Mesopic Visual Performance of Cockpit's Interior based on Artificial Neural Network

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Abstract— **The ambient light of cockpit is usually under mesopic vision, and it's mainly related to the cockpit's interior. In this paper, a SB model is come up to simplify the relationship between the mesopic luminous efficiency and the different photometric and colorimetric variables in the cockpit. Self-Organizing Map (SOM) network is demonstrated classifying and selecting samples. A Back-Propagation (BP) network can automatically learn the relationship between material characteristics and mesopic luminous efficiency. Comparing with the MOVE model, SB model can quickly calculate the mesopic luminous efficiency with certain accuracy.**

Keywords- component; Mesopic Vision; Cockpit; Artificial Neural Network; BP; SOM.

I. INTRODUCTION

A. Cockpit's Interior Ergonomics

Visual comfort occupies an increasing important place in our everyday life, but also in the field of aeronautics which is the subject of this paper. Modern science and technology is people-oriented. More and more human factors were taken into consideration on the development of modern civil airplane.

A subject of applying ergonomics into man-machine relationship develops gradually, which has brought about more and more attention. The ambient light of cockpit consists of natural sunlight, instruments panels, inside lighting systems and interior's reflecting light. The quality of ambient light in the man-machine system should meet the requirements, as well as providing people visual information about activity both in quality and quantity. It should meet ergonomics requirements of perceptive information, aiming at making people comfortable and pleasant.

The cockpit's comfort plays an important role in pilot's job, especially the visual performance. About 80% outside information is received though vision, which makes vision the most important channel to communicate with external world [1]. Visual comfort is the psychological feeling about comfort level in ambient light. So, visual comfort is a quantity of psychological feeling.

Uncomfortable vision will cause a series of symptoms, usually appears as redness and swelling, pain, itching, tears, dizziness or even intestines and stomach problems. Comfortable environment of cockpit would guarantee the pilot keep a normal state in the process of work, to avoid flight accidents caused by visual factors.

In the man-machine ergonomics study, establish the inner relationship between different materials properties and light source, and the received luminance, light intensity, contrast and color in the specific conditions. Simulate different characteristics of efficiency of different light source and different materials. The influences of these multidisciplinary factors are not independent. They're of complicated nonlinear relation. Past studies domestic and oversea are mostly aimed at single factor of variables, without considering the nonlinear relationship between multiple factors and the coupling mechanism.

The established design standards and norms cannot completely meet the pilot's ergonomics requirements in the real flight environment, thus increasing the design difficulty of a cockpit ergonomics system. There's a long history according to the visual ergonomics research in cockpit. Britain and America have already done a lot of experimental and theoretical research, and established design standards of illumination and colorimetry. However, there's only a little study for the interior system of ergonomics problem. The domestic related research is scattered, mainly paused in the qualitative subjective evaluation level, which cannot form a systematic theory. Through the research of aircraft cockpit's coupling mechanism, characteristics of the pilot's visual perception and comprehensive effect with multivariable factors, we can build the civil aircraft cockpit's interior ergonomics theory model and application mechanism.

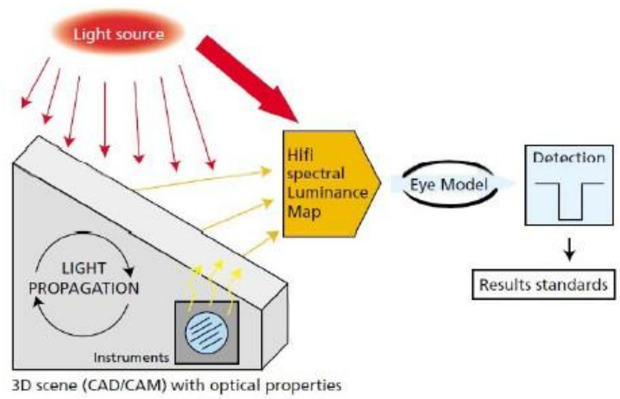


Figure 1. Cockpit's visual system model

OPTIS established a cockpit's visual system model [2] by CATIA based on ergonomic design criteria and a certain type of aircraft cockpit, which is shown in Figure.1. Then various optical properties could be set, including the characteristics of light source spectral and optical materials which participating in the process of light transmission. After that, they can be applied to the optical tracking system to simulate the light process.

For safety reasons, visual information must be seen as comfortable as possible by the aircraft pilot in any light conditions. In this paper, we focus on the cockpit's mesopic visual performance based on the ANN method.

B. Mesopic Vision

Mesopic light levels are those between the photopic (daytime) and scotopic (extremely low) light levels. The mesopic luminance range covers brightness between about 0.001 and 3 cd/㎡. Most night-time outdoor and traffic lighting environments and some indoor lighting are in the mesopic range [3].

As human eyes have different perceptions on light fusions from different frequency, there comes to be different brightness, for observers, between lights of different wavelength even with the same power. Luminous efficiency function curves indicate such a human eye character.

Photopic luminous efficiency function $V(\lambda)$ (in Figure2) , which is fit for delineating the spectral response within a 2-degree range of human eyes in a higher brightness, is the most widely used function in this field and was brought forward on the 6th conference of CIE in 1924. CIE has successively brought forward the function with a wider range of 10 degree and also the luminous efficiency function $V'(\lambda)$ for environments of low brightness less than 0.001cd/㎡.

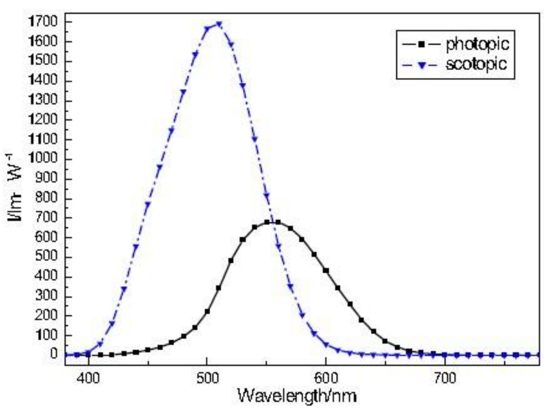


Figure 2. Photopic luminous efficiency function $V(\lambda)$ and scotopic luminous efficiency function $V'(\lambda)$.

Mesopic photometry has a long history. Most mesopic photometry models have concentrated on brightness evaluation. The early works began in the 1950s and then a special research put forward by the Committee of Mesopic Version Photometry in CIE started in 1983. A number of studies of visual performance at mesopic light levels have been conducted, which underscore the importance of recognizing the distinction between photometry and a complete characterization of visual responses at mesopic levels [4]. The EC project MOVE [5] (Mesopic Optimisation of Visual Efficiency) was carried out during 2002-2004 in the EC Fifth Framework programme (G6RD-CT-2001-00598). The objective of the project was to define relevant spectral sensitivity functions for the luminance range of 0.01 – 10 cd/㎡, where standardisation is most urgently needed. The TC1-58 Technology Committee found in 2000 also by CIE came up with a better model using the method of visual performance and such a function below was brought forward [6]:

$$M_m V_m(\lambda) = xV(\lambda) + (1-x)V'(\lambda) \tag{1}$$

Where $V_m(\lambda)$ represents the mesopic luminous efficiency function under the environment of a certain backdrop brightness, M_m is the normalization factor of $V_m(\lambda)$, x is a parameter which is located between 0 and 1 based on backdrop brightness and spectral power. x=1 is in photopic conditions while x=0 in scotopic conditions.

Illumination is defined as the transparent flux on unit area, and flux is available from function below:

$$\phi_x = M_x \int_{380}^{780} P(\lambda) \cdot V_x(\lambda) d\lambda \tag{2}$$

Where ϕ_x stands for the total flux, $P(\lambda)$ is the spectral arrangement function of light source, $V_x(\lambda)$ is the luminous efficiency function on certain brightness, M_x is the normalization factor. $s/p = \phi_s/\phi_p$.

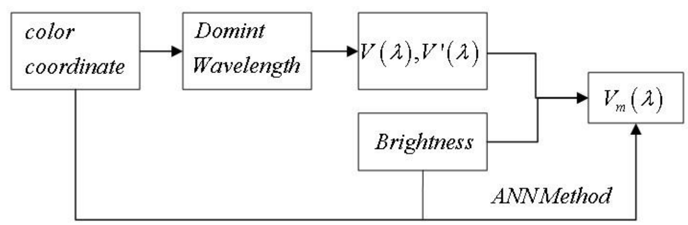


Figure 3. The process of calculating

In this paper, a new method has been used into human vision model to simplify the nonlinear relationship between light characteristics and mesopic vision. In real time scenario, there are many factors taken into consideration. However, we focus on some dominant variable in this paper.

II. Artificial Neural Network

An artificial neural network (ANN), usually called neural network (NN), is a mathematical model or computational model that is inspired by the structure and/or functional aspects of biological neural networks. A neural network consists of an interconnected group of artificial neurons, and it processes information using a connectionist approach to computation.

From 1940s, with human being's fully understanding of the brain structure, composition and the most basic unit, Artificial Neural Network was arose [7]. Simplified model

(ANN) was established after combining mathematics, physics and information processing method, and making neural network abstracted.

As an active marginal subject, the research and application of neural network is becoming a hot pot of artificial intelligence, cognitive science, neurophysiology, nonlinear dynamics, and other related subjects. In last ten years, academic research according to neural network is very active, and puts forward almost a hundred of neural network model. Neural network is also widely used in analysis of input and output with multiple variables. In the process of aircraft design, using the neural network to optimize pneumatic parameters has obtained some progress.

In this paper, SOM network is used to compress a set of high-dimensional input parameters that contain material characteristics onto a two-dimensional SOM grid. SOM network is different from other artificial neural networks in the sense that it uses a neighborhood function to preserve the topological properties of the input space. The neurons will classify the space, each neuron representing a partition of that space.

SOM network employs an Winner-Takes-All (WTA) operation, which only the winner is allowed to adjust the weight connecting to the input. The training process includes sequential steps[8].

a) Initialization: Randomly specify the weight value $W_j, j=1,2,\cdots,m$ (m stands for the number of neurons on competitive layer) and give the initial value of Learning Rate $\eta(0)$ and Radius of Neighbor $N_{j^*}(0)$.

b) Competition: Select a certain sample:

$$X^p = \left(X_1^p, X_2^p, \cdots, X_n^p\right) \tag{3}$$

Then calculate the responses by (4) to all the neurons on competitive layer. Find the winning neuron j^* with the largest response.

$$Y_j = W_j^T X^p,\ j=1,2,\cdots,m \tag{4}$$

c) Adaption: Calculate the radius of neighbor neurons $N_{j^*}(t)$, and all neuron weights in the radius will be adjusted by (2).

$$\begin{gathered} w_{ij}(t+1) = w_{ij}(t) + \eta(t,N)\left[x_i^p - w_{ij}(t)\right] \\ i=1,2,\cdots,n;\ j\in N_{j^*}(t) \end{gathered} \tag{5}$$

Where the Learning Rate η will be the function of training time t and the radius of neighbor N

$$\eta(t,N) = \eta(t)e^N$$

$$\eta(t) = \begin{cases} \eta_0, & t \le t_p \\ \eta_0\left(1-\dfrac{t-t_p}{t_m-t_p}\right), & t_p < t \le t_m \end{cases} \tag{6}$$

In which, t_m is the total cycles for training and t_p is the cycle time keeping the original learning rate. If $\eta(t)$ declines to a tolerance or the training time t is long enough, then the training is finished, or else go to step b) continuing another sample.

After the whole training, the network will be sensitive differently to the samples in database. The samples with close characteristics will generate similar response on the output map, which proves to classify different types of samples successfully.

BP network model is the most typical artificial neutral network (ANN) model, widely used as a multi-layer feed-forward network, which includes input layer, hidden layer and output layer. In this paper, we give color coordinate and brightness as input and mesopic luminous efficiency function as teacher signal, so that the network will be capable of estimating any mesopic luminous efficiency by giving a single light characteristics. The training process follows 7 steps:

a) Initial all network weights to small random values.

b) Input a certain sample $X^p = \left(X_1^p, X_2^p, \cdots, X_n^p\right)$ to the network, and calculate the output of all the neurons.

c) For each neuron k on output layer ($l = L$), calculate the error term $\delta_k^{(L)}$.

$$\delta_k^{(L)} = \left(t_k - o_k\right)o_k\left(1-o_k\right) \tag{7}$$

d) Where, t_k is the teacher signal and o_k is the output of neuron k.

e) For each neuron on hidden layer ($2 \le l \le L-1$), calculate the error terms $\delta_j^{(L)}$.

$$\delta_j^{(l)} = o_j\left(1-o_j\right)\sum_k \delta_k^{(l+1)} w_{kj}^{(l+1)} \tag{8}$$

f) Update the network weights as follows:

$$w_{jk}^{(l)}(n+1) = w_{jk}^{(l)}(n) + \eta\delta_j^{(l)}(n)o_k^{(l-1)}(n) \tag{9}$$

g) Go to step b) for another input sample until the termination condition is met.

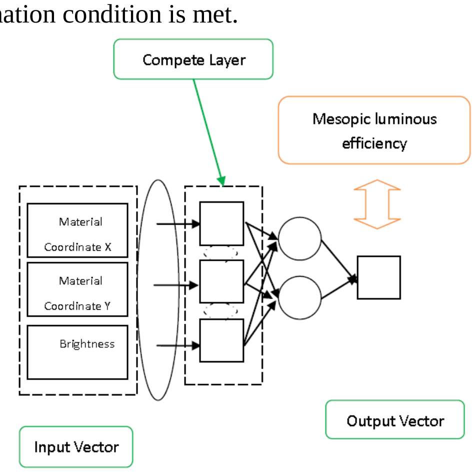
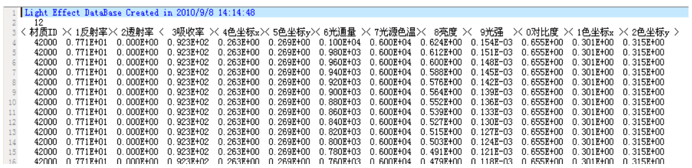


Figure 4. SB model

A new model combines SOM and BP network named SB model, shown as in Figure 4. It uses SOM to classify different samples while BP network to simulate nonlinear relationship between material characteristics and mesopic luminous efficiency.

III. EXPERIMENTAL RESULTS

To study the mesopic vision performance of pilot in cockpit, we gathered measurement variable into an initial database, shown as in Figure 5. In the condition of experiment, input variable including material reflectivity, material transmissivity, material absorptivity, luminous flux, color temperature, material coordinate x and material coordinate y, as well as output variable including brightness, light intensity, contrast, color x and color y.



Light Effect DataBase Created in 2010/9/8 14:14:48

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材质ID	1反射率	2透射率	3吸收率	4色坐标x	5色坐标y	6光通量	7光源色温	8亮度	9光强	0对比度	1色坐标x	2色坐标y
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.100E+04	0.600E+04	0.624E+00	0.154E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.980E+03	0.600E+04	0.612E+00	0.151E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.960E+03	0.600E+04	0.600E+00	0.148E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.940E+03	0.600E+04	0.588E+00	0.145E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.920E+03	0.600E+04	0.576E+00	0.142E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.900E+03	0.600E+04	0.564E+00	0.139E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.880E+03	0.600E+04	0.552E+00	0.136E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.860E+03	0.600E+04	0.539E+00	0.133E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.840E+03	0.600E+04	0.527E+00	0.130E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.820E+03	0.600E+04	0.515E+00	0.127E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.800E+03	0.600E+04	0.503E+00	0.124E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.780E+03	0.600E+04	0.491E+00	0.121E-03	0.655E+00	0.301E+00	0.315E+00
42000	0.771E+01	0.000E+00	0.923E+02	0.263E+00	0.269E+00	0.760E+03	0.600E+04	0.479E+00	0.118E-03	0.655E+00	0.301E+00	0.315E+00

Figure 5. Initial database

After observing, material reflectivity, material transmissivity, and light intensity are invalid. In the condition of color temperature equals 5000K and luminous flux equals 1000lm. Initial database can be trimmed. The sample database shows as Figure 6.

Material Absorption	Material color X	Material color Y	Luminous Flux	Brightness	Luminous Intensity	Contrast	Color x	Color y
92.288	0.263	0.269	300	1.74E-01	4.29E-05	0.6207	0.307	0.321
73.521	0.287	0.307	280	7.55E-01	1.86E-04	0.3778	0.314	0.332
95.429	0.262	0.252	260	5.70E-02	1.40E-05	0.6731	0.306	0.316
86.685	0.253	0.267	240	2.66E-01	6.55E-05	0.4792	0.304	0.321
80.377	0.289	0.303	220	4.64E-01	1.14E-04	0.3524	0.315	0.331
72.87	0.291	0.292	200	5.01E-01	1.23E-04	0.3422	0.315	0.327
94.207	0.324	0.282	180	8.63E-02	2.13E-05	0.6162	0.329	0.323
75.061	0.264	0.265	160	3.59E-01	8.83E-05	0.4206	0.307	0.32
97.864	0.321	0.331	140	2.92E-02	7.19E-06	0.7294	0.325	0.338
85.827	0.304	0.312	120	1.64E-01	4.05E-05	0.473	0.32	0.333
94.768	0.316	0.329	100	5.39E-02	1.33E-05	0.6515	0.323	0.337
69.765	0.317	0.327	80	2.49E-01	6.14E-05	0.3416	0.324	0.337
96.286	0.317	0.325	60	1.18E-02	2.90E-06	0.6541	0.324	0.337
48.836	0.31	0.316	40	2.14E-01	5.28E-05	0.3056	0.322	0.334
59.569	0.338	0.356	20	8.70E-02	2.14E-05	0.3747	0.33	0.345

A. Dominant Wavelength

Calculate the dominant wavelength with x-y chromaticity coordinates in a Chromaticity Diagram [9], just illustrated in Figure 7.

Construct a line between the chromaticity coordinates of the reference white point on the diagram (for instance, CIE-E) and the chromaticity coordinates, and then extrapolates the line from the end that terminates at the filter point. The wavelength associated with the point on the horseshoe-shaped curve at which the extrapolated line intersects is the dominant wavelength. Table 1 gives some common illuminants used as a white reference.

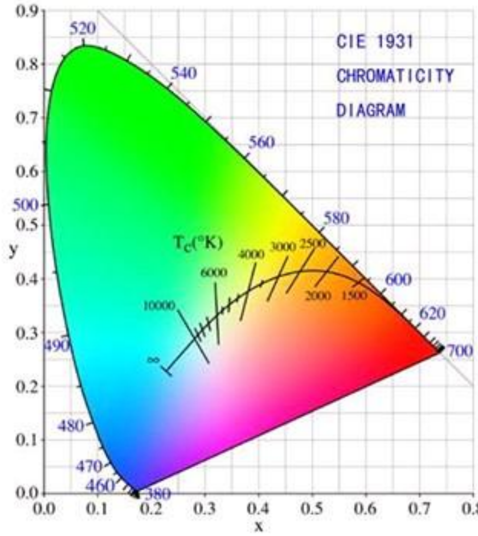

Figure 7. CIE 1931 Chromaticity Diagram

Chromaticity coordinates of some common illuminants used as a white reference.

TABLE I.

Reference White	x coordinate	y coordinate
CIE-E	0.3333	0.3333
CIE-A	0.4476	0.4075
CIE-C	0.3100	0.3162
CIE-D65	0.3127	0.3291

After calculation, the dominant wavelengths of color coordinates are shown in Table 2.

TABLE II. DOMINANT WAVELENGTH OF COLOR COORDINATES

color x	color y	wavelength
0.301	0.315	589
0.308	0.326	597
0.300	0.310	582
0.299	0.315	589
0.308	0.325	599
0.309	0.321	588
0.320	0.317	565
0.301	0.314	580
0.318	0.332	606
0.313	0.327	598
0.316	0.331	609
0.317	0.331	610
0.316	0.330	592
0.315	0.328	597
0.323	0.339	496

B. Mesopic Luminous Efficiency

Then the photopic luminous efficiency and the scotopic luminous efficiency could be obtained by dominant wavelength. The parameter x in formula (1) could be calculated according to Table 4 in reference [5].

According to the brightness and s/p ratios, x could be approximately calculated in certain conditions as shown in Table 2. The s/p ratio is chosen in the condition of typical overcast sky, which is 2.36 [10].

Linear fitting function's used to fulfill the x-value.

TABLE III. X-VALUE FOR MOVE MODEL

wavelength	brightness	x
589	0.6238	0.7721
597	2.8570	0.7977
582	0.2355	0.7660
589	1.1880	0.7799
599	2.2330	0.7917
588	2.6500	0.7958
565	0.5073	0.7703
580	2.3860	0.7933
606	0.2196	0.7657
598	1.4430	0.7830
609	0.5664	0.7712
610	3.2440	0.8012
592	0.2063	0.7655
597	5.5430	0.8229
496	4.4610	0.8120

$M(x)$ is a normalizing function such that $V_m(\lambda)$ attains a maximum value of 1, shown as in Figure 8.

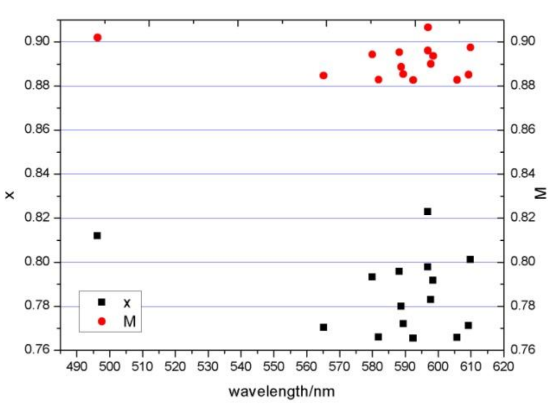

Figure 8. x-value and $M(x)$ distribution results

The MOVE model is applicable for other conditions such as typical sunlight sky and typical direct sunlight sky.

C. SOM Network Results

According to the design requirement, a total of 12 samples are selected, including brightness, color x and color y.

For initialization, we give the initial learning rate $\eta(0)_0 = 0.95$. And the radius of neighbor is defined as following expression:

$$N(t) = 0.9\exp(-10t / t_m = 2000) \qquad (10)$$

According to the test result, total cycles of training t_m is defined as 20000.

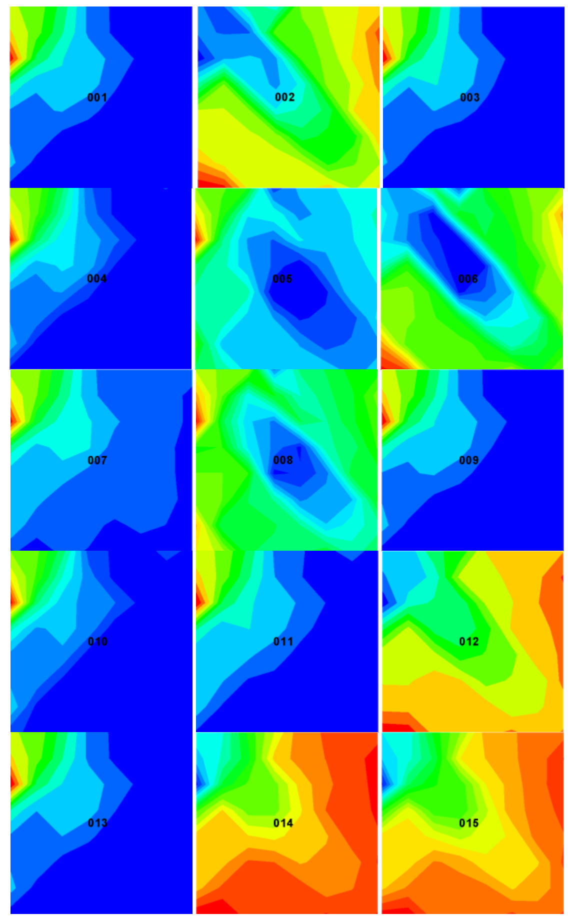

Figure 9. 2d-response by SOM

After the whole training, all 12 samples are classified into 4 groups on a 2×2 map. Table 4 shows the resulting SOM with cluster groups considering the all 3 characteristics. Figure 9 demonstrates the responses to different samples. The number is ranked from left to right and up to down, sign as 001 to 012. The more similar the characteristics of samples are, the closer the colored maps are.

From the colored result, we can easily get that most of the samples performed like the same in group 1. No.012, 014 and 015 are the most distinguishing ones.

TABLE IV.

Group 1	Group 2	Group 3	Group 4
001, 003,004 007,009,010 011,013	002	005, 006 008	012,014,015

D. BP Network Results

Construct a BP network, with color coordinate and brightness as input and mesopic luminous efficiency as teacher signal (target). The number of hidden nodes depends on the number, scale and complexity of samples. To confirm the number of hidden nodes, we take the formula as follow:

$$m = \sqrt{n+l} + \alpha \tag{5}$$

where m is the number of hidden nodes, n is the number of input nodes, l is the number of output nodes, and α is a constant between 1 and 10.

The main parameters of BP network are of $m = 3$ (hidden nodes), $lr = 0.15$ (learning ratio), $mingrad = 1e\text{-}10$ (minimum gradient), and $epochs = 100$.

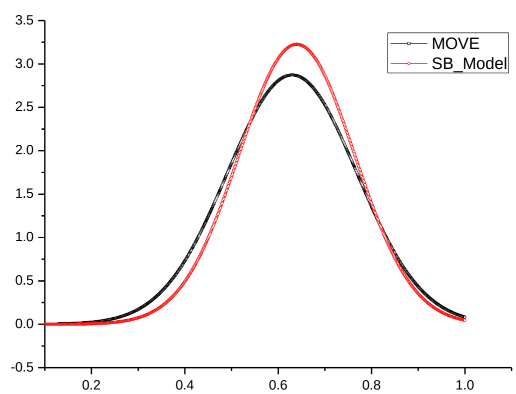

Figure 10. Error density distribution function

After the whole training, the result is shown in Figure 10. The black square line represents error density distribution function of MOVE model, as well as the red circle line represents error density distribution function of SB model. Observing the peak of these two models, mesopic luminous efficiency function of SB model is more concentrated than MOVE model.

CONCLUSIONS

This paper put forward a SB model, which uses SOM network to classified different samples into different groups. Chose a certain group, the training result is better than before. Use BP network to simplify the relationship between the mesopic luminous efficiency, and the different photometric and colorimetric variables in the cockpit. After comparing with the MOVE model, SB model takes advantage of ANN to simplify the relationship, and convenient to calculate mesopic luminous function, as well as has more concentrate error density distribution. To make research more accurate, we will take more research on simulating human's eye, and construct corresponding model. Photopic vision and scotopic vision are taken into consideration in the next as well.

ACKNOWLEDGMENT

The work is sponsored by National Basic Research Program ("973" Program) of China, Issue Number 2010CB734106.

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