delta_i\cos\theta_i \\ y_i &= R\sin\delta_i\sin\theta_i \\ z_i &= R\cos\theta_i \end{aligned} \tag{1}$$

R,δ_i,θ_i can represent different values. And commonly, $0<R<+\infty$, $0<\theta_i<2\pi$, and $0<\delta_i<\pi$; through combination, viewpoint library containing different orientations and distances can be constructed. These viewpoints can be presented by multiple resolution levels. Namely, if one type of resolution of viewpoint is the combination of R, δ_i, θ_i, viewpoints can be performed with different combinations according internal-to-external sequence to form different resolution levels.

1.2 Introduction of image information entropy

The method of introducing in viewpoint information entropy for evaluating the quality of the viewpoint is mainly to analyze the 2D views. It takes the triangle mesh's relative projection area on 2D view as a probability distribution, and takes the Shannon entropy value that is solved for this probability distribution as the correspondingly observed viewpoint quality.

This paper adopts grey-scale map as the probability density function, then, the image information entropy is represented as average of image grey-scale level collection to describe the average information amount of image information source. Then the IMG information entropy expression of images is as follows:

$$\begin{aligned} H(IMG) &= -\sum_{i=1}^{width}\sum_{j=1}^{hight} p(i,j)\log_2 p(i,j) \\ p(i,j) &= x(i,j) / \sum_{i=1}^{width}\sum_{j=1}^{hight} x(i,j) \end{aligned} \tag{2}$$

In the expression: *width* and *height* respectively represent the width and height of the image, showing the size of the image; $x(i,j)$ is the grey-scale value of image at position of (i,j).

The precondition of best viewpoint selection process iteration and update of viewpoint evaluation is also the basis for viewpoint optimization. Commonly, it is considered that a good viewpoint can provide more important information amount. If a 3D image rendered based on a viewpoint contains more amount of information, it is considered that this viewpoint is better. Therefore, evaluation to a certain viewpoint can be transformed as the evaluation to the image rendered by this viewpoint. The optimization process is carried out based on PSO target function intelligent optimization method. For the comparison between viewpoints of VP_i and VP_j, if viewpoint VP_i is better than viewpoint VP_j, when it meets and only meets the following condition: $Imp(VP_i)> Imp(VP_i)$, among which, $Imp(VP_i)$ is the amount of information contained in viewpoint VP_i.

2 Particle Swarm Optimization of 3D visualization viewpoints

2.1 Principle of Particle Swarm Optimization

The particle swarm optimization simulates intelligent behavior of swarms as flock and shoal to solve for optimization. For PSO, The deemed individual is a particle in m-dimension space which flies with certain speed in the searching space. All particles can be judged for quality by fitness function $f(x)$, and then, also by the function, solved the fitness value, which is the 2D image information entropy value rendered for virtual scene. Besides, based on the individual and swarm flying experience, it can comprehensively analyze and dynamically adjust the flying speed in the expectation of flying towards the position of the best particle in the swarm, thus to get the most optimized solution for the optimization problem.

In n-dimension searching space, the swarm is composed of n particles. Set No. i particle is $X_i= x_{i1}$, $x_{i2},\ldots, x_{im}$, among which, i=1,2,…,n, the particle experiencing position is $P_i=p_{i1}, p_{i2},\ldots, p_{im}$. Speed of particle i is recorded as v_i. For each time of iteration, Particle i's motion in m-dimension space follows the following update formula:

$$v_{im}^{k+1} = \omega \times v_{im}^{k} + c_1 \times Rand() \times (p_{im}^{k} - x_{im}^{k}) + c_2 \times Rand() \times (p_{gm}^{k} - x_{im}^{k}) \quad (3)$$

$$x_{im}^{k+1} = x_{im}^{k} + v_{im}^{k} \quad (4)$$

In the formula, v_{im}^{k} is the speed of Particle i in m-dimension in No.k time of iteration; x_{im}^{k} is the current position of particle in m-dimension in No.k time of iteration; c_1 and c_2 are the acceleration constants; ω is the inertia weight; *Rand()* refers to the random numbers between [0,1]; p_{im}^{k} is the best particle position *pbest* of Particle i in m-dimension; p_{gm}^{k} is the best global position *gbest* of swarm in m-dimension.

2.2 Particle Swarm Optimization Realization of 3D visualization viewpoint optimization

Based on the PSO viewpoint optimization process, the basic flow starts from initial viewpoint set and corresponding resolution level, and finds out the best viewpoint by particle evaluation and particle update. This is a multi-iteration process till finding the most satisfied viewpoint or reaching the largest number of iteration.

Select viewpoint as the basic particles of PSO; different viewpoints compose initial sample set of combination optimization process; and the best viewpoint search refers to the process of searching for the optimum in spherical area Ω. Spatial coordinates of viewpoint can be switched and expressed as polar coordinates. The PSO particle expression is:

$$p_i(t) = (R, \delta_i, \theta_i) \quad (5)$$

The target function is the image information entropy, namely the target of the selected best viewpoint is to maximize the corresponding function value. The restriction conditions are the viewpoint orientation and the distance value range. Therefore, the target optimization function is:

$$\begin{cases} \max f_1 = -\sum_{i=1}^{width}\sum_{j=1}^{height} p(i,j)\log_2 p(i,j) \\ \max f_2 = -\sum_{i=1}^{width}\sum_{j=1}^{height} g(i,j)\log_2 g(i,j) \end{cases} \quad (6)$$

$$\text{s.t.} \begin{cases} 0 < R < +\infty \\ 0<\theta<2\pi, 0<\delta<\pi \end{cases}$$

Specific steps of this approach are as shown in Fig. 2 and the followings:

Step 1: determine the initial viewpoint set and the corresponding resolution level;

Step 2: initialize the position and speed of the particle, namely i=1, and transfer as the orientation and distance information of the corresponding viewpoint;

Step 3: render and obtain the rendering views according to the viewpoints, and compute the corresponding 2D image information entropy;

Step 4: compute *pbest* and *gbest*;

Step 5: update particle position and speed (i=i+1), and compute and obtain *gbest*, perform circulated

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iteration;

Step 6: determine whether to end the iteration process or not according to the particle's fitness value or the largest iteration number. Output the optimum particle when the iteration process ends, namely the solution of the optimum viewpoint searching problem: best viewpoint.

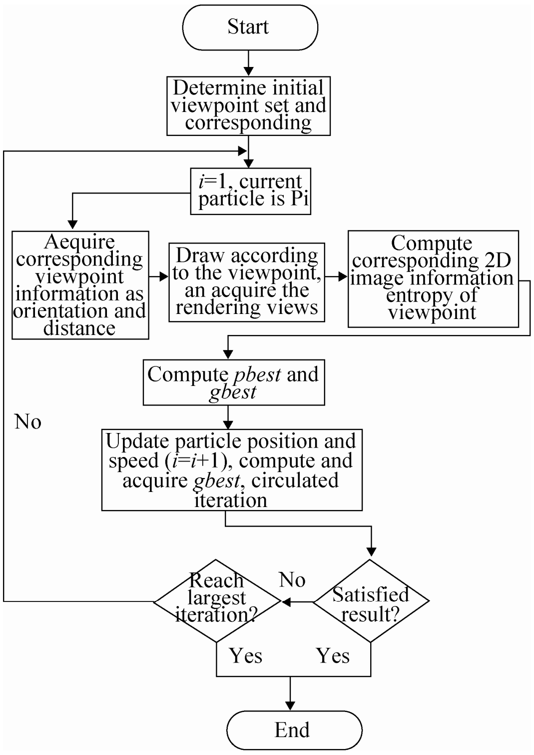

Fig. 2 Algorithm flow of best viewpoint intelligent selection

This approach transfers the search for best viewpoint as problem of searching for optimum parameters within certain range, taking the viewpoint set of all possible viewpoints meeting fixed distance condition to the object as the searching range. According to the 3D visualization experience and practical problem, commonly, it needs to set value range of R to be [200,1 000], and $0<\theta_i<2\pi, 0<\delta_i</2$. Amount of initialized particles is not the more the better, too many particles may decrease the search efficiency, but too few particles may result in increase of iteration times.

3 Experiment result and analysis

It takes the ship viewpoint optimization in surf scene 3D visualization as the experiment object. Set the initial sample set: set R to be four types of 200, 300, 400, and 500, δ=0,1×10º,2×10º,…,9×10º, and θ=0,1×36º,2×36º,…,9×36º. Combining ways of R, δ, and θ are totally 4×10×10 (400) types, namely, the best viewpoint of the ship shall be selected from these 400 sample set. Then, according to the resolution classification of viewpoints, R is divided into 4 levels, δ is divided into 10 levels, and θ is divided into 10 levels. The corresponding PSO setting is shown as in Tab. 1.

Tab. 1 Parameter Setting of Corresponding PSO

Swarm Scale	Particle Dimensions	Largest Iteration Number	Value Range
6	3	50	Orientation Range of Eyeshot and Viewpoint

Firstly, the target optimization function is determined as 2D image information entropy. Fitness value function curves during the evolution process are as shown in Fig. 3 (a), (b) shows the average fitness value of 6 particles during the optimization process and the best fitness value change curve. For optimum individual, levels of R, θ, and δ are respectively 4, 8, and 7. And at this time, the obtained optimum value is 4.401 37, among which, the optimum solution of rendering image information entropy is the 6th particle in generation-2. And its viewpoint position polar coordinates are (400, 60°, 301°), and the corresponding xyz coordinates are: (142, 431, 121). Rendering image at this viewpoint is as shown in Fig. 4(f).

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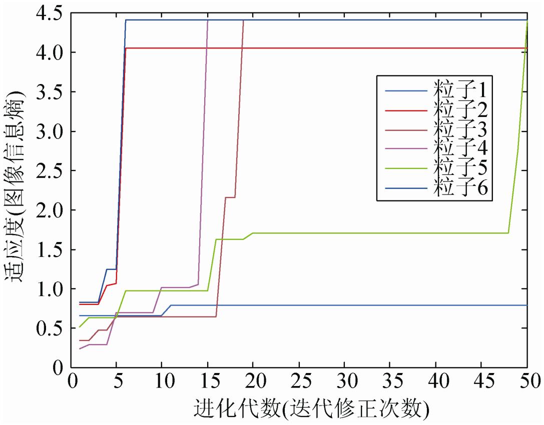
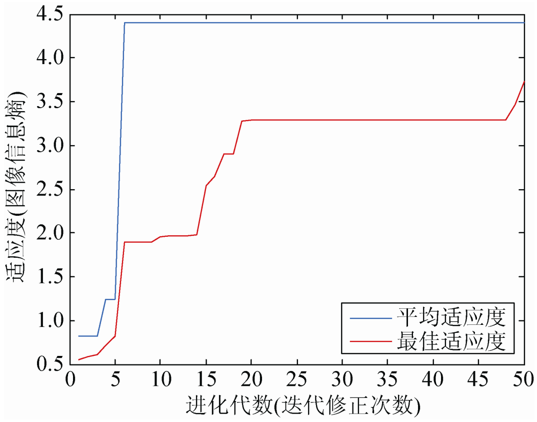


(a) Fitness value change curves of 6 particles



(b) Average fitness value and optimum fitness value change curve

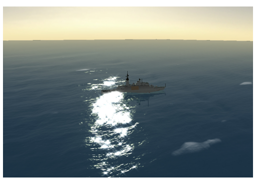
Fig. 3 Combined optimization fitness value change curves of 6 particles

(a) First generation image (b) Second generation image

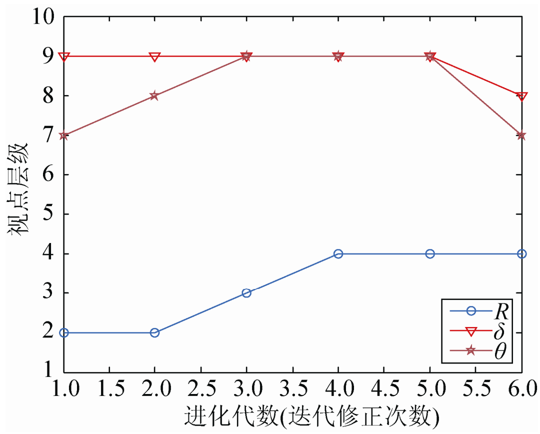
(c) Third generation image (d) Fourth generation image

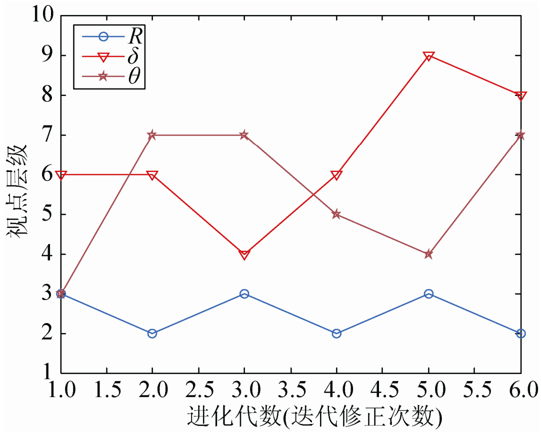
(e) Fifth generation image (f) Sixth generation image

Fig. 4 Image serial of PSO-based optimization process s

It can be seen from Fig. 3 that, all particles gradually close up to the optimum solution during the iteration process. And the fitness value range is respectively [0, 4.5]. The optimum solution obtained by iteration and the rendering images are as shown respectively in Fig.4(a)~(f). Fig. 5 shows optimum searching process of resolution level selection of the No.2 and No.5 particles.



(a) Optimum searching process of resolution level selection of no.2 particle



(b) Optimum searching process of resolution level selection of no.5 particle

Fig. 5 Optimum searching process of resolution level selection of no.2 and no.5 particle

4 Conclusions

This paper uses the image information entropy to evaluate the quality of the viewpoint and uses particle swarm optimization to perform viewpoint

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optimization for the rendering views, which can better solve the problem of rapid selecting of optimum viewpoint, help to realize intelligence and automation, and accelerate the viewpoint selection speed and efficiency of developer. However, the main shortage of viewpoint entropy is that it mainly relies on the 2D views to evaluate the quality of the viewpoint, and the information contained in the 2D views is mainly the project area of the visible triangle, so that the evaluation factors lack of information of 3D virtual scene and fail to present the user's customized and diversified demands for optimum viewpoint. This is also the subject for further study in the future.

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