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# The Study of Smart Grid Knowledge Visualization Key Technologies

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## *Abstract*

*To solve the problems of knowledge visualization for smart grid, such as single manifestations, low-efficient use and not high model reuse rate, a general three-dimensional smart grid knowledge visualization model was presented in this paper. First, the construction method of grid device models based on knowledge-based reasoning was given. Then, the grid visual scene building method was proposed. This included rapid scene organization strategy, and exploration on the storage and re-use mechanism of three-dimensional visualization scene. Moreover, collision detection using swarm intelligence and bionic computing to solve its existing problems. Finally, The feasibility and practicality of the method was verified by a developed intelligent power virtual drill platform based on JME (J Monkey Engine).*

***Keywords***: *smart grid, visual reality, knowledge-based reasoning, collision detection, coordination mechanism*

## 1. Introduction

In the current era of big data, the embarrassed situation “data explosion, lack of knowledge” exists in the smart grid, which can be effectively alleviated dealt by knowledge acquisition process (knowledge discovery, knowledge representation and reasoning) in knowledge engineering [1]. But the acquired knowledge in whatever form presented to users to give them convenient understanding and use must be studied in depth. Currently, there are mainly the following issues: performance of single forms, lack of efficient human-computer interaction mechanism, neglect of knowledge visualization models and scene reuse mechanisms [2-4].

Virtual Reality (abbreviated VR) can generate realistic as one of vision, hearing, touch environment taking computer technology as the core tool and then users can gain the feelings and experiences of “immersed” in the real environment through a natural mean with the objects in the virtual environment interact, making use of particular devices (data gloves, etc.) [5, 6]. Essentially, virtual reality is an advanced computer user interface to provide users with a variety of real-time interactive services simulate users’ actions to a maximum extent and then improve users’ productivity. There are a variety of functions in VR due to its applications on different objects. For example, make design concept visualization; achieve realistic remote site operation, and cheaply simulation train under complex environment, etc. Therefore, the use of virtual reality technology provides a guideline to solve the above smart grid knowledge visualization method problems.

However, designing a successful VR system is a extremely complex task, which calls high demands for software development environment. In addition, the traditional mode of a new application system development and research should be re-implemented almost all of the technical details, which results in low efficiency, long life cycle and high cost. 3-D engine [7], encapsulates the underlying three-dimensional programming interface, implements a large number of three-dimensional calculation algorithms, and can provide efficient development platform, which can greatly accelerate the development process of three-dimensional applications. Three-dimensional visualization knowledge system development in smart grid field

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needs high requirement for real-time and stability. So a universal smart grid knowledge visualization engine is designed based on open source game engine JME in this paper.

This paper mainly studies the implementation method of smart grid knowledge visualization using VR technology. Create a attribute integration between different virtual electrical facilities based on knowledge-base reasoning. Build the grid knowledge display scene through the rational organization strategy, and then design its rapid generation algorithm. Achieve collision detection based on a combination intelligent optimization algorithm of genetic and non-linear programming. Propose scene rendering method based on interactive coordination mechanism. Study on scene storage mechanism for the re-use preparation of models and scene. Finally, verify feasibility and practicability of the method by the application platform development of power operation virtual drill.

## 2.The Model of Smart Grid Knowledge Visualization Method

### 2.1. Related Work

Grid knowledge-base involves grid operation, management control, production and sales as well as some other aspects of knowledge. Specifically, it includes: grid topology knowledge base, electrical atomic devices knowledge base, grid operation control rules base, grid stability analysis knowledge, grid fault diagnosis knowledge, power grid outliers monitoring knowledge, the forecasting class knowledge base of power consumption, power generation and load forecasting etc.

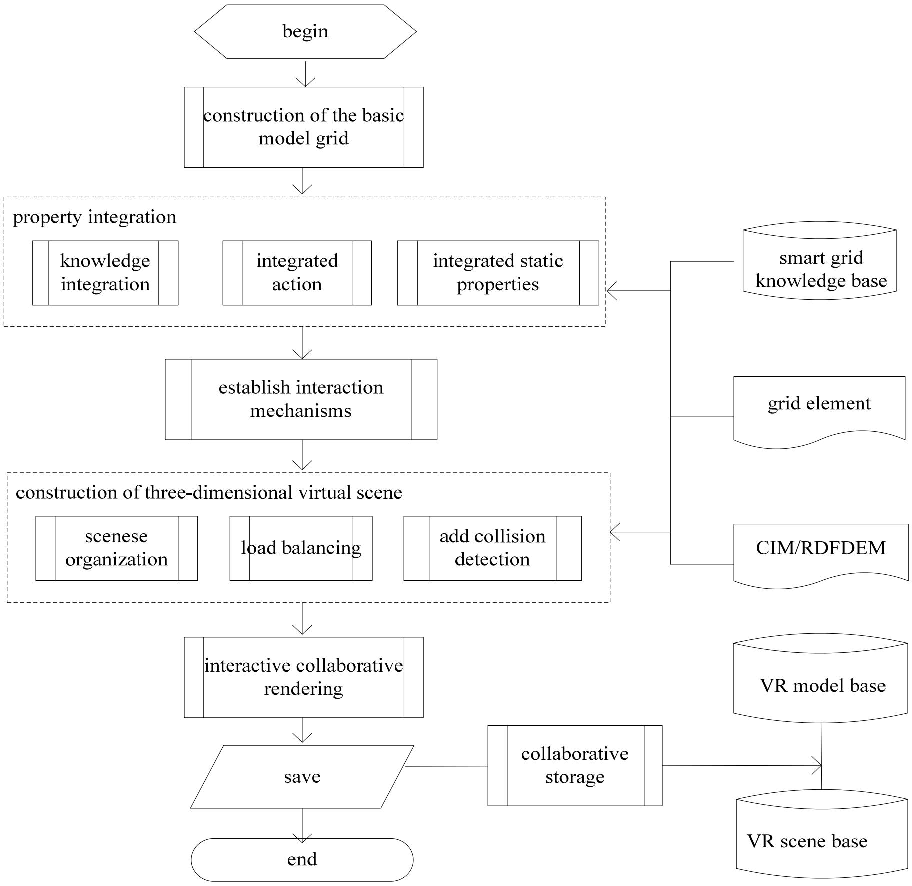


Figure 1. Grid knowledge visualization method processing model

In this paper, the grid knowledge is divided into reasoning, physics and events knowledge. Reasoning type is the knowledge of decision support, and they are primarily used for knowledge property integration. Physics knowledge is defined as the nature properties (manufacturer, model, etc.) of electrical equipment, which is used for static properties integration. Event knowledge refers to the available equipment operating rules, and it is used for action integration.

### 2.2. The Knowledge Visualization Model for Smart Grid

The process of the method (show as Figure 1) is: In VR technology, the smart grid knowledge 3-D visualization model is implemented through establishing the mapping rules between grid knowledge and virtual power device models. And Based on the rational organization strategy of knowledge, the large-scale grid display scene is built, and then their storage mechanism is studied for re-use preparation. This can achieve real-time and a full range of virtual reality display for grid operation status, thereby increasing the hierarchy level of grid visualization. Users can not only enjoy the visual feast but also improve understanding on use grid knowledge more intuitively and quickly.

## 3. Virtual Electrical Equipment Model Construction

### 3.1. Model Base Construction

In order to solve slow loading because of the large size, quantity of models and the opacity problem for animation model parameter-call[8], the format conversion concept of original models is proposed.

Its implementation is: import original models into format converter using modeling software (MAYA, etc.) to isolate the geometric model and physical parameters. The physical parameters files will be called only when the corresponding event is triggered in the scene. The experiment shows that this mechanism can improve the model loading speed significantly, and is very convenient for developers to call the model parameters, improving the working efficiency. The specific implementation process is shown in Figure 2.

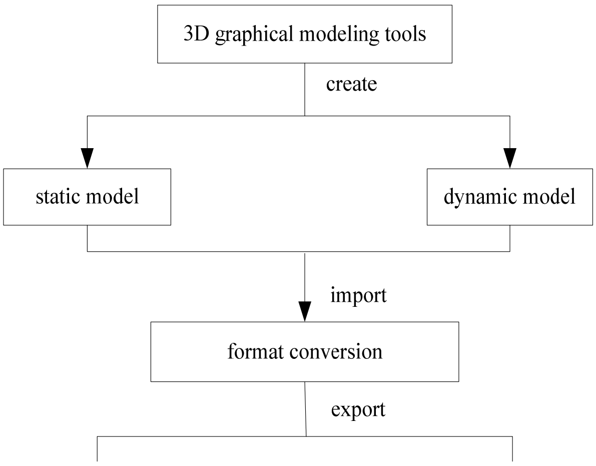


Figure 2. Model format conversion

### 3.2. Property Integration Method Based on Knowledge-base Reasoning Technology

Property integration mainly includes knowledge integration, action integration, and static properties integration. In property integration process, Use knowledge reasoning technique to give the corresponding definition for them, and make preparation for their three-dimensional, dynamic display. Specific description is as follows:

Knowledge integration, associate the electrical equipment with knowledge in knowledge base by device number. When a user interacts with the device, you can view the knowledge of device in particular time and specific circumstances. Action integration, on the one hand, the device can respond to appropriate action in accordance with operating rules, such as circuit breakers actions including opening and closing, etc, on the other hand, it includes voice tracking, visual tracking and viewpoint induction.An equipment property integration display chart is showed in Figure 3

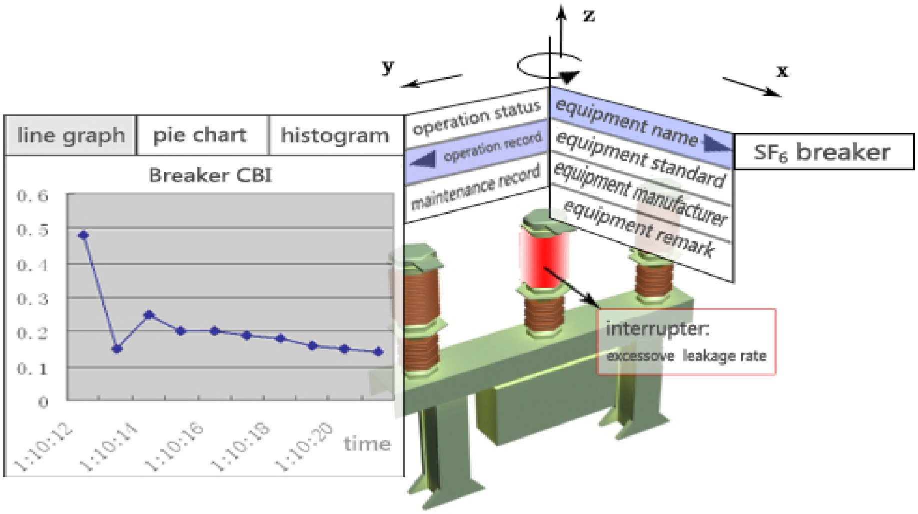


Figure 3. An equipment property integration display chart

## 4. Building of Electricity Virtual Scene

The virtual scene of smart grid knowledge visualization restored the actual electrical work environment. It covers interior scene of cockpit and outside scene which used to perform field operation. Construction of the virtual scene including organizational strategy, scene rendering and scene store three parts, its construction process can be described as repeated execution of these three stages.

The traditional platform used for scene building has many limitations [9]. Firstly, most of them are focus on same fixed fields, just like many of them focused on the substation simulation at present, this will result in that their versatility is reduced. Secondly, their scalability and reusability are mostly confined to models and external programs, there are still large room for improvement. Finally, there is no detailed design for the reusability of the whole scene and the operational tasks.

### 4.1. Organizational Strategy of Electricity Virtual Scene

To maximize improve the efficiency of system development, this paper from the reality proposed a scene dynamic building mechanism used for specific factors. The models (such as: topography, light, etc.) that have lower factors and more general were extracted then packaged in this mechanism which used a tree organization. Fixed node that created for each type of generic model were bound to the scene tree root node. Thereby an original scene XML file was created. Every time when you need to create a new scene, you must import the original scene XML file first. Then you just need to edit the part that must be changed in the actual of the work tasks.

Meanwhile, in order to improve the realism and immersion experience of the scene, you can select corresponding knowledge or event from the knowledge-base then add them to the relevant geometry model when you use modular construction technique to dynamically construct geometric scene. The input and output interfaces that provided by the scene can easily realize the use of data glove, virtual helmet and other three-dimensional interactive devices. Details shown in Figure 4.

This mechanism can be applied to every areas of the smart grid. You only need to improve the database of model and knowledge according to the requirement.

### 4.2. Interactive Collaborative Rendering

A large number of structurally complex device model were contained in the electricity virtual scene. For example, there will be millions of faces to be rendered in a single substation virtual scene [10], it will seriously affect the overall visual effect if the rendering speed is to slow. Therefore, in this paper, in order to improve the scene rendering speed and allow users to feel more smoothly, the interactive collaborative rendering algorithms were used to render the scene and the huge number of equipments.

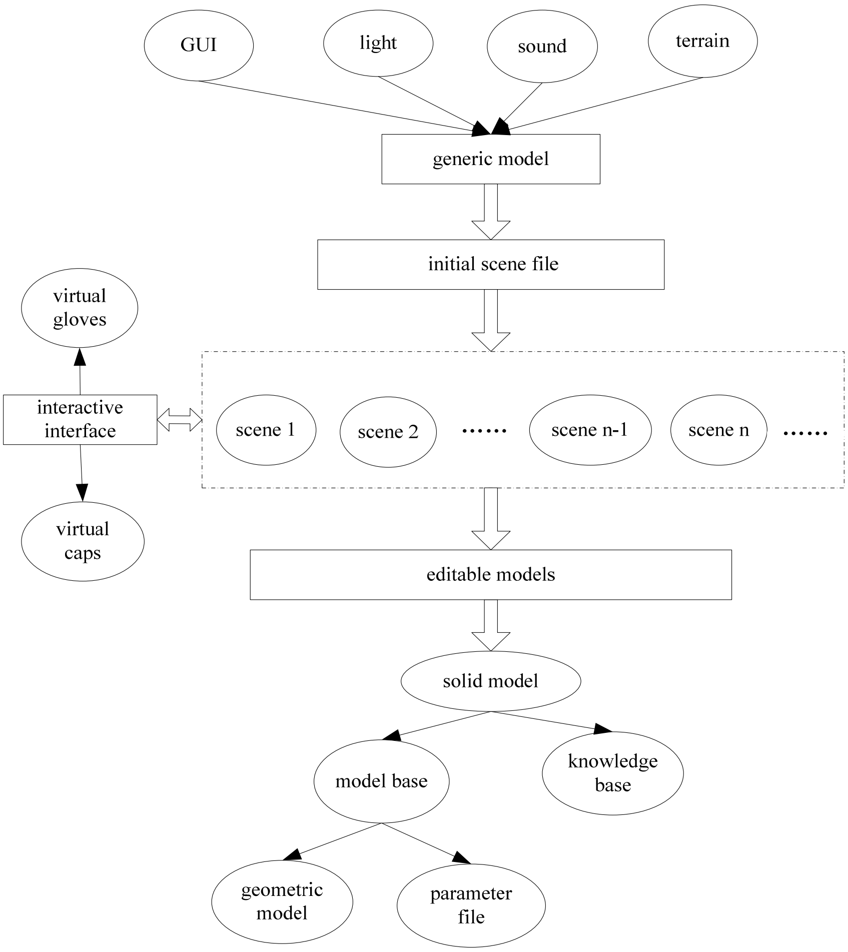


Figure 4. Organizational strategy of electricity virtual scene

In order to achieve some kind of overall goal or function, the process that establishing interconnected relationships between individuals to coordinate their interactions and regulate their activities is named collaboration. Interactive collaborative rendering is based on distributed rendering technology. Firstly, a number of scene rendering tasks on the screen were divided, then the assigned rendering information node, which were corresponded to a data node, was rendered separately and their rendering result was showed independently. Meanwhile, there exist coordinate relationships between the tasks of rendering information node. These coordination relationships which needed to be coordinated with each other include information synchronization, edge stitching, the consistency of the scene content, etc. Finally, all the display nodes were combined to display the final rendering results.

### 4.3. Scene Store and Reuse

In order to improve the reusability and promotional of the scene [11], this paper introduced a file information storing method which is based on XML. Firstly, The no operating factors (such as: topography, illumination , etc.) were extracted and added to the original three-dimensional scene in a generic model style. Meanwhile, the scene description file will automatically record these information about the generic models, ultimately generate the original scene description file. Every time when you create a new scene, you need call for the original scene description file first, the existing generic model will be loaded according to the file, then an original scene will be created. Details shown as Figure 5.

In this method, the models and their description information files that loaded in the scene are separated. When building a new scene, the original scene will be generated according to the original scene description file. Your job is to select the models form the model database and add them to the scene according to the system wiring diagram, then select knowledge from the knowledge-base and add them to the relevant model according to the specific task.A new scene description information file will be reproduced after you finish construction job. The new XML file directory information will be stored in the database. When you need to re-operate the same scene, you can easily make calls from the database .

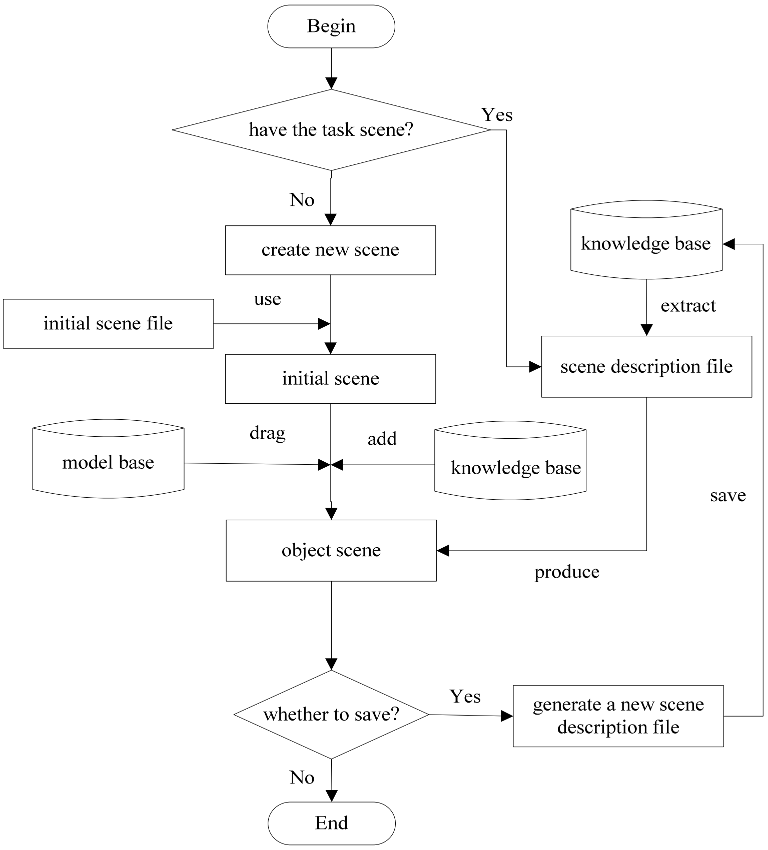


Figure 5. Scene store and reuse

## 5. Collision Detection Based on Swarm Intelligence and Bionic Computing

Corresponding to the real power scene, operators' manipulate objects are electrical equipment in virtual environment. Essentially, this is overall performance of the changing relationship between the 3-D models shape and position. In order to manipulate virtual objects, operators and other objects will appear “collision”. The two purposes of collision detection are respectively the orientation of virtual objects detection and increasing realism [12, 13]. Solving the shortest distance among different objects is one of the key technologies in collision detection algorithm. The distance between two polyhedral is calculated by seeking and tracking their nearest point in this class algorithm and if its value less than or equal to zero, the collision will occur. In addition, to solve the existing problems of collision detection, low speed and precision, the distance in it is reduced to the calculation of a constrained nonlinear programming problem in this paper. Moreover, traditional optimization algorithms, such as linear programming and integer programming, is applied to solve the small scale problems due to their complexity, while they are not suitable for practical engineering applications. So the swarm intelligence and bionic computing technologies are introduced to solve the collision detection problems.

Specifically, combined tabu search with genetic algorithm is proposed in this paper. Tabu search algorithm local search ability is strong while the global search capability is weak. On the contrary, the global search ability is strong and the local search capability is weak of genetic algorithm, so generally, it only gets suboptimal solution, rather than the optimal one. The genetic algorithm adopts selection, cross and mutation operators to search. Thus, this method combines the advantages of two algorithms, one for global search using genetic algorithm, one using tabu search algorithm for local search in order to get the optimal solution.

### 5.1. Related Theoretical Foundation

Definition 1: given m number points $x_1, x_2, \dots, x_m \in R^n$ ($R^n$ is the n-dimensional space) real number $\lambda_1, \lambda_2, \dots, \lambda_n$ ,and $\lambda_1 x_1 + \dots + \lambda_n x_m$ is linear combination of $x_1, x_2, \dots, x_m$ . Specially, when $\lambda_1 + \dots + \lambda_n = 1$ and $\lambda_1, \lambda_2, \dots, \lambda_n \geq 0$ , then $\lambda_1 x_1 + \dots + \lambda_n x_m$ is known as the convex combination of $x_1, x_2, \dots, x_m$ .

Definition 2: Suppose $s \in R^n$ , then all of convex combinations of any finite points in $S$ is called the convex hull of it, and it can be described as $H(s)$ .

$$H(s) = \begin{cases} \sum_{i=1}^{m} \lambda_i x_i \, | x_i \in s, \lambda \geq 0, i = 1, \dots, m \\ \sum_{i=1}^{m} \lambda_i = 1, m \in N_+ \end{cases} \tag{1}$$

Here: $N_+$ is represented as the set of all positive numbers.

Definition 3: the definition of convex polyhedron distance model: $Mind_{A,B} = \|x - y\|$ is represented as the shortest distance between convex bodies A and B, x represents a point on the object A, and y represents a point on the object B. Combined with the above definitions, the shortest distance between objects can be defined as below:

$$Mind_{A,B} = \left\| \sum_{i=1}^{m} \lambda_i x_i - \sum_{j=1}^{n} \sigma_j y_j \right\| \tag{2}$$

Here: $\sum_{i=1}^{m} \lambda_i x_i$ is represented as a point x on A, $\sum_{j=1}^{n} \sigma_j y_j$ is represented as a point y on B, and $\lambda_i$ with $\sigma_j$ should meet the requirements respectively as below:

$$\begin{aligned} st \sum_{i=1}^{n} \lambda_i = 1, \lambda_i \geq 0, i = 1, 2, \dots, n; \\ st \sum_{j=1}^{n} \sigma_j = 1; \sigma_j \geq 0, j = 1, 2, \dots, n. \end{aligned} \tag{3}$$

So by using a convex hull of vertices to represent convex polyhedron, the shortest distance between objects can be converted into a nonlinear programming problem with constraints. Suppose $\lambda_i$ and $\sigma_j$ are the points at $Mind_{A,B}$ getting the minimum value under satisfying the equations and inequalities constraints. For example, if $Mind_{A,B} = 0$ then, A and B will occur collision. Else $Mind_{A,B} > 0$ then, A and B are separated from each other. Since A and B vertex information is known, it is mainly solving the time complexity of optimization, and combined nonlinear programming with genetic algorithm is proposed to solve it in this paper.

### 5.2. The Implementation of Tasu Search-Genetic Algorithm

#### 5.2.1. The Algorithm Flowchart

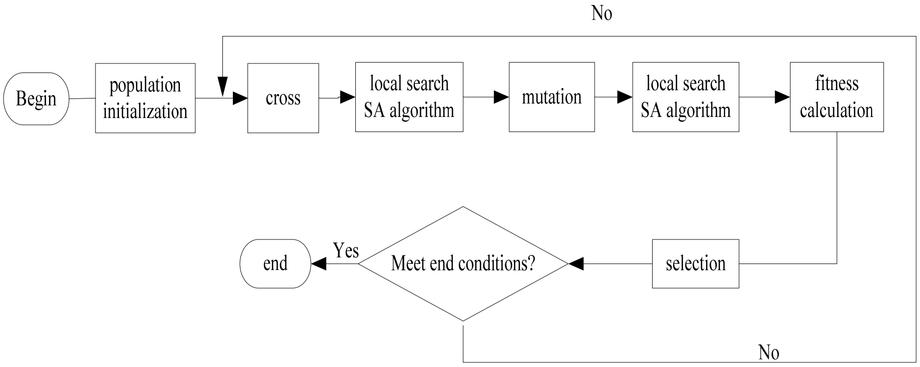


Figure 6. The algorithm flowchart

#### 5.2.2. Dealing with Constraints

The key step that applied the algorithm to solving the optimal problem is constraints processing. Therefore, the mathematical model makes processing on equality constraints and constraints contained only upper and lower limits. Conditions for equality constraints, assuming that there are m independent equations, then the m variables can be linearly expressed by remaining n-m variables. Taking the converted equations into constraints contained lower and upper limits or inequality ones, thus equality constraints will be eliminated. Conditions for constrains processing only contained the upper and lower limits, based on the solutions accuracy requirements, use the binary code variables, connect n binary bit strings together sequentially to form each individual code.

#### 5.2.3. Genetic Operation

(1) The fitness function determination

Fitness function is used to distinguish individuals’ quality in a group, is the sole basis for natural selection, and generally is transformed by the objective function. since the algorithm is used to solve the minimum value of function, fitness assignment function using sequential method: $F[f(x)] = ranking(obj)$ (here, obj represents the output of object function) is taken as the fitness function. The smaller function value is, the greater fitness value is, and the better individual is.

(2) Selection operation

Ergodic random sampling (sus) is taken as the selection operator in this algorithm.

Cross strategy

Cross strategy is based on the cross probability of two individuals exchanging bit value one-by-bit. First select two individuals randomly to form a pair, and select the cross bit from them randomly. And then generate a random number in range [0,1], and if it is greater than the cross bit then the exchange occurs otherwise keep intact.

(3) Mutation operation

Mutation operation select an individual from the population randomly, and then select a point of the individual mutation to produce better individuals. $a_{ij}$ is represented as the j gene of the i individual, and its mutation operation method is:

$$a_{ij=}\begin{cases} a_{ij} + (a_{ij} - a_{\max}) * f(g), r \geq 0.5 \\ a_{ij} + (a_{\min} - a_{ij}) * f(g), r < 0.5 \end{cases} \quad (4)$$

Here, $a_{\max}$ is the upper limit of gene $a_{ij}$ while $a_{\min}$ is the lower limit of gene $a_{ij}$.In addition, $f(g) = r_2(1 - g / G_{\max})^2$, $r_2$ is a random number, $g$ is the current iteration number, $G_{\max}$ is the maximum number of evolution, $r$ is a random number in range [0,1].

(4) Tasu search local optimization

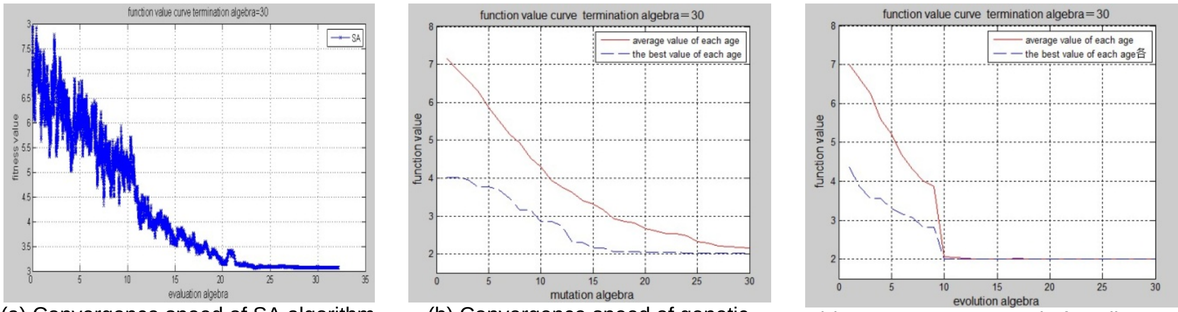
Use the tasu search algorithm to search for local optimization, and select the local optimum value as a new individual chromosome to evolve, taking the results after some algebra as the initial value.

#### 5.2.4. Algorithm Description

```
Begin
  Gen=0； MaxGen=200;pc=[0.6];pm=[0.01];
  initialize(pop);
  While(Gen<MaxGen&&have not find the result)
    begin
      fitness(pop);
      select(pop);
      x,y=combine at random
      if(rand(0,1)>pc)crossover(x,y);
      z=produce a unit at random;
      if(rand(0,1)<pm)mutation(z);
      gen++;
    end
  if(Gen=MaxGen)return exceeding MaxGen;
    else return f;
  x=SA(MindA,B);
 individuals.chrom=SA(individuals.chrom,pop);
End
```

#### 5.2.5. Algorithm Simulation

From the above chart we can see that under the same conditions, the SA-genetic algorithm is better than traditional genetic algorithm in the convergence speed and solution results. So the new algorithm improves search performance of the genetic algorithm.



(a) Convergence speed of SA algorithm

(b) Convergence speed of genetic algorithm

(c) Convergence speed of nonlinear programming-genetic algorithm

Figure 7. Algorithm simulation comparison

## 6. Instance of the Virtual Electrically Operation Drill Platform

Based on the above theoretical results, combined with JME engine, this paper developed a common intelligent power operation virtual drill platform which is used for substation employees' safety training. After the field research in multiple substation, we through the use of knowledge engineering technology constructed the appropriate knowledge base, which includes electrical safety knowledge, equipment operating procedures, handling precautions. Based on the extraction of device model, system wiring diagrams and equipment operation information from the collection of live photos and videos we completed the construction of equipment model and the expansion of the model events knowledge base.

Practice has proved that the platform can quickly achieve the construction of the target scene and the setting of operational tasks. With high practicality and promotional value, the platform can not only meet the requirements of operation drill but also greatly improve the reuse rate of the model and knowledge, reduce the costs of system maintenance.

## 7. Conclusion

This paper focused on the research of the key technology of smart grid domain knowledge three-dimensional visualization. Firstly, through the use of knowledge reasoning technology build the smart grid knowledge base and model library; Secondly, the organizational strategy of scene construction and interactive collaborative rendering mechanism of three-dimensional scene were studied, improved algorithms for collision detection based on nonlinear genetic algorithm; Again, explored the storage and reuse mechanisms of the virtual three-dimensional scene; Finally, developed a common platform for intelligent power operation virtual drill based on the above findings, through the practical application verified the practicality and efficiency of these findings. However, for the issues of complex scene generation and rendering speed, there is further room for improvement, which will also be the direction of future research work.

## Acknowledgment

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