Study on Fidelity evaluation method of visualization simulation

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Abstract

With rapid development of visual simulation in the various fields, simulation fidelity evaluation ought to extend indicator in order to adapt different simulation evaluation. But now, most of visual system evaluations are based on subjective feeling of experts with indicators ignored. Fuzzy AHP method was presented in order to decrease the influence of field specialist's opinion. First, the characteristic of visualization simulation system is proposed. Second, fidelity evaluation method of simulation system is given, and a set of evaluation indicators were presented. And then, the value of evaluation result was given, and shows that the evaluation method of visual simulation system has better practicability and prospect in project.

Keywords: fidelity, simulation, visualization, fuzzy AHP, evaluation of credibility

1 Introduction

Visual simulation technology has become more and more important in simulation, and the study of visual simulation technology is also more in-depth, but also to carry out a preliminary study of visual simulation fidelity. Fidelity analysis must establish appropriate evaluation indicator hierarchy and evaluation methods. Although many researchers carry out some work in the field of visual simulation assessment, but the indicator hierarchy for assessing research is still limited. Zhang wei and Wang Xingren [1] has evaluated visual simulation system by fuzzy evaluation method, but the indicators hierarchy contains only five simple indicators, such as pictures and other elements. Huang Anxiang [2] has calculated the main visual display and dynamic system fidelity in the whole task-based military simulation systems, but for military simulation fidelity visual system assessment only considered the projection, such as spherical distortion quality indicators, and does not involve three-dimensional model fidelity, and other aspects of virtual environments. Li Xin [3] established road safety assessment simulation system of driving simulators and visual simulation, but only refer to the relevant three-dimensional model of road safety and road safety assessments, which have no reference value to develop visual simulation system.

In order to establish objective assessment indicators of visual simulation systems, and improve the level of service applications, we propose a set of evaluation indicator system of visual simulation system.

2. Visual simulation system fidelity evaluation concept

2.1 VISUAL SIMULATION FIDELITY

Fidelity refers to the degree which a model or simulation reproduces the state and behavior of a real world object, feature or condition. Therefore, fidelity is a measure of the realism of a model or simulation entities [4]. Simulation fidelity has also been described as "degree of similarity".

Fidelity is represented by decimal boundary between 0 and 1. As boundary conditions, the fidelity of 0 indicates no similarities between the simulation and the simulation object, simulation fidelity of 1 means completely accurate reproduction of the simulation object, and has no difference.

According to this definition, fidelity is the output level of the complex three-dimensional picture for the actual appearance of entity, including the shape, color, texture, and other information in visual simulation systems. It is mainly to solve the "look like" problem in fidelity of visual simulation. Therefore visual fidelity simulation system boundary conditions: 0 means that it does not have any similarities in appearance between simulation and emulation objects, but 1 means a completely accurate description between simulation and simulation entities.

2.2 RESEARCH CONTENT OF VISUAL SIMULATION SYSTEM FIDELITY

Research content to assess the visual simulation system is divided into three main areas: 1. select the appropriate assessment methods; 2. establish an effective system of indicators for measurement and evaluation of fidelity; 3. how to effectively guide the establishment of visual simulation systems by index system.

Due to the complexity of the visual simulation system, we can’t use simple indicators to cover all of its elements. It is generally needed to establish the index system to determine the hierarchy of influence factors set [5,6,7,8], and evaluate each layer index system by AHP (Analytic Hierarchy Process, AHP). The underlying index generally visual simulation system is based on human visual and auditory experience as evaluation criteria, and not very

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accurate quantification, fuzzy analytic hierarchy process (Fuzzy AHP) is used usually in the evaluation process [9].

Specific steps if AHP visual simulation fidelity is as follows:

1) Establish a hierarchy fidelity simulation system assessment, namely decompose fidelity index, and refine the various factors of visual simulation fidelity simulation system which related to a variety of qualitative and quantitative factors. If the index can't be given directly to the value of quantitative indicators from 1 to N, the indicators need to continue to break down until you can get some quantifiable indicators parameters, which are directly measurable indicators.

2) Access to the underlying index fidelity. Through a variety of checking, testing or verification, we can be obtained directly quantization index value. These quantitative indicators of metrics often are inconsistent, we need unify their measure standard, and experts grade the underlying index.

3) The use of AHP / Fuzzy AHP comprehensive index method. Fuzzy AHP method or using the most advanced composite indicator values fidelity simulation system AHP method to calculate the relative weight of each indicator, and then get up layer by layer based on a weighted score of the underlying index.

4) Analyze the results and submit a report. The report should include information on the evaluation process of the expert, the index system hierarchy list and description of the process, Kiviat graph, and authoritative expert assessment conclusions.

3 Evaluation method of visual simulation system fidelity

There have a lot of research on fidelity evaluation method of simulation system. The paper put forward a fuzzy comprehensive evaluation method [4, 10]. The concrete mathematical methods are as follows.

3.1 DETERMINE THE WEIGHT SET

Suppose the factor set are $U(u_1,u_2,\cdots,u_m)$, weight distribution is calculated by Fuzzy AHP method. In order to retain the Fuzzy uncertain information, this process consists of 4 steps.

The first step: experts fill in factor weight comparison table, and the relative importance of the same layer two indexes give subjective judgments. The weight comparison of factors is as shown in Table 1. In this paper, fuzzy number level is divided by 9 scale: when the subjective importance evaluation comparison is "extremely important" or "extremely important", the value is 0.1, 0.2, ..., 0.9 respectively. The score of important comparison degree is m, degree of confidence is δ, when degree of confidence is "very confident", "little confident ", "less confident", a value of δ is 0.05, 0.1, 0.15 respectively. the triangle fuzzy function to the expert scoring is $a=(a_l,a_c,a_r)$,where $a_l=m-\delta$, $a_c=m$, $a_r=m+\delta$.

TABLE 1 The criterion table of project weight comparison

	Index	Comparison of u1 and u2	Comparison of u2 and u3
Important degree	Extremely important		
	Interval value		
	Important		
	Interval value		
	Equally important		
	Interval value		
	Less important		
	Interval value		
	Extremely minor		
Confidence level	Very confident		
	Little confident		
	Less confident"		

The second step: give the judgment matrix triangular structure of the K expert fuzzy number complementary.

$$A^{(k)}=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1m} \\ a_{21} & a_{22} & \cdots & a_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mm} \end{bmatrix} \quad (1)$$

where

$$a_{ij}=(a_{lij},a_{cij},a_{rij})=\begin{cases} (a_{lij},a_{cij},a_{rij}) & i>j, i\neq j \\ (1-a_{rij},1-a_{cij},1-a_{lij}) & i<j, i\neq j \\ (0.5,0.5,0.5) & i=j \end{cases}$$

The third step: the normalized weight vector calculation of the K experts. Calculation of triangular fuzzy number complementary judgment matrix row and normalized, available

$$\overline{w}^{(k)}=\left[\overline{w}_1,\overline{w}_2,\cdots,\overline{w}_m\right]^T \quad (2)$$

where

$$\overline{w}_i=\frac{\sum_{i=1}^{m}a_{ij}}{\sum_{i=1}^{m}\sum_{j=1}^{m}a_{ij}}=\left(\frac{\sum_{i=1}^{m}a_{lij}}{\sum_{i=1}^{m}\sum_{j=1}^{m}a_{rij}},\frac{\sum_{i=1}^{m}a_{cij}}{\sum_{i=1}^{m}\sum_{j=1}^{m}a_{cij}},\frac{\sum_{i=1}^{m}a_{rij}}{\sum_{i=1}^{m}\sum_{j=1}^{m}a_{lij}}\right)$$

comparing $\overline{w}_i$ to $\overline{w}_i$,The value of $\overline{w}_i\geq\overline{w}_j$ is P_{ij}. As shown in the following Equation:

$$p_{ij}=\lambda\max\left\{1-\max\left(\frac{\overline{w}_{jc}-\overline{w}_{il}}{\overline{w}_{ic}-\overline{w}_{il}+\overline{w}_{jc}-\overline{w}_{jl}},0\right),0\right\}+ (1-\lambda)\max\left\{1-\max\left(\frac{\overline{w}_{jr}-\overline{w}_{ic}}{\overline{w}_{ir}-\overline{w}_{ic}+\overline{w}_{jr}-\overline{w}_{jc}},0\right),0\right\} \quad (3)$$

where $\lambda\in[0\ 1]$

A possibility degree matrix is $P=(p_{ij})_{m\times m}$. It is obvious that the matrix P is a fuzzy complementary judgment matrix. The P line sum is normalized, get the weight vector:

$$w^{(k)} = \left[w_1, w_2, \cdots, w_m\right]^T \tag{4}$$

The fourth step: there are K experts to participate in the system evaluation. Count the K experts set value statistics: through the expert judgment matrix are given, each weight vector can be obtained, and calculate the average value to the final weight vector is:

$$W = \frac{\sum_{k=1}^{K} w^{(k)}}{K} = [\frac{\sum_{k=1}^{K} w_1^{(k)}}{K}, \frac{\sum_{k=1}^{K} w_2^{(k)}}{K}, \cdots, \frac{\sum_{k=1}^{K} w_m^{(k)}}{K}] \tag{5}$$

3.2 FIDELITY EVALUATION

Evaluation of a given set of experts is $S(s_1, s_2, ..., s_n)$, each factor u_i has a fuzzy evaluation $R(r_{i1}, r_{i2}, ..., r_{in})$. Written in matrix form:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}_{m \times n} \tag{6}$$

where R is the single factor evaluation matrix; R_{ij} is the subject value of u_i for s_j. Because of the different impact factors, the weight is different. A weight vector is $W = [w_1, w_2, \cdots, w_m]$, comprehensive evaluation can be expressed as:

$$D = W \cdot R. \tag{7}$$

The symbolic representation is a fuzzy algorithm, and can be denoted as $M(+,*)$.

4 Visual simulation evaluation index system

Sun Guobin [5] analyzes simulation credibility, reliability concept, and their relationship with VV&A, points out the difficulty of simulation credibility evaluation is how to establish an effective index system. If there is no effective index system, any methods do not have practical value on the study of the visual simulation system fidelity.

Despite extensive research and many effective methods, the researcher doesn't establish a complete visual simulation fidelity index system. At the present, the index system which has built is very simple. But in fact these indicators can't cover the visual simulation of the demand, and can't guide the visual simulation system.

Based on a large amount of visual simulation system, the paper put forward a set of fidelity hierarchy structure of index system, including the basic factors of visual simulation system, the first and the second level indicators such as shown in Figure 1.

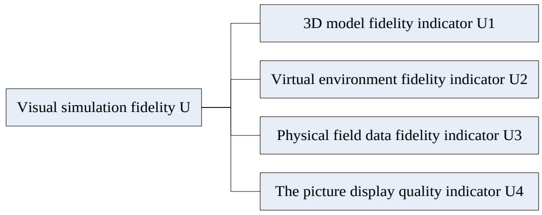

FIGURE 1 The first level indicators of visual simulation fidelity

The first level indicators of visual simulation fidelity is denoted by U and divided into 4 sub-indicators: 3D model fidelity, virtual reality, physical field data fidelity and quality of displayed images, respectively U1 to U4, the following will be described.

4.1 THREE DIMENSIONAL MODEL FIDELITY INDICATORS

The 3D model established by 3D modeling tool is the basis of visual simulation. The fidelity is the evaluation index on the three-dimensional model, divided into 3 levels, as shown in Figure 2.

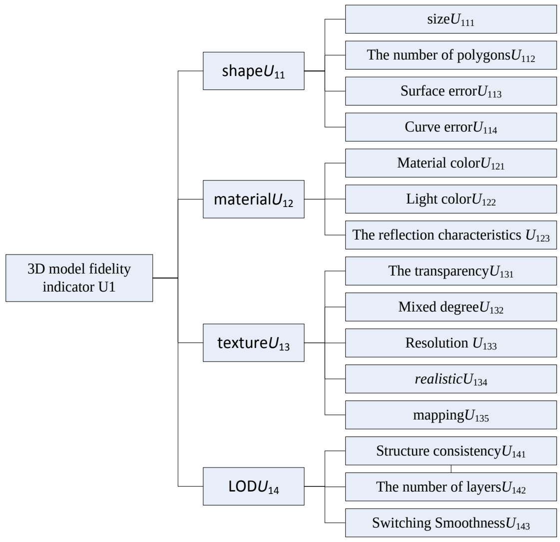

FIGURE 2 3D model fidelity indicator

As the triangular mesh surface model generally adopts the scene simulation, the appearance is the three-dimensional mesh model description, divided into 4 bottom indexes. The size is the comparison of models in each direction and true among simulation objects scale; the number of polygons is the total number of triangle including the whole 3D model, can display frames influence the output picture; surface error and error curve respectively refers when using the triangular mesh model error to approximate the surface or curve values.

Material include three second level indicator, which is 3D model of color, light color, reflection characteristics, which described on the basis of surface characteristic of OpenGL polygon model.

In the visual simulation, the general use of texture mapping technique is aimed to represent surface details for the object. The essence of texture mapping is to establish the corresponding relationship between the 2D graphics and 3D surface. Most developable surface will produce distortion from the 3D surface to the 2D surface, so the texture mapping of the main problems to be solved: one is how to repeat the details, the other is how to minimize the surface distortion. Texture index of three-dimensional model have 5 bottom indexes, which is transparency, degree of mixing, resolution, fidelity and mapping methods.

LOD is the technology of visual simulation modeling, which is usually used to solve contradiction between model precision and computational power. We usually use the LOD model in visual simulation system, must establish the appropriate LOD layers, and ensure that all levels between the structural consistency and switching smoothly.

4.2 VIRTUAL ENVIRONMENT FIDELITY INDEX

Fidelity Index of the virtual environment is divided into 3 levels, including second level indicators include voice, special effects, terrain, ocean, atmosphere, respectively by U_{21} to U_{25}, and each is divided into a number of underlying indexes. As shown in Figure 3.

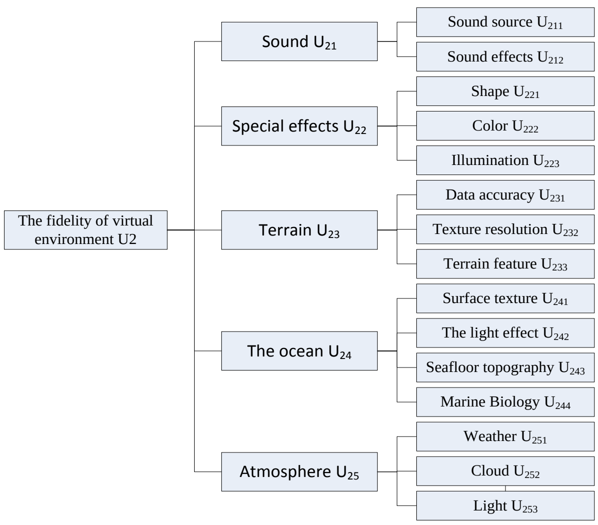

FIGURE 3 Virtual environment index

Terrain data precision (U_{231}) is used to measure the generate terrain data file itself accuracy; and generating algorithm (U_{235}) is the measurement of transform algorithm error from the terrain data file between the 3D terrain model.

4.3 PHYSICAL FIELD DATA FIDELITY INDEX

There are all kinds of physical field in the visual simulation, such as the magnetic field, electric field, acoustic field etc. Most is not visible, but an important role for the operation of the system, so often used in visual simulation of physical field data visualization technology to show these effects. This paper puts forward the indexes of physical field data fidelity, as shown in Figure 4.

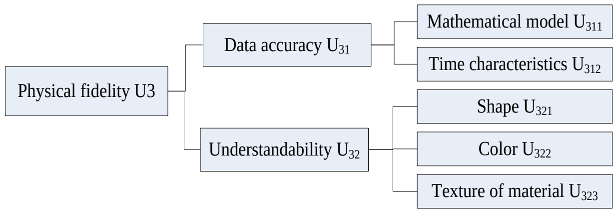

FIGURE 4 Physical field data fidelity index

The accuracy of the data is a measure of physical field calculation model of mathematics, divided into mathematical model, error, time characteristics; understanding is the understanding of the physical field visualization simulation user visual effect degree, understanding degree evaluation of physical shape, respectively from several color, material and pattern.

4.4 THE QUALITY INDEX OF THE PICTURE

The visual simulation system of the output image fidelity is also concerned with hardware. The picture display quality index is not concerned about the characteristics of internal hardware, but for the simulation system demand, carries on the appraisal to the picture itself. As shown in Figure 5, the image quality is divided into 4 indexes: fluency, color saturation, brightness and contrast. Fluency is divided into display frames and display resolution of 2 bottom indexes.

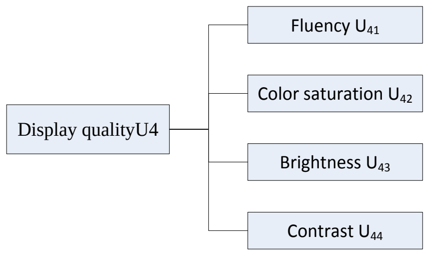

FIGURE 5 The quality index of the picture

4.5 SOUND EFFECT INDEX

The appropriate sound effects can enhance the 3D environment immersion and screen display content understanding. Evaluation of sound is divided into 4 sub indicators, which include the air/ground attenuation, the signal-to-noise ratio, weapons effect, environment sound, as shown in Figure 6.

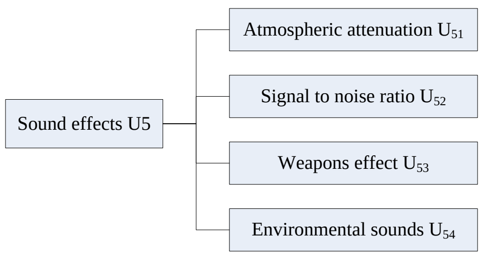

FIGURE 6 Sound effect index

5 The evaluation of visual simulation system by Fuzzy AHP

According to the view above the proposed simulation fidelity structure index system, we give a weapon combat visual simulation system fidelity evaluation. For the sake of brevity, we take the evaluation of the 3D model fidelity of U1 as example.

5.1 DETERMINE THE WEIGHT CLASSIFICATION INDEX

For U_{11}, U_{12}, U_{13}, U_{14} of the two level indexes, let 10 experts to evaluate the weight. The weight of the first k expert evaluation as follows:

$$\begin{pmatrix} (0.5,0.5,0.5) & (0.65,0.7,0.75) & (0.6,0.7,0.8) & (0.75,0.8,0.85) \\ (0.25,0.3,0.35) & (0.5,0.5,0.5) & (0.25,0.3,0.35) & (0.55,0.7,0.85) \\ (0.2,0.3,0.4) & (0.65,0.7,0.75) & (0.5,0.5,0.5) & (0.7,0.8,0.9) \\ (0.15,0.2,0.25) & (0.15,0.3,0.45) & (0.1,0.2,0.3) & (0.5,0.5,0.5) \end{pmatrix}$$

The weight vector of triangular fuzzy number is as follows:

$$\overline{w}^{(k)} = \begin{pmatrix} (0.278, 0.338, 0.414) \\ (0.172, 0.225, 0.293) \\ (0.228, 0.288, 0.364) \\ (0.100, 0.150, 0.214) \end{pmatrix}.$$

The corresponding possibility degree matrix P is:

$$\begin{pmatrix} 0.500 & 1.000 & 0.872 & 1.000 \\ 0.000 & 0.500 & 0.019 & 1.000 \\ 0.128 & 0.981 & 0.500 & 1.000 \\ 0.000 & 0.000 & 0.000 & 0.500 \end{pmatrix}$$

Then, get the weight vector:

$$w_{U_1}^{(k)} = [0.422, 0.190, 0.325, 0.063]^T$$

Using the same method can be obtained by other experts on U_{11}, U_{12}, U_{13}, U_{14} grading, the weighted average method to get the weight vector of the 4 level two indexes for:

$$w_{U_1} = [0.412, 0.144, 0.363, 0.081]^T$$

Similarly, we can calculate U_{11}, U_{12}, U_{13}, U_{14} of each factor sub index with respect to the weight vector of their weight. 3D model fidelity of various factors is shown in Table 2. The data in the table can be used as the guiding principle of 3D modeling: shape is the most important for the 3D model fidelity, then the texture, then number of layers and material resolution. The most important thing is to get enough the shape data; and the shape factor is divided into 4 sub factors, which the important factors is the size of the model and the number of polygons.

TABLE 2 All the weight factors fidelity 3D model

The second level	Weight	The third level	Weight
ShapeU_{11}	0.412	SizeU_{111}	0.361
		The number of polygonsU_{112}	0.376
		Surface errorU_{113}	0.211
		Curve errorU_{114}	0.052
MaterialU_{12}	0.144	Material colorU_{121}	0.372
		Light colorU_{122}	0.435
		reflection characteristics U_{123}	0.193
TextureU_{13}	0.363	The transparencyU_{131}	0.043
		Mixed degreeU_{132}	0.102
		Resolution U_{133}	0.297
		realisticU_{134}	0.331
		mappingU_{135}	0.227
LODU_{14}	0.081	Structure consistencyU_{141}	0.539
		The number of layersU_{142}	0.135
		Switching SmoothnessU_{143}	0.326

5.2 CALCULATION OF THE FUZZY COMPREHENSIVE EVALUATION

Let 10 visual simulation evaluation personnel to rate the visual simulation system, get the evaluation matrix. We take torpedo model as an example, and the model appearance factors U11 results is as shown in Table 3.

TABLE 3 The second level evaluation table

Expert number	1	2	3	4	5	6	7	8	9	10
U_{111}	7	9	8	8	8	6	7	8	8	9
U_{112}	6	7	7	6	7	5	6	8	7	7
U_{113}	8	8	9	8	7	7	8	7	9	7
U_{114}	6	7	7	8	7	6	7	7	7	6

Thus, the evaluation matrix R:

$$R_{11} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0.1 & 0.2 & 0.5 & 0.2 \\ 0 & 0 & 0 & 0 & 0.1 & 0.3 & 0.5 & 0.1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.4 & 0.4 & 0.2 \\ 0 & 0 & 0 & 0 & 0 & 0.3 & 0.6 & 0.1 & 0 \end{bmatrix}$$

So the comprehensive evaluation results are:

$$D_{11} = W_{11} \bullet R_{11} = (0,0,0,0.038,0.164,0.376,0.308,0.114)^T$$

In the same way, we have

$$D_{12} = W_{12} \bullet R_{12} = (0,0,0,0.017,0.142,0.375,0.411,0.055)^T$$

$$D_{13} = W_{13} \bullet R_{13} = (0,0,0,0.143,0.221,0.242,0.346,0.048)^T$$

$$D_{14} = W_{14} \bullet R_{14} = (0,0,0,0.03,0.113,0.33,0.423,0.104)^T$$

According to the sub factors assessment results, obtained the evaluation vector as:

$$D_1 = w_1 R_1$$
$$= (0.412,\ 0.144,\ 0.363,\ 0.081)^T \bullet \begin{bmatrix} 0 & 0 & 0 & 0 & 0.038 & 0.164 & 0.376 & 0.308 & 0.114 \\ 0 & 0 & 0 & 0 & 0.017 & 0.142 & 0.375 & 0.411 & 0.055 \\ 0 & 0 & 0 & 0 & 0.143 & 0.221 & 0.242 & 0.346 & 0.048 \\ 0 & 0 & 0 & 0 & 0.03 & 0.113 & 0.33 & 0.423 & 0.104 \end{bmatrix}$$
$$= \left(0,0,0,0,0.072,0.177,0.323,0.346,0.081\right)$$

For evaluation, can use the percentile for each rating assignment: from the "worst" to the "best" 9 levels were set to 20~100 [11], the score of the shape comprehensive evaluation is:

$$H = \left(0,0,0,0,0.072,0.177,0.323,0.346,0.081\right) \bullet (20,30,40,50,60,70,80,90,100)^T = 81.79$$

The evaluation results show that, the shape and 3D model of the torpedo is consistent with the actual model, and can meet the requirements of visual simulation.

6 Conclusion

The new indicator hierarchy of visualization simulation is presented, which can cover all factors of visualization simulation. On the basis of new indicator hierarchy, the fuzzy AHP evaluation method is improved to reduce the subjective factors of evaluation experts. Evaluation method and indicator hierarchy is proved to be effective through the application of a visual simulation system. In addition, assessment method of visual simulation system is also applied to other fields, and has a certain application prospect and value, will play a major role in the practical engineering application.

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