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Camouflage Assessments with Digital Pattern Painting Based on the Multi-Scale Pattern-in-Picture Evaluation Model

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Abstract
In general, traditional evaluations of target camouflage effects are usually conducted based on observational data and general results of statistical analysis. This widely applied methodology quantifies the detection and identification probabilities of camouflage objects but has considerable shortcomings. This data evaluation process is laborious and time-consuming and very low in reproducibility, which sheds light on the necessity of developing a more efficient method in this study field. The growth of computer-aided image processing technology provides technical support for camouflage effect evaluation based on digital image processing. Digital pattern painting, which has been previously applied to combat utility uniforms, is a new methodology full of potential due to its broad geographical adaptability. This study proposes a multi-scale pattern-in-picture method to evaluate camouflage effects at different distances. We also established a computer-aided background image library and camouflage assessments with digital simulation and created an evaluation system that could be effectively applied to combat utility uniforms. More than 40 testers participated in this study, who were asked to score the designed camouflage schemes using the evaluation system proposed. The data from simulation assessments and individual evaluations show that the computer-aided simulation assessments conducted as part of this research can efficiently and objectively evaluate the camouflage effect on military objects.

Keywords
computer-aided, camouflage assessment, pattern painting, evaluation, simulation, military camouflage.

1. Introduction

The extent of the integration of spot shapes, sizes, colours, and spatial distributions is the key criterion to evaluate the effect of camouflages. Experiments on animal predatory activities [1, 2], simulated animal behaviors [3, 4], and the mechanisms of squid discoloration [5-7] have demonstrated that simulated camouflages can be used in studies focused on the evaluation of camouflage effects [8]. Traditionally, in camouflage effect evaluations, testers are organised to observe the targets under field conditions, and the detection and identification probabilities of these target objects under camouflage are quantified based on statistical analysis results. However, this time and labor-consuming method is disadvantageous due to its operation, low convenience, and high costs.

However, the adaptive trials face many obstacles when encountering time and financial limitations if some external conditions change. Also, the test results are insufficient to objectively reflect camouflage's adaptability in a war zone. Numerous studies have been conducted to seek workable and effective methods to evaluate camouflage effects, including those integrating object detection [9], target-background similarity metrics [10], color pattern strategies [11], self-organizing background subtraction [12], and spatiotemporal optical blob reconstruction [13]. Yao et al. [14] studied adaptive image camouflage with a human visual system model. Juarez-Sandoval et al. [15] developed an innovative digital image ownership authentication strategy via camouflaged unseen-visible watermarking. Yang et al. [16] proposed a fused evaluation index for camouflage patterns based on human visual perceptions. Liu et al. [17] developed a method for extraction of the dominant background color(s) based on the algorithm of color image fast fuzzy c-means clustering.

A photo simulation system was developed in Austria [18] and has proved to be perfectly applicable in evaluating camouflage effects. The first step in using the system is to collect a variety of field pictures, which are subsequently displayed by three projectors on a space of 9 lattice screens. The three projectors used at this stage of the process serve different purposes. Projector 1 is mainly used to project slides of objects, either with or without actual objects. Projector 2 shows superposition grids, and projector 3 displays the pause slide (relaxing scene). After that, the participants observe the images on the projection screen and use a 9-key keyboard, where each key corresponds to a lattice field on the projection screen, to record their observation results and time spent. The US military once used a different methodology and applied virtual reality to evaluate camouflage effects dynamically [19]. In this specific experiment, the scenes in this evaluation were shot in real camouflage situations with a focal length of 35 mm. The image of each group went through three different editions, allowing the researchers to obtain: (i) an original image of the stationary target, (ii) a computer-made image of the moving target, and (iii) a non-target image after erasure. Furthermore, German scholars developed a real-time computer-aided camouflage assessment system (CART, Camouflage Assessment in Real-Time)

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[20, 21] that could effectively identify and track many objectives. Similarly, the Visual Perception Laboratory (VPL) in the US used professional software combined with three high-resolution projectors (up to 52342 × 6000 pixels) to display a 180-degree circular screen image to evaluate camouflage effects [22, 23]. Some analog evaluation studies were also carried out by researchers from home and abroad [24-26], and the majority of these reports were based on a limited number of pictures. Moreover, most of the evaluation results of camouflage effects were drawn after the observations were statistically analyzed.

Deformation camouflage spots based on the generative adversarial network model provide new insights into design deformation camouflage patterns, allowing to evaluate their camouflage effects [27]. Hall et al. [28] used a two-alternative forced-choice paradigm to design camouflage patterns and concluded that if only a very short time of stimulus presentation is present in the task, task-specific training is irrelevant to the success of target detection. This conclusion makes the paradigm particularly suitable for the robust estimation of camouflage efficacy.

Considering the outcomes of previous relevant research, we calculated the detection probability in the evaluation of camouflage effects based on statistical results of the observations reported by our testers. As computer-aided techniques develop at full speed, digital pattern painting has emerged as a new and more effective pattern painting camouflage strategy, able to simulate the special coarseness and 3D undulation of natural backgrounds. This paper proposes an assessment system integrating digital pattern painting simulations at different distances. It is essential to clarify that, before assessing the camouflage, we had to perform the color reduction of images captured by digital cameras to alleviate color differences. Then, we constructed a pattern-in-picture evaluation model and simplified the "soldier", simulating the body with a camouflaged rectangle. This step was conducted to better evaluate the camouflage effect of digital pattern painting conveniently at different distances. The participants were instructed to use the simulation system to score the designed camouflage schemes. Our experimental results show that the method proposed is effective and suitable for quantitative evaluation of the camouflage effect.

One of the main features of evaluating the camouflage effect is that it is closely related to color. We first examined previous color reproduction experiments to accurately obtain the color stimulus values of the target and background. After considering their results, we could describe the multi-scale pattern-in-picture evaluation model in detail and explain it by taking an individual soldier as an example. Then, the model was used to optimize various individual camouflage design schemes. In order to verify its accuracy, we organized observation experiments for different individual camouflage design schemes. Our outcomes and observation data prove that the multi-scale, pattern-in-picture evaluation model suits our purposes and could be successfully used for camouflage evaluation with accuracy.

2. Color Reproduction

As the high-tech electronics industry develops rapidly, digital cameras are widely used in data collection and evaluating color features of backgrounds and objects. However, there is a big difference between the colors captured by digital cameras and the natural tone, which can directly affect the effectiveness of camouflage assessments. The captured colors must be exact to measure the color differences more accurately. Ideally, the colors captured by digital cameras are the same as those standard colors in the color spectrometer laboratory, established based on the human eye's perception. However, due to some real-world difficulties, we still needed to perform color reduction in the images captured by digital cameras to upgrade the quality of our camouflage assessments.

The color checker passport, developed by X-Rite, is composed of color cards, gray balance cards, white balance cards, and three-level gray cards. In the 2.25 × 3.25-inch (5.715 × 8.255 cm) color cards, 24 color patches are carefully selected and arranged as 4 × 6 columns, and the color values can be obtained on the company website [29]. The passport's support software enables color correction and reproduction, and these procedures are often applied in many areas of image processing.

We manually constructed the test color samples and coating materials used in our study, with the size of a color sample being 100 × 100 mm. Each sample contained 12 swatches (Fig. 1), and all samples were sprayed twice with a spray gun. The colors were carefully selected to represent different typical natural backgrounds, such as concrete, woodlands, grasslands, and yellow lands. The color values of the samples are given in Table 1. The L*a*b* mode is a color mode published by the International Commission on Lighting (CIE) in 1976. The L*a*b* mode consists of three channels, the first channel being the lightness, or "L*". The color of channel a* ranges from red to dark green; Channel b* is from blue to yellow.

In 2015, a comparative experiment on color reproduction was conducted on the outskirts of Nanjing using a Canon EOS 450D digital camera and Shimadzu UV-3600 spectrometer. The test color samples were composed of 12 color planks (100 × 100 mm), and the color difference was calculated by the CIEDE2000 color difference equation [30, 31]. The CIEDE2000 formula was released by CIE in 2001. This formula was developed by members of the CIE Technical Committee and provides an improved procedure for calculating industrial color differences. Color value measurements were made by averaging all the values within the target region. Then, we performed compatible comparisons of color differences between reproduced colors and standard values (Table 2) based on calculations using the CIEDE2000 color difference equation in the CIE Lab color space. The ratios of color difference reduction between the reproduced colors and the standard values are shown in Table 3.



Fig.1 Test color samples

Sample number	Sample	CIE 1976 L*a*b*		
		L*	a*	b*
1	Black	29.23	0.17	-1.57
2	Gray	46.39	-0.36	-3.68
3	Light white	64.52	0.67	1.65
4	Black green	31.92	-1.94	3.03
5	Dark green	34.97	-4.08	11.19
6	Green	43.89	-13.27	18.41
7	Yellow green	46.16	-3.38	27.62
8	Dark brown	42.08	5.37	15.19
9	Red brown	44.67	14.29	25.70
10	Brown	45.18	9.79	22.83
11	Clay	54.63	17.39	25.67
12	Ocher	55.49	13.54	42.32

Table 1. Color values of the samples

It can be seen from Table 2 and Table 3 that there is a significant difference between the test color values of the digital pictures and the standard values. The average color difference is 12.68, with a standard deviation of 4.28, which is more than enough to affect the accuracy of camouflage assessments. However, with color checkers, both the average color difference and its standard deviation decreases significantly, suggesting the effectiveness of color reproduction via color checkers. However, even though the 24-color color checker passport has great potential in real-world applications, it still cannot perfectly adapt to the 12-color samples. Consequently, the color difference must be greater than zero, and these color samples are not well-distributed in general. In other words, errors are inevitable in color reproduction, making it less satisfactory in terms of accuracy.

3. The pattern-in-picture evaluation model

For a soldier wearing a combat utility uniform, the biggest exposure surfaces appear when standing face to face or back to face, which is when the camouflage effect of the pattern painting should be evaluated. A simplified simulation of a standing soldier wearing a combat utility uniform was developed to perform such evaluations on a computer. Fig. 2 demonstrates that the soldier and his physical features are according to the average: height of 1.85 m, weight of 75 kg, and shoulder width of 0.42 m.

A soldier wearing woodland camouflage uniforms is demonstrated in Fig. 2 (a), whose maximum body width in camouflage is 0.60 m. To simplify the process, we established that a standing man in a camouflage uniform could be represented by a rectangle of 0.42 × 1.54 m or 0.60 × 1.85 m. To properly represent the maximum exposure area of a standing soldier, a rectangle of 0.42 × 1.54 m was chosen for simulation (Fig. 2 b and 2 c). It can be concluded from Fig. 2 (a) and 2 (c) that the rectangular simulations are feasible in the evaluation of camouflage effects with computers.

The design of a soldier's pattern painting should adapt to the threat of reconnaissance in different ways from various distances. With optical reconnaissance devices, an object can be observed clearly from a far distance, but it can also be observed more closely by the naked eye. Currently, many reconnaissance devices are available in the market, so the concept of an equivalent observation distance was used to minimize the influence of the viewing distance. The standard distance range we considered in this paper was 10 m ~ 100 m. It is noteworthy that the camouflage effect can be evaluated by selecting a specific distance or all equivalent reconnaissance distances, and detection threats at different distances can be assigned varying weights. We examined camouflage effects at various distances but with the same weight.

A Canon EOS 400D was used to take photos for camouflage effect assessments (Fig. 3), and the standard photo size was set at 3888 × 2592 pixels. The simulated soldier was 1.80 m (556 pixels) tall and 0.60 m (185 pixels) wide in the picture. The observation effects from different distances are shown in Fig. 4. Table 4 shows the sizes of simulated "soldiers" and their corresponding simulation boxes at different equivalent observation distances.

Here, grouping was used to compare 15 digital camouflage pattern painting schemes according to their texture styles. The schemes were divided into three groups (Group 1, 2, and 3). Subsequently, two schemes with better camouflage effects were selected from each group for comparison.

The schemes designed A-O are shown in Fig.5. Fig. 6 illustrates the simulation

Number	1	2	3	4	5	6	7	8	9	10	11	12	Average	Standard deviation
Testing	6.23	17.53	15.18	4.59	7.61	12.79	16.50	12.13	15.01	16.21	15.09	13.31	12.68	4.28
Color checker	1.01	8.95	8.32	3.02	4.78	7.32	8.09	7.36	8.37	6.31	7.21	6.17	6.41	2.38

Table 2. Color reproduction accuracy with color checkers

Number	1	2	3	4	5	6	7	8	9	10	11	12	Max.	Min.	Average
Color checker	83.79	48.94	45.19	34.20	37.19	42.77	50.97	39.32	44.24	61.07	52.22	53.64	83.79	34.20	49.46

Table 3. Ratio of color difference reduction

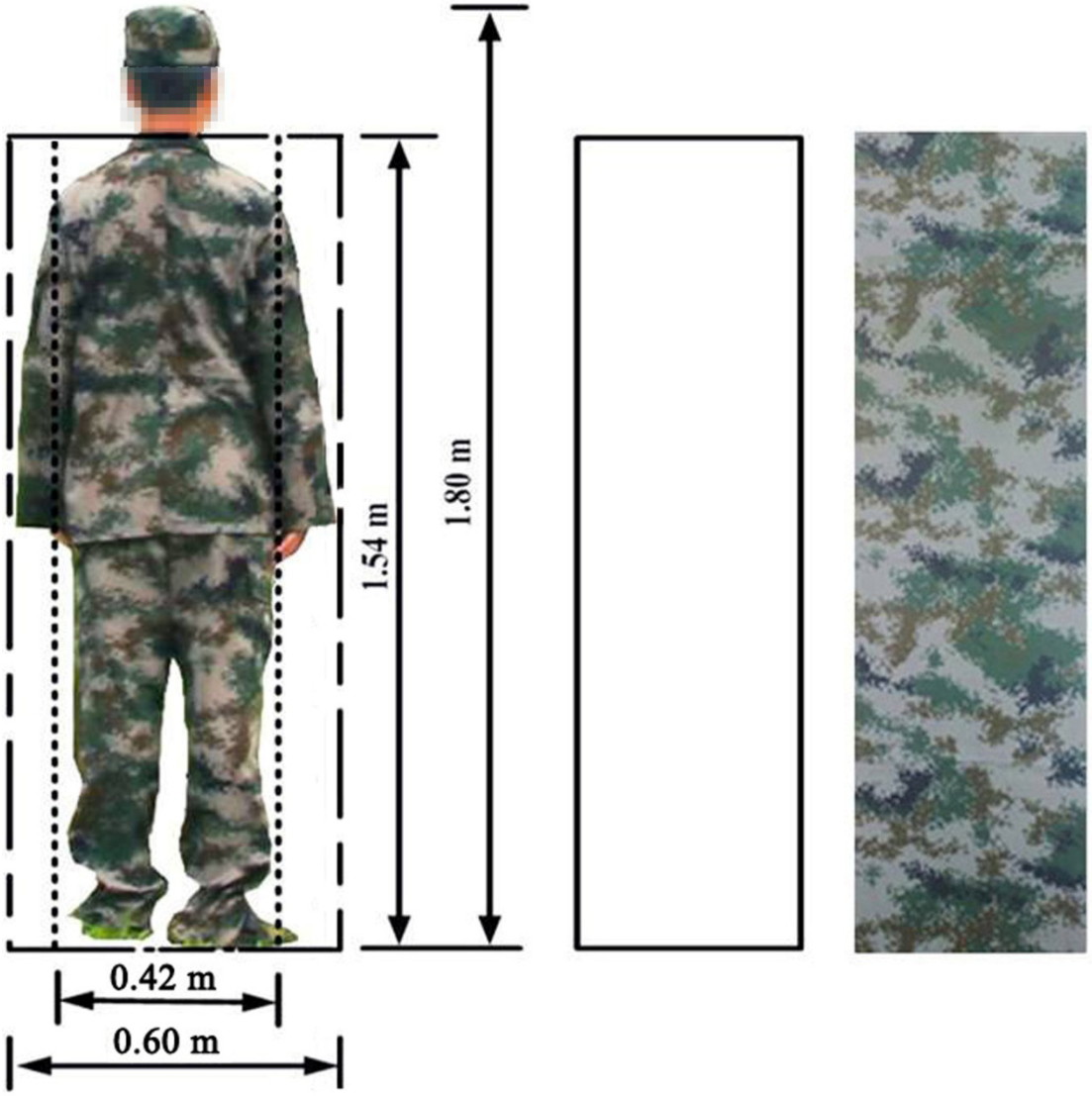


Fig.2 Simplified simulation of camouflages



Fig.3 Picture taken by the digital camera at an equivalent observation distance of 10 m

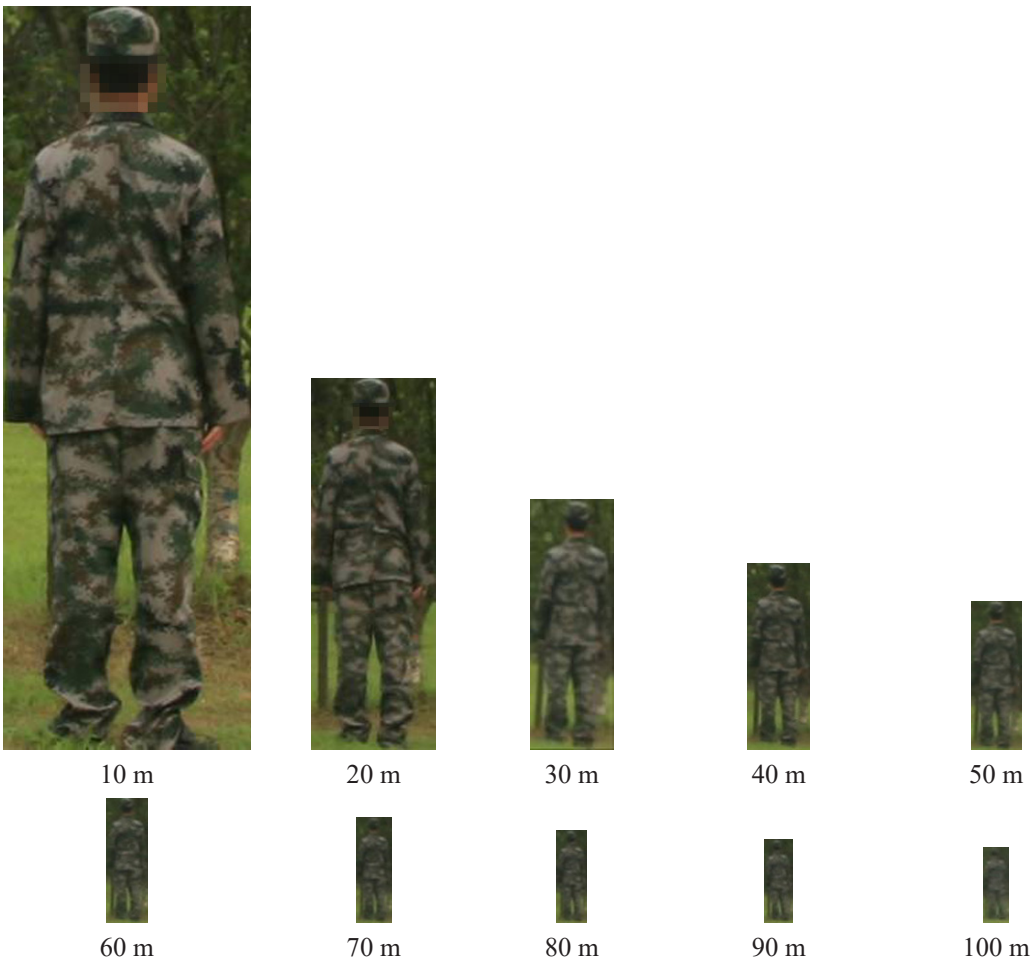


Fig.4 Observation effects from different distances

Distance / m	10	20	30	40	50	60	70	80	90	100
Size / pixels	185×556	93×278	62×186	46×139	37×111	31×93	27×80	23×70	21×62	19×56
Box / pixels	130×476	65×238	43×159	33×119	26×95	22×79	19×68	16×60	14×53	13×48

Table 4. "Soldier" sizes and their corresponding simulation boxes from different distances

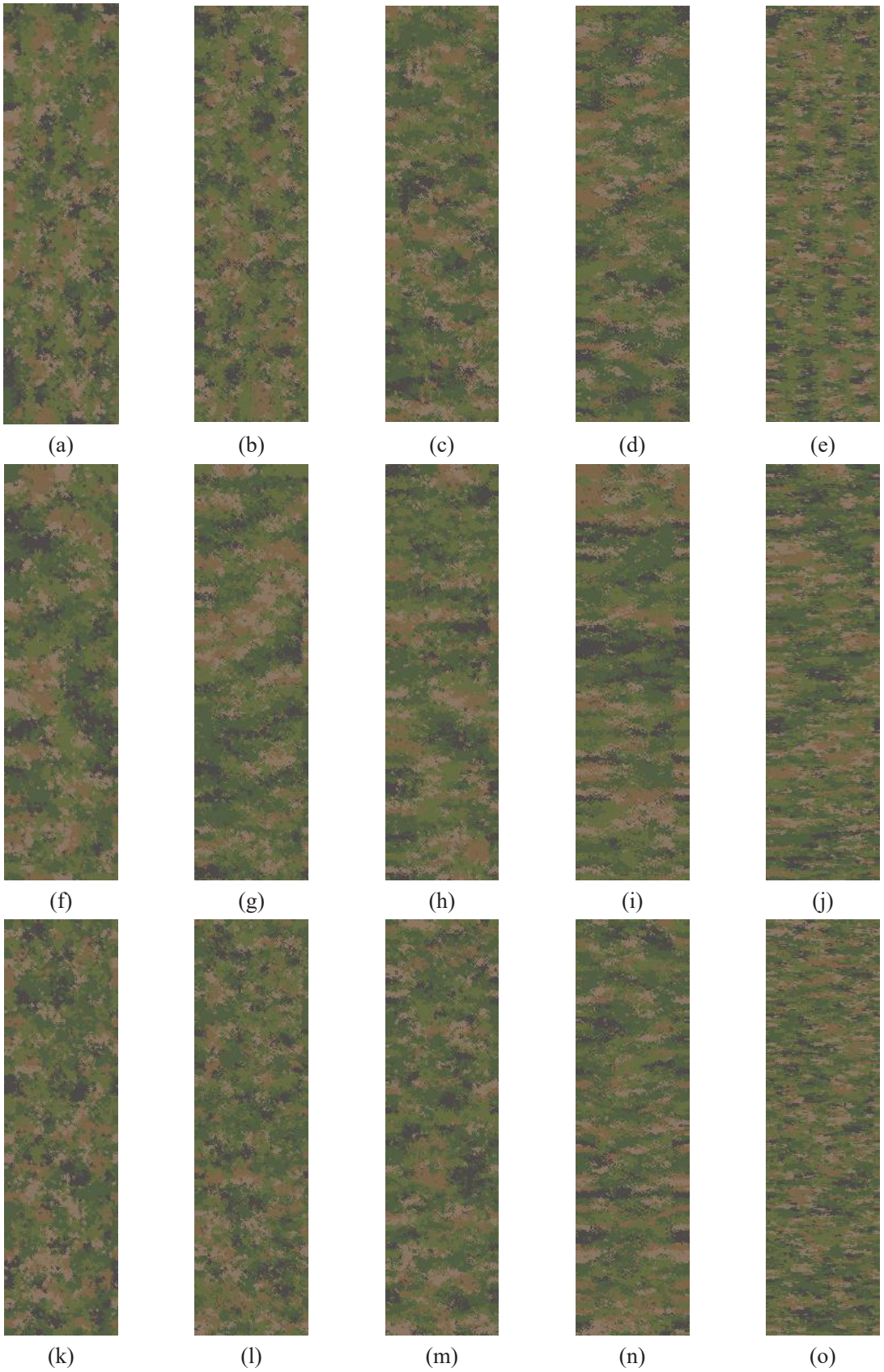
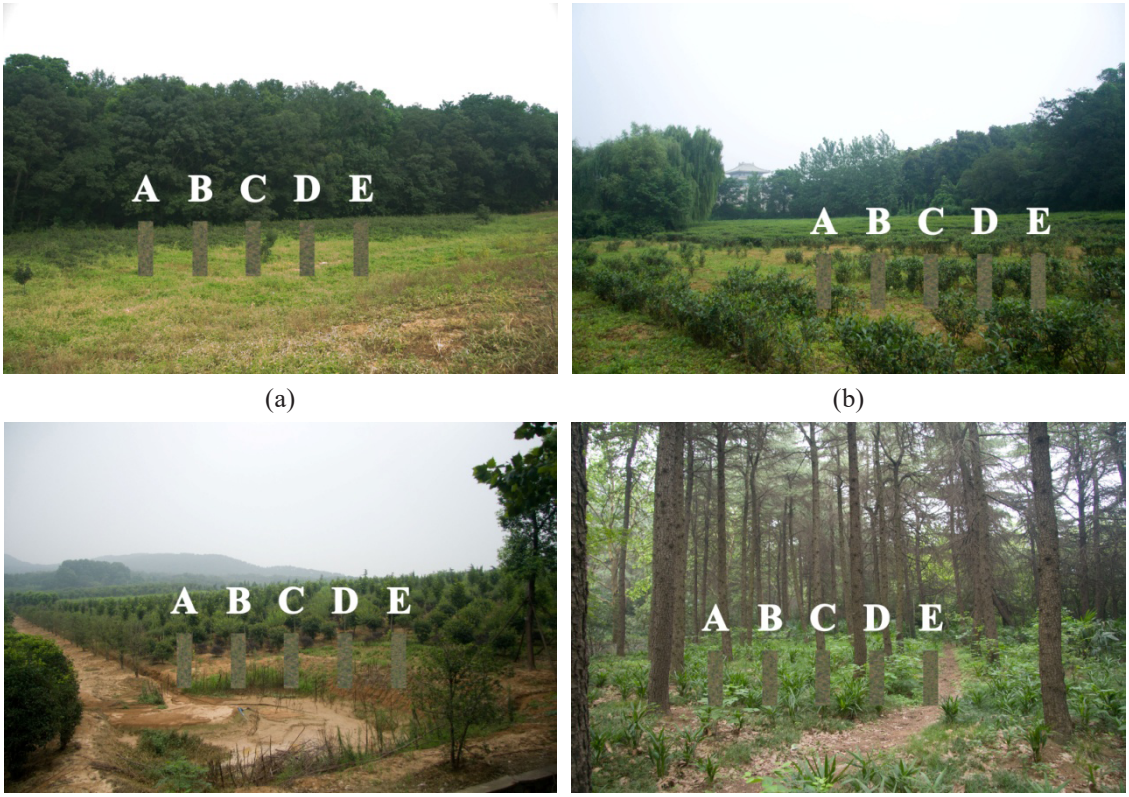


Fig.5 Schemes designed



(a) (b) (c) (d)

Fig.6. Simulation effect of group 1 in four images of mottled woodland backgrounds

effects of group 1 in four images with mottled woodland backgrounds. For convenient illustrations, several pairs of typical experimental images with woodland backgrounds were chosen to be displayed. Still, the actual experimental data were calculated based on the results from numerous photos. A model of the degree of feature similarity was constructed on the descriptor to quantitatively evaluate the degree of amalgamation between the target and the background in terms of brightness, color, and spatial distribution [32, 33]: (i) combine brightness, orientation, and color difference to obtain a visual attention interest map; (ii) quantify the shift process of visual attention focus based on the gray level difference of interest images; (iii) calculate the argument and amplitude of each pixel within a square target area centered on the visual focus; and (iv) define the feature distribution similarity between the target and background based on the components of the overall amplitude of the region. When evaluating the camouflage effect of a target, the feature similarity is defined by adjacent areas of the target area. The greater the feature similarity between the target area and background area, the better the fusion effect of the target area and the background in terms of shape, color, brightness, and spatial distribution. On the contrary, the smaller the feature similarity, the greater the characteristic difference between the target and the background. With this model, we could calculate the degrees of feature similarities of each scheme in each image, as well as the average degree of all schemes. The projects were sorted within each group, and the calculated results are shown in Table 5. The characteristic similarity degree quantifies the fusion effect between the design camouflage pattern and the background. To be more persuasive, we used four typical forest background scenarios to calculate the characteristic similarity degree between each scheme and the background, and then took the average value as the average characteristic similarity degree of the scheme. Each scheme is ranked based on the average value of the characteristic similarity degree. The characteristic similarity degree represents the fusion effect between the target and background. The greater the characteristic similarity degree, the better the fusion effect of the two, and the better the camouflage effect. Therefore, those with a high characteristic similarity degree have good camouflage effects and are ranked high.

As shown in Table 5, based on their average degrees of feature similarities, the six optimal schemes selected for comparison from 20 background images were C and D in group 1, H and I in group 2, and M and N in group 3. The six optimal schemes were put together, and their similarity degrees were calculated and compared. The degrees of feature similarities of the six optimal schemes are shown in Table 6.

As can be seen from Table 6, the six optimal schemes showed very close degrees of feature similarities, with a difference range of 0.0030. Based on such

Group	Scheme	Characteristic similarity degree					Sorted within groups
		Background a	Background b	Background c	Background d	Average	
1	A	0.6003	0.6038	0.7056	0.6045	0.6285	3
	B	0.5983	0.6018	0.7008	0.6021	0.6258	4
	C	0.6108	0.6145	0.7247	0.6155	0.6414	2
	D	0.6273	0.6315	0.7529	0.6324	0.6610	1
	E	0.5928	0.5961	0.6914	0.5966	0.6192	5
2	F	0.5855	0.5886	0.6770	0.5888	0.6100	4
	G	0.5863	0.5894	0.6786	0.5896	0.6110	3
	H	0.6062	0.6099	0.7149	0.6102	0.6353	1
	I	0.5966	0.5999	0.6986	0.6006	0.6239	2
	J	0.5803	0.5833	0.6671	0.5834	0.6035	5
3	K	0.5865	0.5897	0.6788	0.5899	0.6112	5
	L	0.5956	0.5990	0.6957	0.5992	0.6224	3
	M	0.5963	0.5998	0.6970	0.6000	0.6233	2
	N	0.6182	0.6222	0.7363	0.6227	0.6498	1
	O	0.5871	0.5903	0.6799	0.5905	0.6119	4

Table 5. Degrees of feature similarities of 15 schemes

Group	1		2		3	
Scheme	C	D	H	I	M	N
Average characteristic similarity degree	0.5183	0.5206	0.5210	0.5183	0.5180	0.5197
Sorted	4	2	1	4	5	3

Table 6. Degrees of feature similarities of the six optimal schemes

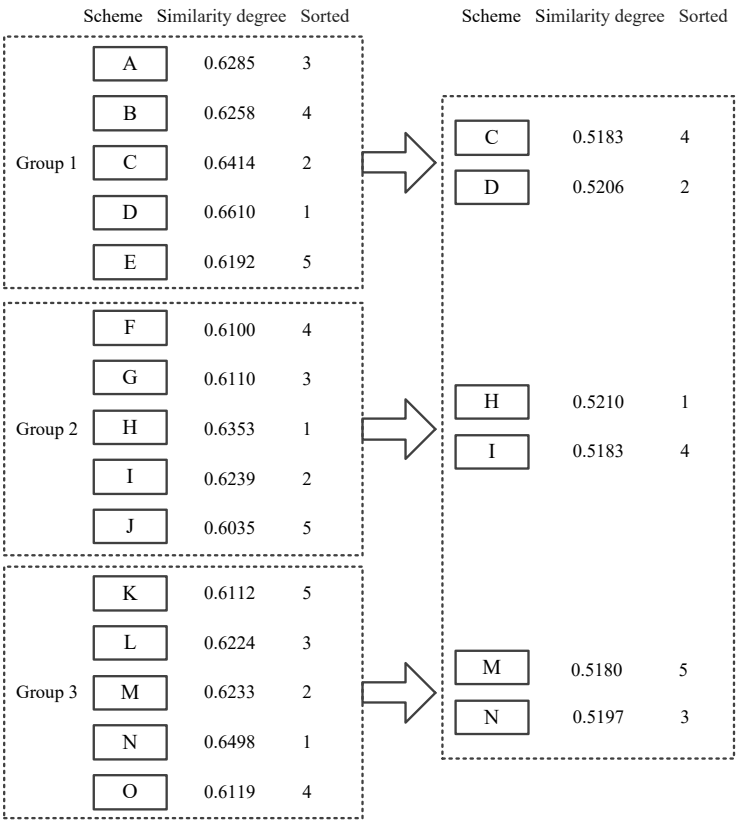


Fig.7. Flow of scheme selection

results, the three schemes selected for further comparisons were H, D, and N, in which the optimal one was H of Group 2. The whole process of scheme selection is shown in Figure 7, which illustrates the flow of optimal scheme generation.

The 15 schemes were sorted and selected based on their degrees of feature similarities. However, the optimal scheme determined by calculation still needed further experimental verification. Therefore, the individual digital camouflage simulation and evaluation experiments were organized as follows.

4. System for simulation and evaluation of individual digital camouflages

The digital camouflage pattern painting on combat utility uniforms should adapt to a broad background, which means the number of samples must be enough. The system for simulation and evaluation of individual digital camouflages should be

established based on randomly retrieved background images from a sufficiently representative database.

In the process, we used the figure of a standing soldier, which could be simplified as a camouflage rectangle of the same size, and the designed pattern painting was pasted onto the rectangle within the background image. After that, we could adequately simulate the effect of the camouflage combat uniform, which is displayed in the blue box in Fig. 8. To obtain an intuitive comparison of different camouflage patterns and their camouflage effects, the position of the "soldier" and the background were identical. Moreover, some minor factors were eliminated, and the standing personnel was represented by an equivalent box. In addition, two different schemes were pasted on one background image and put in two separate blocks on a screen. Subsequently, testers were organized to select the scheme with better camouflage effects, and the selection results after multiple tests were used to assess the simulated camouflage effects.

Fig. 9. Illustrates the user interface system constructed based on the dynamics described above. As can be seen, two schemes displayed left and right with the same position and background were observed simultaneously, thus the camouflage effect of the two schemes could be adequately evaluated and scored. It can be divided into two parts: the upper part is where the images are displayed, which is divided into two sub-regions of the same size; and the lower part is where the images are controlled, which is also divided into two sub-regions, i.e., the evaluation area (on the left) and the image reading and control area (on the right). At this stage, we used two different evaluation and assessment rules. The first one was used to score the two schemes according to the Likert Scale (very poor, poor, fair, good, and very good), and people were assigned to give 1, 2, 3, 4, or 5 points, respectively. Subsequently, we analyzed the pros and cons of the two schemes. We were able to draw the evaluation results of the schemes designed after recording the schemes' parameters.



Fig.8. Designed pattern painting on background images for effect simulations

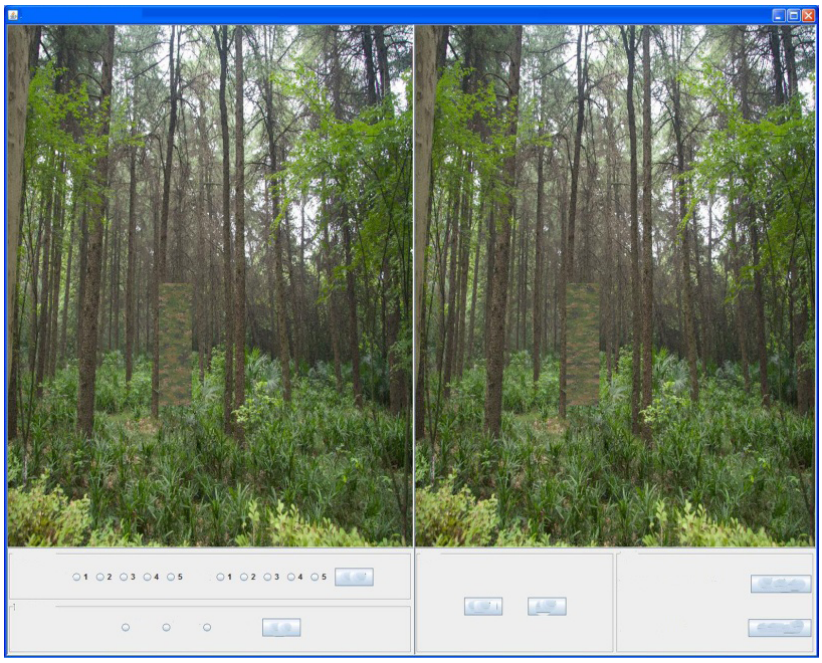


Fig.9. User interface of a system constructed for the simulation and evaluation of individual digital camouflages

Several tests of simulation assessments were performed on the designs of digital camouflages for soldiers in Nanjing in December 2015. The background images were randomly chosen from a database of 560 woodland pictures, and the images pasted on the background images were designed by the 15 schemes mentioned above. Forty-three people participated as testers, and participants were divided into three groups (Group A: 19 undergraduates; Group B: 19 undergraduates; and Group C: 5 postgraduates). The Likert Scale was used to quantify the camouflage effects in the experimental evaluations. A background image and two different schemes were randomly selected, then the patterns in the pictures were projected on a screen of 120 inches, 4:3, 2438 × 829 mm using a Hitachi HCP-340X projector (Fig.10). The projector was calibrated by an X-rite

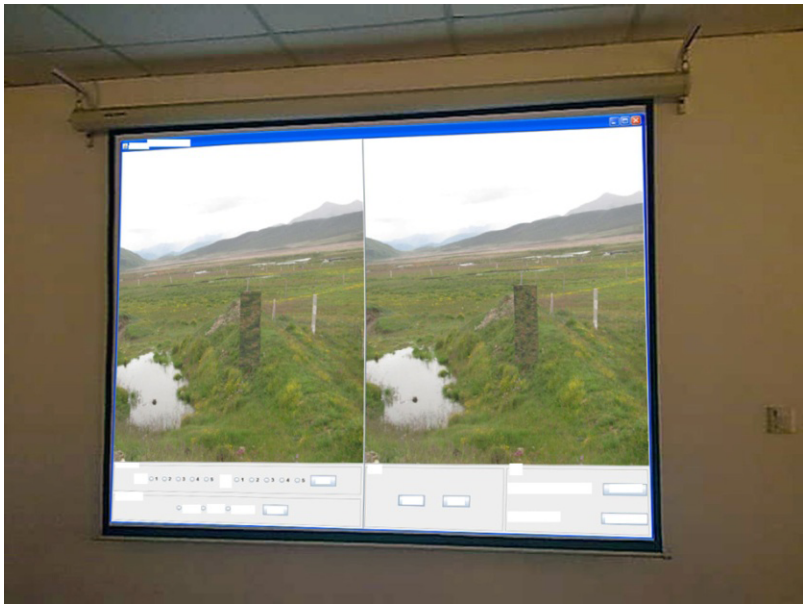


Fig.10. Patterns in pictures displayed on the projection screen

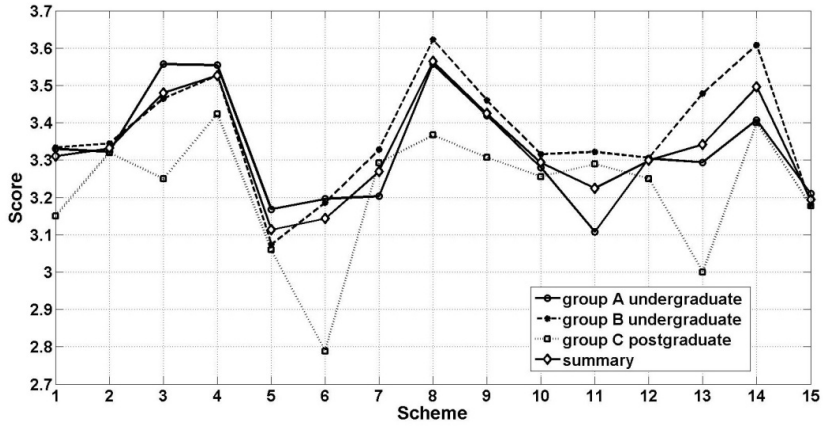


Fig.11. Simulation evaluation results

Group	Scheme	Characteristic similarity degree model		Simulation evaluation	
		Similarity degree	Sorted within groups	Score	Sorted within groups
1	A	0.6285	3	3.3105	4
	B	0.6258	4	3.3318	3
	C	0.6414	2	3.4793	2
	D	0.6610	1	3.5263	1
	E	0.6192	5	3.1132	5
2	F	0.6100	4	3.1433	5
	G	0.6110	3	3.2694	4
	H	0.6353	1	3.5639	1
	I	0.6239	2	3.4241	2
	J	0.6035	5	3.2930	3
3	K	0.6112	5	3.2245	4
	L	0.6224	3	3.2985	3
	M	0.6233	2	3.3419	2
	N	0.6498	1	3.4961	1
	O	0.6119	4	3.1932	5

Table 7. Comparison of results of degrees of feature similarities and simulation evaluations

i1 Display Pro, a color correction device to alleviate color aberration. Then, the testers were asked to observe and score the two schemes within 30 seconds. The total number of tests was 100, which gave us a simulation evaluation dataset containing 4300 data points.

5. Data analysis

Fig. 11 illustrates the average of 4300 simulation evaluation data points after calculation. The figure schemes numbered from 1 to 15 correspond to the schemes from A to O in the illustrations above, Table 5, Fig. 5 and Fig. 7.

As can be seen, the variation range of the evaluation scores was as small as 0.83, suggesting the 15 schemes selected shared the same color configurations. Besides, the score differences among the three groups were also not very significant, and the final scores showed a similar variation trend despite some slight variations in their maximum values. Judging from the scores, the optimal schemes were scheme D in Group 1, scheme H in Group 2, and scheme N in Group 3.

Table 7 shows a comparison of results of degrees of feature similarities and simulation evaluations. We interpret that the sorted results were basically the same, and the best schemes in each group were identical. These two features can confirm the validity of our mixed methodology.

6. Conclusions

This study puts forward a novel pattern-in-picture evaluation model and a system for individual digital camouflage simulation and evaluation. Specifically, the evaluation model is a promising tool for military applications and may upgrade the current methods used to select and plan camouflage schemes. Furthermore, the amalgamation degree between the target and its surrounding backgrounds in brightness, color, and space distributions was used to evaluate the camouflage effects quantitatively, using the model of degrees of feature similarities as a base. Then, 15 designed schemes were sorted

and selected by the calculation model, which needs further verification.

Our arrangements helped us conduct effective simulation and evaluation experiments for individual digital camouflages, and we came to the conclusion that the best schemes in each group were identical to those obtained from the two simulation methods. Prior to this stage of our research, their validity was confirmed by the degrees of feature similarities and the Likert Scales. The background images used in this paper were woodland-type pictures, and we purposely excluded desert and grassland backgrounds as we found that they produce consistent conclusions.

It is equally important to acknowledge the shortcomings of our evaluation process based on the simulation procedures we conducted. Firstly, we identified that evaluation experiments on camouflage effects may require a dual display, which guarantees that the two contrast pictures are not compressed or distorted, giving a better display effect. Secondly, ordinary projectors have a serious color distortion problem, which would affect testers' judgment to some extent. Therefore, a professional projector should be used to guarantee the accuracy of experimental results. The multi-scale pattern-in-picture evaluation model can be widely used in camouflage assessments for multiple targets in a variety of backgrounds.

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