Evaluation of the effectiveness of camouflage patterns using visual methods based on target detection time and distance surveys

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ABSTRACT

Evaluation of camouflage effectiveness is the final step in research to create a set of camouflage products, for a scientifically based evaluation of the effectiveness of a set of camouflage products. In the article, the authors present a method for evaluating camouflage effectiveness experimentally based on the visual assessment of 10 observers in 2 stages: in the laboratory and in the field, from which the most suitable patterns are selected. The results after the survey determined 01 most suitable pattern for each background, with the shortest target detection range in mountainous terrain being L = 35 m (pattern R5), with the shortest target detection range in urban terrain being L = 30 m (pattern D1). The research results will be used to develop a complete camouflage effectiveness evaluation process.

Keywords: Camouflage effectiveness; Camouflage pattern; Visual evaluation; Target; Background; Observer.

1. INTRODUCTION

Evaluation of camouflage effectiveness is an important step in drawing conclusions about a complete camouflage system. The design and optimization of camouflage patterns are considered the opening step in perfecting a set of camouflage products, but whether that set of products will be as effective as expected or not depends entirely on whether the evaluation of camouflage effectiveness in the final steps is accurate, detailed, specific [1, 2]. Research on selecting appropriate camouflage pattern textures for camouflage outfits is considered to have the potential to bring the results of evaluation and wide application in the future with the continuous development of technology and increasing interest in security and camouflage.

Camouflage patterns, along with the development of science and technology, are increasingly optimized and perfected, and simultaneously, methods to evaluate the effectiveness of camouflage patterns are also increasingly improved. Like modern machinery and equipment used such as high-resolution cameras, AI-integrate image processing computers, etc., in real combat on the battlefield, the decision-making to start shooting at the final target though depends still on soldiers, the observer’s vision is still an evaluation method that cannot be absolutely replaced by machinery and equipment. Some methods to evaluate camouflage effectiveness can be mentioned as:

- Image analysis [3, 4]: Use image analysis tools to determine the geometric elements, color and contrast of pattern textures. Image processing software and tools such as Photoshop, Illustrator or special image analysis software such as Substance 3D can be used for information extraction and measurements.

- Similarity analysis [5]: Use methods and tools to measure the similarity between pattern textures. Methods such as visual similarity evaluation can be applied to compare and evaluate the similarity between pattern textures.

The above methods help to study, analyze and evaluate the texture of the pattern in a quantitative and objective manner. However, in reality on the battlefield, the decision to fire at the final target is still up to the soldier, so the human eye is still an assessment method that cannot be completely replaced by machines and equipment. Therefore, the research and development of methods to evaluate the effectiveness of visual camouflage by human eyes is still extremely necessary.

Through surveys to evaluate human perception of textures, according to the time or distance of detecting targets in the background context, from which conclusions are drawn about the effectiveness of camouflage patterns [6].

The methods to evaluate the effectiveness of camouflage patterns in the world are published in a limited way due to military secrecy reasons and have some limitations such as:

+ Not yet linked to the camouflage requirements of each specific object in the country;

+ Not close to the reality of the terrain background in the country.

The research situation on camouflage in our country has begun to receive attention and be promoted in recent years, however, domestic publications on camouflage effectiveness assessment are mainly based on computer analysis [7, 8]. Therefore, the requirement is to have studies on visual assessment by human eyes, through experiments associated with specific terrain backgrounds. In order to perfect the methods of evaluating camouflage patterns, in order to improve the camouflage effectiveness for domestic military objects. On that basis, this paper presents a method of evaluating camouflage effectiveness by survey method to determine the time and distance of target detection.

2. THEORETICAL BASIS FOR EVALUATING THE EFFECTIVENESS OF CAMOUFLAGE PATTERNS USING SUBJECTIVE METHODS

2.1. Theoretical basis

Human observation ability is limited by visual acuity according to the theory of human psychology and visual perception [6]. Visual acuity is the spatial resolving capacity of the visual system, or in other words, this may be thought of as the ability of the eye to see fine detail. For camouflage in the visible area, it is required to limit detection by human eyes (of the enemy) directly or supported by optical devices operating in the visible area (binoculars). Many studies on pattern design have applied both Gestalt theory on the perception of patterns or shapes, fractal geometry theory, etc. [9, 10]. All of these factors are directly related to the main parameters in pattern design, which are mentioned in the next section.

Detection is not just about seeing an object with the eyes but also includes other parallel psychological processes that represent the relationship between stimuli and human senses. Many key parameters in camouflage pattern composition can be mentioned, most of which come from aesthetic and arts theory. In this study, we discuss two basic parameters including Gestalt psychology and fractal geometry.

a) Gestalt psychology and visual perception

There are duly principles of sensory organization of elements that must be considered in design of the composition of shapes aesthetically along with the corresponding technical value in camouflage patterns. In fact, Gestalt psychology reflects the relationship between two or more shapes and composition of the shapes at the surface level creating a new overall shape that is different from the individual shape. Gestalt psychology is also formed based on the fundamental and universal principles of perception organization, as follows [10]:

- Law of proximity – elements that are close to each other tends to be grouped together;
- Law of similarity – a link between elements of similar nature;
- Law of continuity – elements belong together, and form a continuous line or pattern, connected together as part of a whole;
- Law of closure - closed element groups tend to fill in the open element groups;
- Law of smallness – our perception of small surfaces tends to be as a figure on large background;

- Law of symmetry – our perception of symmetrical surface area tends to be a shape on an asymmetrical background.

b) Fractal geometry

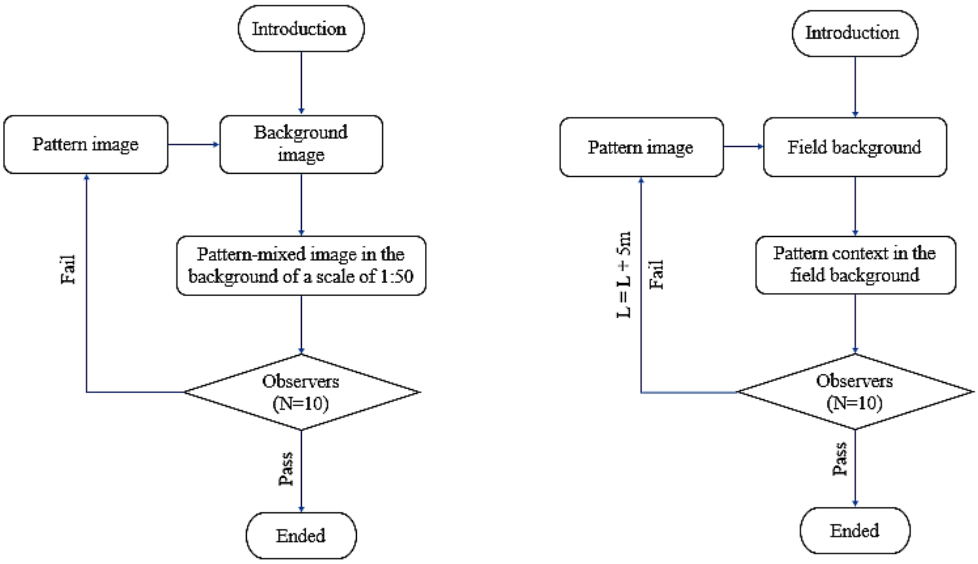
A fractal is a natural phenomenon or a mathematical set that exhibits a repeating pattern that displays at every scale while zooming in or out. If the replication is exactly identical at every scale, then it is called a self-similar pattern. Fractals are infinitely complex patterns that are self-similar across different scales. Fractals are identical fragmented geometric shapes. These shapes are first applied to camouflage patterns of leafy forests, as developed using graphic techniques to design patterns appropriate to the environment [11]. Landscapes, trees, leaves and branches are often subjects for fractal analysis – figure 1:

Figure 1. *Examples of fractal geometry in nature.*

In their early days, camouflage designs were a form of artwork, in which the designs were done by graphic artists. Recent work on computer-aided military camouflage design includes small shape units that are combined in shape and color to create a natural appearance [12]. Therefore, fractal analysis can be applied to analyze military camouflage patterns.

2.2. Procedure for evaluating camouflage effectiveness experimentally

After being designed and optimized, the camouflage patterns need to be evaluated for camouflage effectiveness using one or more different methods [13, 14]. In this study, the authors evaluate the effectiveness of patterns using a visual experimental method with a multi-layer optimization process. For evaluating detailedly and accurately, the authors propose an evaluation process consisting of two stages – figure 2:



a) In the laboratory. *b) In the field.*

Figure 2. *Algorithm diagram for evaluating camouflage effectiveness using visual methods.*

Stage 1: Laboratory pre-evaluation – figure 2a

At this stage, a set of camouflage patterns is tested with a group of 10 observers. A set of images with a corresponding camouflage background pattern (at a scale of 1:50 of the image size) is created from a computer-aided simulation. The observer's task is to detect the hidden camouflage pattern in that background image, set for 3 seconds, which means if the observer takes more than 3 seconds to identify, it will be evaluated as 1 (pass), if detected within 3 seconds then 0 (fail). This process is repeated for all 10 observers and all camouflage patterns, and each observer's rating score for the patterns is recorded.

Stage 2: Evaluating in the field - figure 2b

The next step in the evaluation process is the experimental stage, which tests whether the created pattern meets the camouflage requirements for soldiers in the field, aiming to determine the range of detection of camouflage patterns in the terrain. The term "Range of detection" is construed as the distance between the observer and the pattern from which he/she can detect the pattern in the environment. For this test, patterns are placed directly in the field, a group of observers stand at a certain distance from the simulated scene, if the observer fails to detect the patterns (pass) – leading to his/her test ends, if the observer detects the patterns (fail) – the distance continuously increased from the scene and watching the process repeated until the observer fails to detect the patterns, that distance will be recorded.

3. EXPERIMENTAL EVALUATION OF CAMOUFLAGE EFFECTIVENESS AND DISCUSSION

3.1. Evaluation of camouflage effectiveness in the laboratory

During the research process, the authors analyze and select a number of patterns for two types of terrain backgrounds, mountains and urban areas. The order of painting the typical colors is interchanged, and the ratio of colors and the pattern size is adjusted to create different patterns – figures 3, 4.

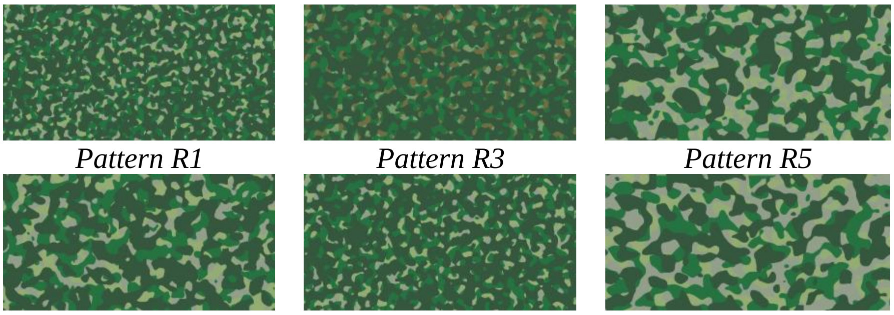


Figure 3. *Some patterns are designed for mountainous terrain.*

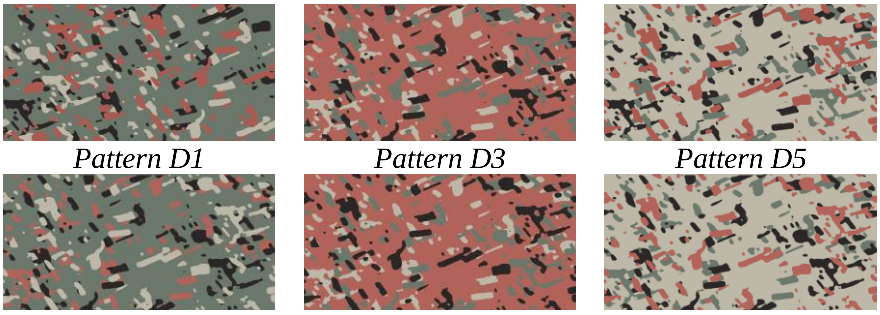


Figure 4. *Some patterns are designed for urban terrain.*

At this stage, there are six sets of camouflage patterns for each corresponding terrain background, R1-6 - for mountainous terrain (figure 3), D1-6 - for urban terrain (figure 4). Using computer-aided image simulation software (Photoshop), images of these patterns are included in the background image at a ratio of 1:50 (based on image size). The observer is responsible for finding hidden patterns in the background image with a time threshold of 3 seconds. The procedure is as described in section 2.2, the results of each observer's evaluation score for each pattern are recorded in table 1.

Table 1. *Statistical table of experimental results of the designed patterns.*

Patterns	**Observers**										**Overall score**
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**K**	
Mountainous terrain											
R1	0	0	0	0	0	1	0	1	0	1	3
R2	1	0	0	1	0	1	1	0	1	0	5
R3	1	0	1	0	0	1	0	0	1	0	4
R4	0	1	0	0	1	0	0	1	0	0	3
R5	1	1	1	0	0	1	1	0	1	1	7
R6	0	1	1	1	0	1	0	1	1	0	6
Urban terrain											
D1	1	1	0	0	1	0	0	1	1	1	6
D2	1	1	0	0	0	1	0	0	1	1	5
D3	0	0	0	0	1	0	0	1	0	1	3
D4	0	0	0	1	0	1	1	0	1	1	5
D5	1	0	1	0	0	1	0	0	0	0	3
D6	0	0	1	0	1	0	0	1	1	0	4

Score 1: If the observer takes more than 3 seconds to detect the patterns (pass);
Score 0: If the observer detects the patterns within 3 seconds (fail).

Using the experimental evaluation method of computer-aided simulation with a group of observers to the patterns in the corresponding terrain background image, the research team obtains the results as shown in table 1. As a result, for each terrain background, the research team selects 3 patterns for the best camouflage, respectively, R2, R5, R6 - for mountainous terrain and D1, D2, D4 - for urban terrain.

3.2. Evaluation of camouflage effectiveness in the field

To determine the most suitable pattern for each terrain background, the research team proposes to continue testing in the field. Using the visual evaluation method, the patterns are attached directly and hidden on the terrain corresponding to the assessment of the group of 10 observers (A, B, C, D, E, F, G, H , I, K). The experimental procedure is carried out as described in section 2.2, the group of observers take turns standing at a certain distance from the simulated scene (L = 5 m). If they fail to detect the camouflage patterns (i.e. pass) then the person's experiment stopped. If they detect the camouflage patterns (i.e. fail), continuously increasing the distance (L = L + 5 m) and observing again, repeated from this process until the position is determined where the observer cannot detect the camouflage patterns, then ending.

The experimental layout diagram is shown as shown below – figure 5:

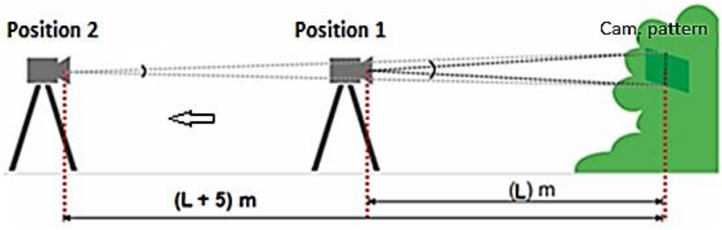
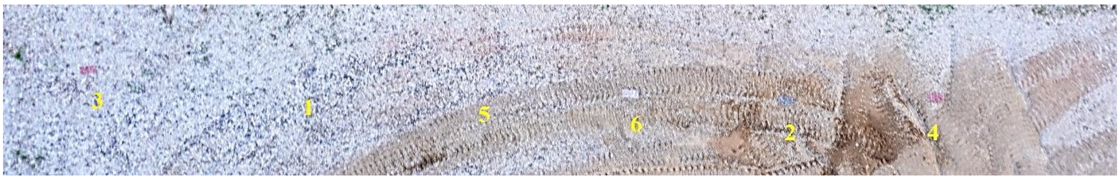


Figure 5. *Experimental diagram in the field.*

The patterns are arranged in the background context, the experimental images are captured by a surveillance camera mounted on a drone and are described as shown below - figure 6:

a) Experimental patterns for mountainous terrain.



b) Experimental patterns for urban terrain.

Figure 6. *Experimental context of patterns.*

The results of the distance positions at which the observer fails to detect the camouflage patterns are shown in table 2.

Table 2. *Statistical table of experimental results with mountainous and urban patterns.*

L, *m*	**R2**	**R5**	**R6**	**L, *m***	**D1**	**D2**	**D4**
5	+	+	+	5	+	+	+
10	+	+	+	10	+	+	+
15	+	+	+	15	+	+	+
20	+	+	+	20	+	+	+
25	+	H	+	25	H	+	+
30	+	B	+	30	A, B, C, D, E, F	B, H	+
35	H	A, C, D, E, F, I	B, H	35	G, I, K	A, C, D, E, F, I	B, E, H
40	B, E	G, K	A, C, D, E, F, I	40	-	G, K	A, D, F, G, I
45	A, C, D, F, G, I	-	G, K	45	-	-	K, C
50	K	-	-	50	-	-	-

- Position marked "+": Where all 10 observers detected the camouflage pattern;
- Position marked "-": Where all 10 observers didn't detect the camouflage pattern.

The result of this experiment is a statistical probability with a skewed distribution, so the median value will represent more accurate value than the mean value. To find the median value of a finite list of numbers, we arrange all the observations in ascending order, then take the value in the middle of the list [15]. For example, the median value for pattern R2 do the following:

- Sort results in ascending order: 35, 40, 40, 45, 45, 45, 45, 45, 45, 50

The median value is the value in the middle position (because there are 10 results, the middle position is 5th), deducing: Median value = (n/2)th observer = 5th observer = 45 m;

With other patterns, doing the same thing, we get:

- For R5: 25, 30, 35, 35, 35, 35, 35, 35, 40, 40

Median value = Observer No. (n/2) = Observer No.5 = **35 m**;

- For R6: 35, 35, 40, 40, 40, 40, 40, 40, 45, 45

Median value = Observer No. (n/2) = Observer No.5 = 40 m.

- For D1: 25, 30, 30, 30, 30, 30, 30, 35, 35, 35

Median value = Observer No. (n/2) = Observer No. 5 = **30 m**;

- For D2: 30, 30, 35, 35, 35, 35, 35, 35, 40, 40

Median value = Observer No. (n/2) = Observer No. 5 = 35 m;

- For D4: 35, 35, 35, 40, 40, 40, 40, 40, 45, 45

Median value = Observer No. (n/2) = Observer No. 5 = 40 m.

Based on the experimental results, it can be concluded that the camouflage patterns most suitable for the mountainous and urban terrain backgrounds are R5 and D1, respectively.

4. CONCLUSIONS

In the article, the authors present the process of evaluating camouflage effectiveness using visual methods. Specifically, human eye evaluation is carried out in two stages, both in the laboratory and in the field.

In the laboratory: The results obtained are that for each type of terrain background, the research team selected 3 patterns with the best camouflage ability, respectively R2, R5, R6 - for mountainous terrain and D1, D2, D4 - for urban terrain.

In the field: The results showed that the pattern with the shortest detection distance for mountainous terrain was R5 (L = 35 m), and the pattern with the shortest detection distance for urban terrain was D1 (L = 30 m). Therefore, the camouflage pattern R5, D1 is considered the most suitable pattern for the surveyed terrain background.

The research results of the article are used to evaluate camouflage effectiveness and complete a set of procedures for evaluating camouflage effectiveness using many different methods for different criteria in future studies.

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TÓM TẮT

Đánh giá hiệu quả của họa tiết ngụy trang bằng phương pháp trực quan dựa trên khảo sát thời gian và cự ly phát hiện mục tiêu

Đánh giá hiệu quả ngụy trang là công đoạn cuối cùng của quy trình nghiên cứu chế tạo một bộ sản phẩm ngụy trang, kết quả của nó cho phép đánh giá dựa trên cơ sở khoa học về hiệu quả của bộ sản phẩm ngụy trang. Bài báo này trình bày một phương pháp đánh giá hiệu quả ngụy trang bằng thực nghiệm trên cơ sở nhận định trực quan của 10 người quan sát theo 2 giai đoạn: trong phòng thí nghiệm và ngoài thực địa từ đó lựa chọn ra những họa tiết phù hợp nhất. Kết quả sau khi khảo sát đã xác định 01 mẫu họa tiết phù hợp nhất cho từng phông nền, với địa hình rừng núi phạm vi phát hiện mục tiêu ngắn nhất là L = 35 m (mẫu R5), với địa hình đô thị phạm vi phát hiện mục tiêu ngắn nhất là L = 30 m (mẫu D1). Kết quả nghiên cứu sẽ làm cơ sở để xây dựng một quy trình đánh giá hiệu quả ngụy trang hoàn chỉnh.

Từ khoá: Hiệu quả ngụy trang; Họa tiết ngụy trang; Đánh giá trực quan; Mục tiêu; Phông nền; Người quan sát.