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Application of C-SVM Classification Algorithm to the Lighting Visual Comfort of University Classrooms

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ABSTRACT

Considering the quality of the classroom light-environment will directly affect students' eye health and learning efficiency, it is a problem to be solved that how to evaluate the visual comfort levels of the classroom light-environment and save lighting energy on the premise of necessary visual comfort. Aiming at these problems above, this study restored the classroom scene through adjustable full-size light-environment simulation laboratory, in which 135 subjects participated in the visual comfort evaluation experiment of the indoor light-environment. After features (illuminance and correlated color temperature) and labels (comfort levels) preprocessed ,we trained and visualized the visual comfort classification models of desktop reading and blackboard reading using the algorithms of C-Support Vector Machine (C-SVM). Through the contour map and the scatter diagram, we get the classification boundary of different comfort levels and the relationship between visual comfort and lighting parameters, which has guiding significance to classroom lighting design and evaluation.

KEYWORDS: Classroom lighting; Visual comfort; Lighting energy efficiency; Subjective evaluation experiment; C-SVM

INTRODUCTION

The quality of indoor artificial light-environment has important influence on the indoor space user's psychological feeling, visual effect, visual fatigue, physiological rhythm and so on. Classrooms are the main venues for students to study in, the pros and cons of the light-environment will directly affect not only the students' eyesight health, but also the student's psychological feeling and learning efficiency (Gao, 2013). Considering the variable classroom usage patterns, it is necessary to verify the comfort range of light parameter of desktop reading, blackboard reading and PPT reading. Only in this way can we guide the light-environment design of classrooms according to the actual usage patterns.

The A.A.Kruithof's lighting comfort curve, which is considered the classic research on spatial light-environment visual comfort, roughly shows the corresponding relationship among the visual comfort, color temperature and illuminance (Kruithof, 1941). After that, visual comfort of light-environment research mainly divided into two directions: one is to further explore the relationship among the visual comfort, illuminance and correlated color temperature (CCT) under different space types based on Kruithof's curve; The other one is to use the methods of fuzzy comprehensive evaluation, linear regression or some other mathematical methods to find the mathematical relationship among the visual comfort, illuminance, CCT and other explanatory variables.

However, most research results are controversial or difficult to apply to practical applications. As an important algorithms in the fields of pattern recognition and machine learning, support

vector machine (SVM) which is based on the theory of VC (Vapnik-Chervonenkis) dimension theory and structural risk minimization principle performs well on the nonlinear and small sample classification or regression problems, which causes scholars' continuous exploration on the optimization of this model and the practical application in recent years (Ben et al, 2012; Kaya et al, 2012; Huo and Duan, 2011). This research tries to develop a classification model using the algorithm of C-support vector machine (C-SVM) with features of illuminant parameters and labels of subjects' visual comfort level. The results can be visualized on 2d contour plots which can estimate the quality of light-environment easily and guide the lighting design of the same space type.

METHODS

Experiment Platform

The experiment was carried out in the experimental module of variable building space designed and constructed independently by Tianjin university. The length and width of the experimental module are both 24 m, which can be divided into any space by partitions. The ceiling is composed by the 16 pieces of 6 m * 6 m lift alone LED lighting modules with individual lift range of 3 m to 9 m. Each lighting module deploys 12 LED tube lights which can be adjusted within a certain range of luminous flux and CCT. Therefore, it can stimulate real light-environment of any regular space with proper scene decoration. The experiment cabin exterior and interior view are shown in Figure 1.

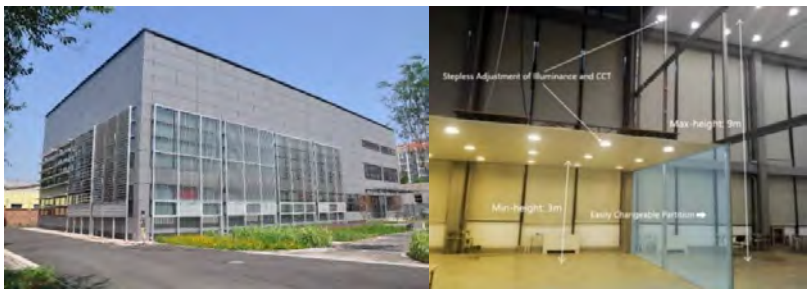


Figure 1. Exterior and interior view of the experiment cabin.

Working Condition

This experiment was carried out in a 12 m * 6 m * 9 m stimulated classroom through space adjusting device. As shown in Figure 2, The outer windows were covered with opaque grey curtain and 18 sets of desks (size: 1.2 m * 0.6 m) and chairs and a blackboard (size: 2 m * 1m) were put properly.

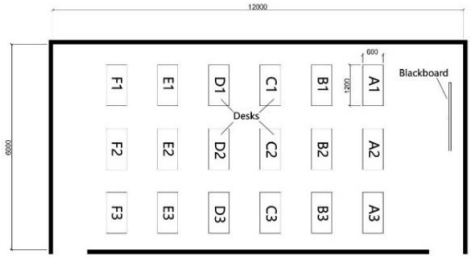


Figure 2. Stimulated classroom setting.

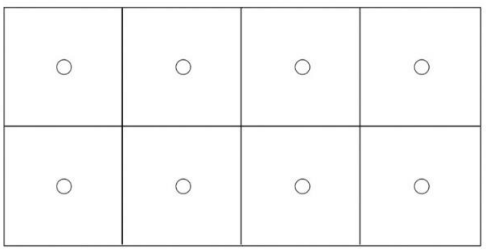


Figure 3. Measuring points on blackboard.

In this experiment, the visual comfort of desktop reading and blackboard reading was taken as the evaluation object. The experiment set up 74 working conditions with only general lighting, making sure that the illuminance parameters of the two lighting modules were consistent. With adjustment of lighting parameters under different working conditions, the 0.75 m horizontal illuminance and CCT covered 20-1100 lx and 2670-6700 K respectively, and

making sure the color rendering index was above 80 in any case. The illuminance and CCT of each measuring point in each working condition was measured by the spectrophotometer (KONICA MINOLTA CL-500A). The layout of measuring points on the blackboard is shown in Figure 3, and the measuring points on desktops were the subjects' visual center of reading. The average value of two-time measurement of each point was taken as the final measured value. The measuring time was chosen after 20 o'clock to minimize the effect of natural light.

For the blackboard surface, the arithmetic mean value of all measurement points was taken as the average illuminance of current working condition. The formula is as follows:

$$E_{av} = \frac{1}{M \cdot N} \sum E_i \qquad (1)$$

In this formula: E_{av} is the average illuminance and the unit is lux (lx); E_i is the illuminance of the *i*th measure point, and the unit is lux (lx); M and N are respectively the longitudinal and transverse measurement points. The measurement results are shown in Table 1 and Table 2:

Table 1. Measurement values of light-environment parameters on desktop.

Condition No.	Percentage of maximum power of white light	Percentage of maximum power of yellow light	Measuring point	Average illuminance (lx)	CCT (K)
1	0%	80%	A1	582.60	2729
			...	...	...
			F3	682.45	2750
...	...	...	...	...	...
74	20%	80%	A1	704.20	3075
			...	...	...
			F3	835.80	3129

Table 2. Measurement values of light-environment parameters on blackboard.

Condition No.	Percentage of maximum power of white light	Percentage of maximum power of yellow light	Average illuminance (lx)	CCT (K)
1	0%	80%	361.05	2711
2	80%	0%	378.84	6506
3	50%	50%	393.01	4030
...	...	...	...	...
74	20%	80%	436.18	3054

Subjective evaluation experiment of visual comfort in light-environment.

As shown in Fig. 4, 8 group experiments were carried out in which 16 to 18 undergraduates or postgraduates aged 20 to 26 evaluated the visual comfort of desktop reading and blackboard reading under 74 sets of lighting conditions. The whole subjects were consists of 135 students with a roughly equivalent sex ratio.

Figure 4. Subjective evaluation experiment of visual comfort in classroom light-environment.

After taking 1-minute rest with eye masks on between adjacent sets of working conditions, the subjects can minimize the influence of the former light-environment. Each question on the subjective evaluation questionnaire, with an evaluation standard of "If it is conducive to learning or not", must be chosen one number among 0 to 10 as the visual comfort score of the current conditions. The questionnaire is as Table 3:

Table 3. Subjective evaluation questionnaire

Condition No.										
1.Which do you think is the visual comfort score of current desktop reading?										
0	1	2	3	4	5	6	7	8	9	10
2. Which do you think is the visual comfort score of current blackboard reading?										
0	1	2	3	4	5	6	7	8	9	10

RESULTS

Data preprocessing

We removed the outliers of visual comfort evaluation scores according to the quartile of 8 group experiments. Then we get mean value of the visual comfort evaluation scores of the same seat position, and discretized the average of normal values into 4 range: $0 <$ comfort average≤ 2.5, $2.5 <$ comfort average≤ 5, $5 <$ comfort average≤ 7.5 and $7.5 <$ comfort average≤ 10, representing "awful", "uncomfortable", "good" and "excellent". For visual comfort of blackboard reading, we still need to take arithmetic mean value of 18 subjects in the same group of experiment as the overall comfort value of each condition. Finally, the label of each lighting condition is expressed as integer 0~3, which corresponding to "awful", "uncomfortable", "good" and "excellent" visual comfort level. The data prepared for modeling are shown in table 4 and table 5.

Table 4. Desktop reading data.

No.	Illuminance	CCT	Evaluation
1	582.60	2729	2
2	664.95	2727	2
3	637.55	2723	2
4	612.55	2730	1
5	701.60	2726	1
...	...	...	...
1332	835.80	3129	2

Table 5. Blackboard reading data.

No.	Illuminance	CCT	Evaluation
1	361.05000	2711	2
2	378.84375	6506	2
3	393.00625	4030	2
4	115.60000	6355	1
5	137.02500	4045	2
...	...	...	...
74	436.17500	3054	2

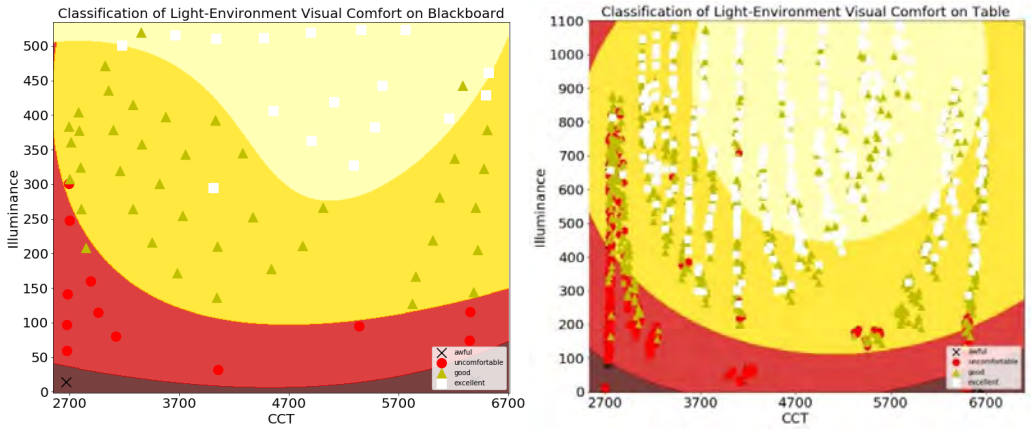
Light-environment evaluation modeling based on C-SVM

Support vector machine (SVM) is a machine learning algorithm based on VC dimension theory and the principle of structural risk minimization(Brereton and Lloyd, 2010), and can improve the generalization ability of the models as far as possible, even to the limited training set. So the SVM model has a good performance on small sample data. By using Python3.6 and its extension packages, we built C-SVM light-environment quality evaluation models of desktop reading and blackboard reading with the kernel of radial basis function (RBF).The specific modeling process is shown as follows:

(1) Divide training set and test set: in this study the blackboard reading visual comfort experiment has 74 groups of data samples, while desktop reading comfort experiment 1332

ones. They were divided into training set and test set randomly according to the proportion of 4:1 respectively, which prepared to train and test the C-SVM model.
(2) Parameter adjustment and model training: C-SVM models were trained for desktop reading and blackboard reading respectively with features of average illuminance and CCT and labels of visual comfort level pre-processed; Through adjusting the parameter by grid search and K-fold cross-validation, we get the optimal C and gamma value (the penalty factor C for error, gamma for parameter of RBF kernel function), and prevent model overfitting by observing the training set prediction accuracy.
(3) Then we got the C-SVM light-environment evaluation model by training on the whole training set with the optimal combination of C and gamma obtained in the previous step.
(4) At last we can evaluate the performance of the trained C-SVM model by predicting accuracy on test sets.

Eventually we got the C-SVM model for desktop reading and blackboard reading as shown in Figure 4, and "x" means "awful", "●" means "uncomfortable", "▲"means "good", "■" means "excellent":



a) b)

Figure 4.Visual comfort C-SVM model. a) For blackboard reading(accuracy on test set and training set are 0.933 and 0.898), b) For desktop reading(accuracy on test set and training set are 0.667 and 0.663).

DISCUSSIONS

As shown in Fig.4, the horizontal axis represents CCT, the vertical axis represents the illuminance, yellow and white areas are for good and excellent combinations of illuminance and CCT, red and dark red area are for uncomfortable and awful ones. The following conclusions can be drawn from the two graphs:

For blackboard reading:
a) The light yellow area is the best for blackboard reading visual comfort and should be as a priority for teaching mode. The lowest vertical illuminance of blackboard is required to be 290 lx in the goal of achieving "excellent" visual comfort with a CCT of 5000 K at the same time. When the CCT is adjusted lower or higher than 5000 K, we must increase the illuminance to maintain the same level of visual comfort at the price of higher lighting power density (LPD). Even if there are special requests for the CCT of light source, try not to make CCT lower than 4000 K or higher than 6000 K, or we need above 400 lx of illuminance to achieve the same visual comfort level, which is not conductive to energy saving.
b) The yellow area is recommended as a good or acceptable area for non-teaching mode. In this area, the lowest vertical illuminance of blackboard should be limited to 100 lx with a CCT

of 4000-5500 K at the same time. Similarly, CCT lower than 4000 K is not recommended.
c) Red and dark red area are uncomfortable and awful area respectively. If the vertical illuminance of blackboard is lower than 100 lx, no matter what CCT can meet the requirement of visual comfort. Therefore, the vertical illuminance of blackboard should be higher than 100lx.

For desktop reading:
a) The light yellow area is the best for desktop reading visual comfort and should be as a priority for self-study or reading mode. Similarly, the lowest vertical illuminance of desktop is required to be 450 lx in the goal of achieving "excellent" visual comfort with a CCT of 5000 K at the same time, but we cannot achieve "excellent" area if the CCT is lower than 3700 K or higher than 6500 K. Even if there are special requests for the CCT of light source, try not to make CCT lower than 4200 K or higher than 6000 K for the sake of energy saving.
b) The yellow area is recommended as a good or acceptable area when there is less use of desktop. In this area, the lowest vertical illuminance of desktop should be limited to 140 lx with a CCT of 5200 K at the same time. Similarly, CCT lower than 3700 K or higher than 6500 K is not recommended for energy efficiency.
c) Red and dark red area are uncomfortable and awful area respectively. If the vertical illuminance of blackboard is lower than 140 lx, no matter what CCT can meet the requirement of visual comfort. Therefore, the vertical illuminance of desktop should be higher than 140 lx.

CONCLUSIONS

The quality of indoor light-environment is often difficult to evaluate directly. The research results of lighting-environment visual comfort experiment show that the light-environment quality evaluation model based on C-SVM has good interpretability, strong generalization capacity and low risk of wrong classification in the limited sample space. It can effectively identify the visual comfort level of classroom light-environment, which is also a guide to other research of light-environment quality in different space types.

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