Camouflage Effectiveness Assessment Based on Fusion with Constant Color Background

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Abstract. In the constant-color background, the structure feature is more influential in evaluation of the target camouflage effectiveness its surface is covered by the color that matches the background compared with the color feature. Against this, a method fusing the index of similarity and the index of difference is proposed. The index of similarity is designed based on texture, orientation and intensity features and described by saliency maps. The index of difference is designed based on target's own feature of straight-section edge and described by the weighted maximum entropy principle. These two features are fused to evaluate the camouflage effect. Experimental results show that our camouflage evaluation framework accords with the human visual perception mechanism.

1. Introduction

The technique of camouflage effect evaluation has a very important role in the design, implementation and optimization of the camouflage scheme[1]. With the continuous development of computer technology, the camouflage effect evaluation method based on digital image features is gradually replacing the traditional subjective-based manual interpretation method due to its advantages of high processing efficiency, strong objectivity, and low occupancy rate of human resources[2,3]. In recent years, the main contributions of relevant scholars in the field of objective camouflage effect evaluation are: Wang He designed approximate measurement indicators based on the tolerance near set theory to evaluate camouflage effect[4]; Xue F extracted background-related characteristics and target’s own characteristics to evaluate camouflage effect[5]; Lin used feature’s similarity based on image quality assessment techniques to judge the target camouflage effect[6]; Lin also evaluated the effect of camouflage with the data obtained from eyeball motion[7]; Jia Qi introduced the human eye's visual attention mechanism to establish a corresponding evaluation model[8,9]. The above methods all extract the most perceptible color information of the human visual system for the design of the effect evaluation indicator. In the case of the constant-color background (desert, jungle) and the target’s surface is covered with a corresponding camouflage color, The effect of color brightness contrast of the target and the background will be greatly reduced in the evaluation of camouflage effects.

Therefore, the paper extracts characteristic which can reflect the surface texture (called context-related characteristic) to design the quantization index of similarity with visually significant characteristic; At the same time, taking into account the target being belong to Man-made geometry,
which has its own outline edge (the target's own relevant feature) that is easily found by the human visual system. So we can extract the straight-line-segment edge features of the target and quantify the features as an indicator of the difference used the maximum entropy principle in effect evaluation.

Finally, a nonlinear fusion of the similarity index and the dissimilarity index is designed to evaluate the disguise effect of the target under the constant-color background. The results show that the comprehensive evaluation index is in good agreement with the professional interpretation results.

2. Differentiation indicators

2.1. Line-segment edge feature extraction

According to the human visual attention mechanism, the straight-line feature in the image is a typical rule that is easy to be visually noticed. It mostly appears in the surface texture and outline edge of the man-made objects in the image, and it is easier to be recognized by the human eye firstly in the natural scene mainly composed of irregular bodies[10,11]. Therefore, in the evaluation of camouflage effect, the number and length of long-straight-line segments existing in the camouflaged target edge are introduced as an important indicator for measuring the target’s camouflage effect. The specific line feature extraction process is as follows:

STEP1: Input the image with the camouflaged target(a), using the edge detection algorithm to perform edge detection, and obtain the edge processing map(b).

STEP2: Setting a set of thresholds((T1,...,Ti,...),i ∈ N) based on the sensitivity of the length of the straight-line segment in the human visual system with the Hough Transform ,straight line segments(b) under different thresholds (x,unit: pixel) extraction;

STEP3: Statistics the number of edge segments (mi) within thresholds gi : (T1, Tij] in the camouflaged areas and background areas .And note the maximum straight line length is n.

2.2. Feature quantization of line segments based on weighted maximum entropy

The principle of maximum entropy is a criterion in the learning of probability models. It is believed that the model with the largest entropy is the best model among the set of models that satisfy the constraints. This principle is widely used in the image segmentation. It is considered that the image features in the target region and the background region are similar, and when the entropy addition between the two regions reaches a maximum, the background and target segmentation are optimal[12,13].Inspired by this, the principle of maximum entropy is used in camouflage effect evaluation. The larger the total image feature entropy within the camouflaged region and the surrounding background region, the easier the camouflaged target is from the surrounding background, the worse the target camouflaging effect is, vice versa.

We get the number of edge segments(called mi) in each threshold group from the previous section , p(gi) indicates the threshold group (gi) ‘s the probability of appearance. And it is defined as (O: target area, B: background area):

\[ P_{o,b}(g_i) = \frac{m_i}{\sum m_i} \]  

(1)

The value has no effect on the target discovery probability, which is different from the characteristics of the general case processing. According to the study of Xu Shan et al, the relationship of the length of the edge segment and the probability of being discovered is a convex curve with a horizontal asymptote \( P(n) = 1 \) and \( P(1) \rightarrow 0 \). In order to meet the above requirements, we use functions \( P(x) = \log_a(x), x > 1 \) approximate expression of this relationship. Thus, the feature entropy is weighted and its weight coefficient is defined as:
\[ w_i = P\left(\frac{T_i + T_{i+1}}{2}\right) / \sum P\left(\frac{T_i + T_{i+1}}{2}\right) \]  

Then, the feature entropies of the target area (O) and the background area (B) are respectively represented as:

\[
\begin{align*}
H_O(t) &= -\sum w_i p_i(g) \ln p_i(g) \\
H_B(t) &= -\sum w_i p_B(g) \ln p_B(g)
\end{align*}
\]  

The total entropy of the target and surrounding background is:

\[ H(t) = H_O(t) + H_B(t) \]  

The greater the total entropy value, the greater the distinction between the camouflaged target and the surrounding background in the image, and the worse the target camouflage effect to be evaluated. Vice versa.

3. Similarity Indicators

Relevant studies have shown that significance is an important measure of the degree of interest in human visuals, and the regions with higher significance are more likely to cause human visual attention. Therefore, the similarity test based on the saliency metric is reasonable to use in camouflage effect evaluation. The lower the region’s significance is, the better the target’s camouflage effect is.

The specific flow of this model is shown in the following figure 1:

**Figure. 1** The flow chart of saliency extraction algorithm

Feature extraction and quantification

When evaluating a target camouflage effect coated with a corresponding camouflage color under the constant-colour background, the gradient, texture, and the brightness are used to characterize the difference between the target and the background, due to the degraded effect to distinguish between the camouflaged target and the surrounding background.

Among them, the brightness and gradient information are expressed by the corresponding histogram. Since the texture information belongs to the area information, the expression can be quantified by a statistical method based on the image gray histogram.

Significant calculation

Significant detection based on histogram contrast is used to calculate the characteristic saliency values of texture, gradient and brightness. Due to space limitations, the specific calculations can be found in paper. From this, saliency based on texture, gradient, and brightness \( S_1, S_2, S_3 \) can be obtained.

Significant fusion

The linear fusion of the saliency test results of different features, which to create the saliency-based similarity indicator:

\[ S = \left(\frac{S_1 + S_2 + S_3}{3}\right) \]
4. Camouflage Evaluation Example

4.1. Comprehensive evaluation index establishment

In order to more fully evaluate the camouflage effect of the target, we fuse the similarity index and the difference index for the comprehensive evaluation index design. The former reflects the integration of the camouflaged target with the surrounding background, and the latter reflects that the camouflaged target distinguishes itself from the surrounding background.

Since the influence of the two on the target camouflage effect is opposite, the fusion between the two is not a linear additive relationship. We consider the characteristics of the two indicators and their relationship with the camouflage effect. A multiplicative strategy of index multiplication is used to express the “and” relationship between the two indicators by multiplying the indicators. The specific expression is defined as:

$$C = \frac{S}{S + c_1} \times \frac{0.1H(t)}{0.1H(t) + c_2}$$  \hspace{1cm} (6)$$

Among them, \(c_1\), \(c_2\) are small constant values to avoid that the overall evaluation index is too large due to the small denominator. Because of the saliency, the size of the maximum entropy is inversely proportional to the disguise effect. Therefore, the greater the comprehensive evaluation index is, the worse the camouflage effect is.

The comprehensive evaluation process is shown in Figure 2. Determining the target area (target area to include the smallest circumscribed rectangle) disguised different ways in the image to be compared.

Considering that the background part far away from the target has relatively weak influence on the target detection result, eight adjacent rectangular areas of equal area around the target area are selected as the background area. The structural features of the target area and the surrounding background area are extracted and the length of the edge of the straight line segment is extracted. The saliency map is used to quantify the structural features and the improved maximum entropy principle quantifies the length of the line segment edge.

**Figure. 2 Framework of comprehensive camouflage-effect evaluation**

4.2. Example verification and result analysis

In order to test the effectiveness of the proposed comprehensive evaluation method for camouflage effect, this paper chooses to verify the method of covering different camouflage nets under a single green space background.

In a green plot, cover different systems of camouflage nets (numbers 1, 2, and 3) and use aerial photography to acquire experimental plots at the same height, as shown in the figure 3:
Figure. 3 Camouflage net of (a) No. 1, (b) No. 2, and (c) No. 3; (d) Sketch map of “target+background”

Extract the characteristics of the edge of the target and its surrounding background, according to the actual situation, let the threshold \( T_l = 1, T_r = T_{l+1} + 5 \). Due to space limitations, some of the threshold values of the lower edge straight line segment are listed as follows in the figure 4:

Figure. 4 Sketch map of straight-line edge of camouflage net NO.1 in different thresholds

The weighted maximum entropy theory is used to quantify the edges of the straight line segment of the target and the background region. The results are as shown in the following table 1.

Table 1. The saliency based on different features of camouflage targets

| Camouflage net | NO.1  | NO.2  | NO.3  |
|----------------|-------|-------|-------|
| \( H_w(t) \)   | 1.6356| 1.6279| 1.6288|
| \( H_k(t) \)   | 2.1541| 1.8728| 2.0004|
| \( H(t) \)     | 3.7897| 3.5007| 3.6292|

According to the chart, the edge lengths, sparsity, and corresponding feature entropy values of the straight line segments of the target area and the surrounding background area in the images containing the camouflage network are different, which verifies that the straight line segment edges can be used for index design to reflect the difference between the target and the background.

Different camouflage networks correspond to different total entropy values, which indicates that the total entropy value can be used as a dissimilarity index and then a similarity index to evaluate comprehensively when evaluating the camouflage effect of the target.

The saliency map is obtained using the distinctive features of the disguised target, and the saliency of the target and the surrounding background is quantified. The specific results are as follows in the figure 5 and the table 2:

Figure. 5 Sketch map of saliency based on features fusion with camouflage net of (a) No. 1, (b) No. 2, and (c) No. 3

Table 2. The saliency based on different features of camouflage targets

| Camouflage net   | NO.1  | NO.2  | NO.3  |
|------------------|-------|-------|-------|
| Color            | 0.1607| 0.1745| 0.1562|
| Texture          | 0.4216| 0.2291| 0.2981|
| Intensity        | 0.3643| 0.1962| 0.3057|
| Orientation      | 0.3514| 0.2561| 0.2886|
| Features fusion  | 0.3791| 0.2853| 0.2975|
As can be seen from the table, the three camouflage networks have little discrimination based on the saliency indicators of the color features, and cannot effectively evaluate the camouflage effect of different camouflage nets under the background of the green space; and the saliency detection results of the fused textures, directions, and brightness characteristics. The three kinds of camouflage nets in the value have a high degree of discrimination, and it is easier to describe the different targets more completely and reasonably than the saliency of a single feature.

Fusion indicators and similarity indicators were used to obtain comprehensive evaluation indicators, as shown in the following table 3:

Table 3. Index of comprehensive evaluation and comparison

| Camouflage net | NO.1   | NO.2   | NO.3   |
|----------------|--------|--------|--------|
| Ours           | 0.9491 | 0.9392 | 0.9419 |
| Visual result  | Bad    | Excellent | Good |

From the table 3, we can see that the proposed method extracts features related to the image structure: texture, direction, edge line segments and brightness, and the results of reasonable quantification and fusion have good consistency with the interpretation results.

5. Conclusions
We present a new method for evaluating the camouflage effect of multiple targets in a single color background. The method highlights the role of structural features and considers both positive and negative aspects of similarity and difference. The test results prove the validity of the method, can replace the subjective artificial interpretation method to evaluate the target camouflage effect, and make up for the insufficiency of the existing methods to evaluate the failure under a single color background. This article still has the problem of noise interference in the process of extracting the edge line segment, and hopes to further solve it in the future research. The method has certain reference significance for the detection of camouflage effect based on infrared images and is reflected in the next research work.

References
[1] Yunhui Y, Zhan W, Dong Dewei, et al. Current Actuality and Development Tendency of Military Camouflage Technology[J]. China Mechanical Engineering, 2012,23(17): 2136-2141.(CHINA)
[2] ZHAO Dehui, WANG Pengye, DONG Zongge, LI Mingfeng. Optical Camouflage Effectiveness Assessment Fusing the Different Features[J]. Journal of air force engineering university(natural science edition).(CHINA)
[3] Guo Tong,Hua Wenshen,Liu Xun,Liu Xiaoguang,Cui Zihao.Comprehensive Evaluation of Optical Camouflage Effect Based on Hyperspectra[J].Laser & Optoelectronics Progress,2016,53(10):101002.(CHINA)
[4] Wang He, Bai Tingzhu. Evaluation of Optical Camouflage Based on Tolerance Nearness Sets Theory[J]. Acta Optica Sinica, 2012, 32(12): 1210001. (CHINA)
[5] Xue F, Wu F, Wang J, et al. Camouflage texture design based on its camouflage performance evaluation [J]. Neurocomputing, 2017.
[6] Lin CJ, Chang CC, Lee Y H. Evaluating camouflage design using eye movement data[J]. Applied ergonomics, 2014, 45(3): 714-723.
[7] Lin CJ, Chang C, Lee Y, et al. Evaluating camouflage design using eye movement data.[J]. Applied Ergonomics, 2014, 45(3): 714-723.
[8] Qi J, Xuliang L, Chao W, et al. Evaluation of engineering camouflage effectiveness based on human visual attention mechanisms[C]. International Conference on E-business and E-government, 2011: 1-4.
[9] Jia Qi, Lü Xuliang, the Chao Wu, et Al. Camouflage Evaluation of FFectiveness the using Human Visual Attention mechanism [J]. Journal of Applied Sciences, 2011, 29 (3): 294-298. (CHINA)

[10] Hou Yimin, Tang Yue, Sun Xiaoxue, Sui Wenxiu. Application of Gaussian-Rayleigh Mixture Model in Remote Sensing Image Segmentation [J]. Acta Optica Sinica, 2015, 35(s1):s110004. (CHINA)

[11] Zhang Zhenjie, Hao Xiangyang, Liu Songlin, Cheng Chuanqi. Line Detection Based on Hough One-Dimensional Transform [J]. Acta Optica Sinica, 2016, 36(4):0412005. (CHINA)

[12] Sun Xiaoyan, Dong Huailin, Wang Beizhan, Su chuangye. Region-based segmentation method of ships in remote sensing image [J]. Computer Engineering, 2008, 34(10):196-198. (CHINA)

[13] Chen L, Chen X, Wang S, et al. Foreign Fiber Image Segmentation Based on Maximum Entropy and Genetic Algorithm [J]. Journal of Computational Chemistry, 2015, 03(11): 1-7.