The Theoretical Aspects of Possibilities of an Advanced Videosimulation Test for Camouflage Effectiveness Evaluation

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ABSTRACT

The paper deals with some aspects of testing the effectiveness of camouflage means. There are described the advantages and disadvantages of individual methods and the alternative videosimulation test. The way of experimental data processing is described in more detail, and there are initial reflections on the properties of the newly proposed alternative videosimulation test.

Keywords: *camouflage effectiveness, resolution limits, videosimulation*

1.0 INTRODUCTION

Whether adaptive or non-adaptive, in order for camouflage to be used, its effectiveness must be duly tested. Properly performed assessment of camouflage effectiveness supports the development and acquisition of camouflage that better matches and disrupts properties in the natural background. There are a number of methods to test this effectiveness. Trials that employ the eyes of human observers represent a specific group of evaluation procedures. Field tests where observers walk and search for camouflaged objects is the most natural way of testing camouflage effectiveness. Nonetheless, this method is logistically complex, time-consuming, and, unfortunately, unrepeatable under persistent conditions. On the other hand, photosimulation or videosimulation tests that use observers sitting in testing rooms and viewing recordings of scenes containing camouflaged objects are repeatable under persistent conditions, but their results are not as natural as those obtained in a field test. While the dispersion of the camouflaged object recognition range is evaluated in the case of field tests (in which the observer reports the distance at which a suspicious entity is recognized as a camouflaged object), the dispersion of the camouflaged object recognition time is estimated in the photosimulation test (in which the observer reports the moment in time at which the object is recognized as a camouflaged one). The subsequent task is to find not only the correlation between these two types of measurement, but also to find the transformation between two types of results. Theoretical and experimental work on this topic in maritime environments was done in papers [1], [2]. This report deals with the theoretical aspects of a possible new method of alternative videosimulation test, the results of which will provide the same type of results as a field test. Central to the proposed videosimulation test is a video recording captured by a camera deployed on a drone. However, in contrast to the traditional approach in experiments where video represents the perspective of an air reconnaissance viewpoint, in this new concept, the drone's movement during the recording simulates an observer walking in the field.

2.0 PREPARATION AND ORGANIZATION OF CAMOUFLAGE EFFECTIVENESS TESTS

To be able to evaluate the correlation among field and laboratory effectiveness tests, it is valuable to conduct the testing under conditions that are similar as possible. That means capturing both images and videos for both photosimulation and videosimulation tests, respectively, at the same time and location where the field test is carried out. For the purpose of this report the files (images or videos) used in the laboratory tests are called capturing files. Since the capturing files are obtained while the field test is in progress, maximum compliance in locations, light, and weather conditions can be achieved. This means that the effectiveness is evaluated for the same:

- Locations (i.e., the same landscape typology, color, structure, etc.).
- Light and weather conditions (i.e., the level of illumination, the sun orientation, type of illumination, such as direct or scattered light, etc.).

The flow chart for the assessment of camouflage effectiveness is presented in Figure 1. The trial is prepared and organized on the assumption of requirements (i.e., types of objects to be camouflaged, types of patterns, types of landscape typology to be camouflage used in, etc.). The field test is then carried out in the appropriate location, where the capturing files are obtained under the same conditions as the field test. During the laboratory test, the photosimulation, videosimulation, or another alternative testing is carried out. The data from all types of testing are finally processed and the camouflage effectiveness is evaluated.

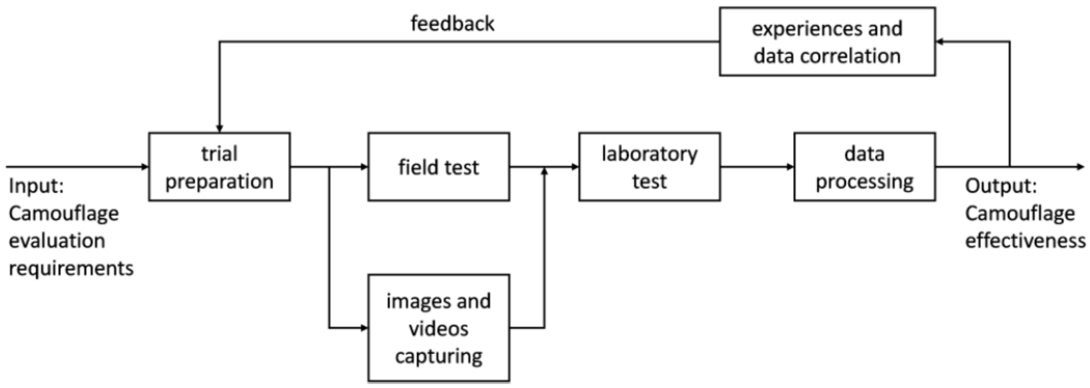

Figure 1: Flow chart for the assessment of camouflage effectiveness.

The experiences from trial organization and the result about the data correlation among the tests can be used as the feedback for the next trial preparation. We can assume the following camouflage evaluation requirements, where: N_L is the number of locations (see Figure 2), and N_p is the number of camouflage patterns to be tested. For the purposes of this paper, the unique pattern will be named using a Greek letter. Thus, the patterns create the set ($\alpha, \beta, ..., n^{th}, ..., \omega$), where ω is the last pattern with the rank N_p. Once the test is organized, an important condition must be fulfilled, which is that a unique observer at a unique location can identify a unique camouflage pattern only once. As a result, the required number of observers (N_o) to pass the field test is:

$$N_o = N_m \cdot N_p. \tag{1}$$

Where N_o is the number of observers needed to fulfil the task of field test, N_m is minimum number of realizations of a random variable to determine reliable statistical indicators, and N_p is the number of tested camouflage patterns.

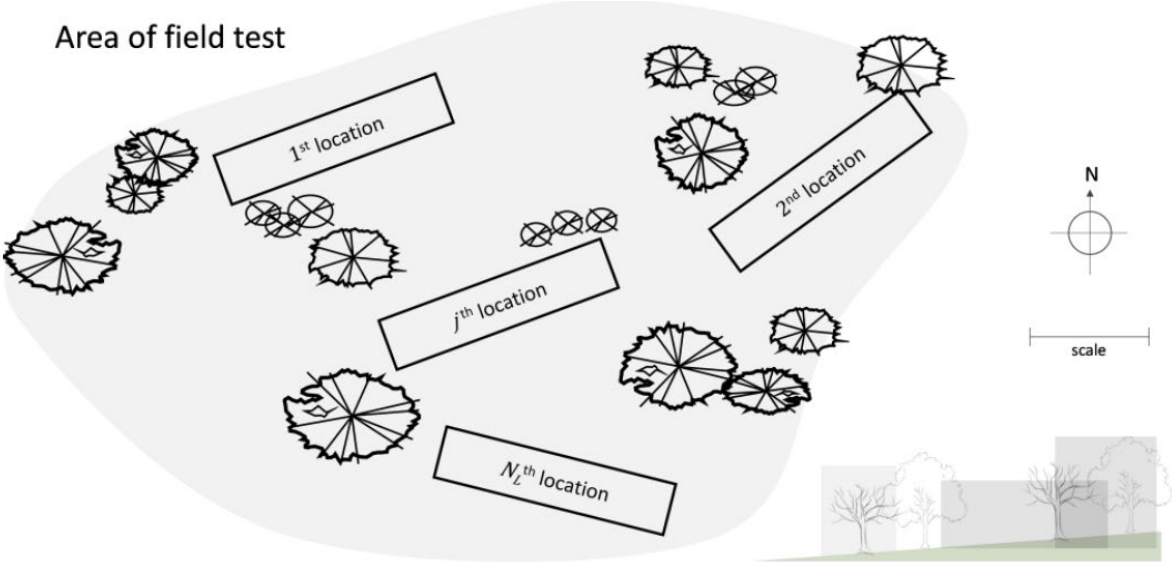

Figure 2: Area of field test.

2.1 Field Test Organization

The current location is chosen to represent the desired background of the current test under the current circumstances. An example of the arrangement of the organization in the current location is illustrated in Figure 3. The appropriate position of the target in the current location is selected. A camouflaged object (person, vehicle, etc.) with a camouflage pattern to be tested is considered a target. Next, the path along which the observer will move forward is selected. The starting position for the test is also determined. The task of the unique observer is to follow a predetermined path and search for the target. The observer moves freely, followed by the supervisor.

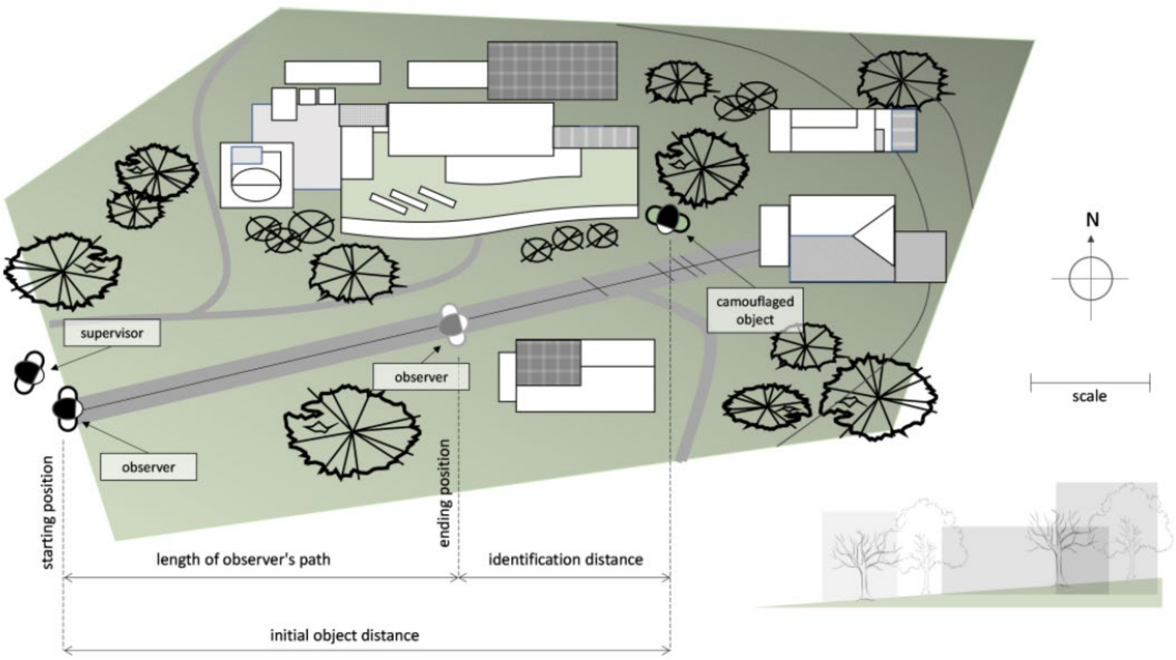

Figure 3: Organization in current location.

The observer starts from the starting position. Once the observer acquires the target, the observer stops moving. The observer describes the position of the target to the supervisor. In the case where the observer acquires a false object as a target, the observer continues the task of moving forward and searching for the target. In the case where the observer acquires the object correctly, the task ends and the distance d_{ni}^{j} to the target is measured by the supervisor. The symbol d_{ni}^{j} represents unique result of the i^{th} observer searching for the target with the n^{th} camouflage pattern in the j^{th} locations, where $i \in \langle 1, N_o \rangle$ and $j \in \langle 1, N_L \rangle$. The task is continuously repeated with all of the observers for all of the camouflage patterns. Thus, a set of data is collected for the current location, as presented in Table 1. The organization of the field test is expressed in the form of the flowchart in Figure 4. The unique observer realizing the task at the j^{th} location is then denoted as:

$$i = (n-1)N_m + q, \tag{2}$$

where q is the order of the observer in the sequence; $q \in \langle 1, N_m \rangle$.

Table 1: Set of distances as the result of a field test in j^{th} location.

	Observer's order					
	1	2	…	q^{th}	…	N_m
Camouflage α	$d_{\alpha 1}^{j}$	$d_{\alpha 2}^{j}$				$d_{\alpha N_m}^{j}$
Camouflage β	$d_{\beta\ N_m+1}^{j}$					$d_{\beta\ 2N_m}^{j}$
…						
Camouflage n^{th}	…			d_{ni}^{j}		
…						
Camouflage ω	$d_{\omega\ (N_p-1)N_m+1}^{j}$					$d_{\omega\ N_p N_m}^{j}$

2.2 Laboratory Photosimulation Test Organization

In laboratory testing, both photosimulation and videosimulation tests can be provided. Both tests simulate the observer's view of the scenery. In the case of a photosimulation test, this is a static image. This static image represents the point of view from some virtual distance when viewed on the screen. Based on the condition of image or video capturing together with the condition of a laboratory test, the virtual range R_j can be determined for all the sceneries representing the locations. The process of determination of virtual range R_j is precisely described in Ref. [3]. One of the disadvantages of the photosimulation test is an unnaturally still ("frozen") view. This disadvantage can be improved by not presenting a still image during the photosimulation test, but a video sequence of the scenery from a still camera. The view for the observer of the videosimulation test appears to be more natural, since objects such as trees, leaves, and so on, move slightly. However, the results of the photosimulation and videosimulation test with a static camera are still the same. From this type of laboratory testing, the evaluated camouflage effectiveness is valid for said virtual distance only and the time characteristics of the acquiring probability can be determined.

An illustration of the static view for an observer for both the photosimulation and videosimulation tests is presented in Figure 5. The observer's task during the laboratory (photosimulation or videosimulation) test with a still camera is to observe the screen and search for the camouflaged target. The time τ necessary to acquire the camouflaged object is measured. For the purposes of determining camouflage effectiveness, the set of capturing files (still images or the video sequences, respectively) is presented to a number of observers.

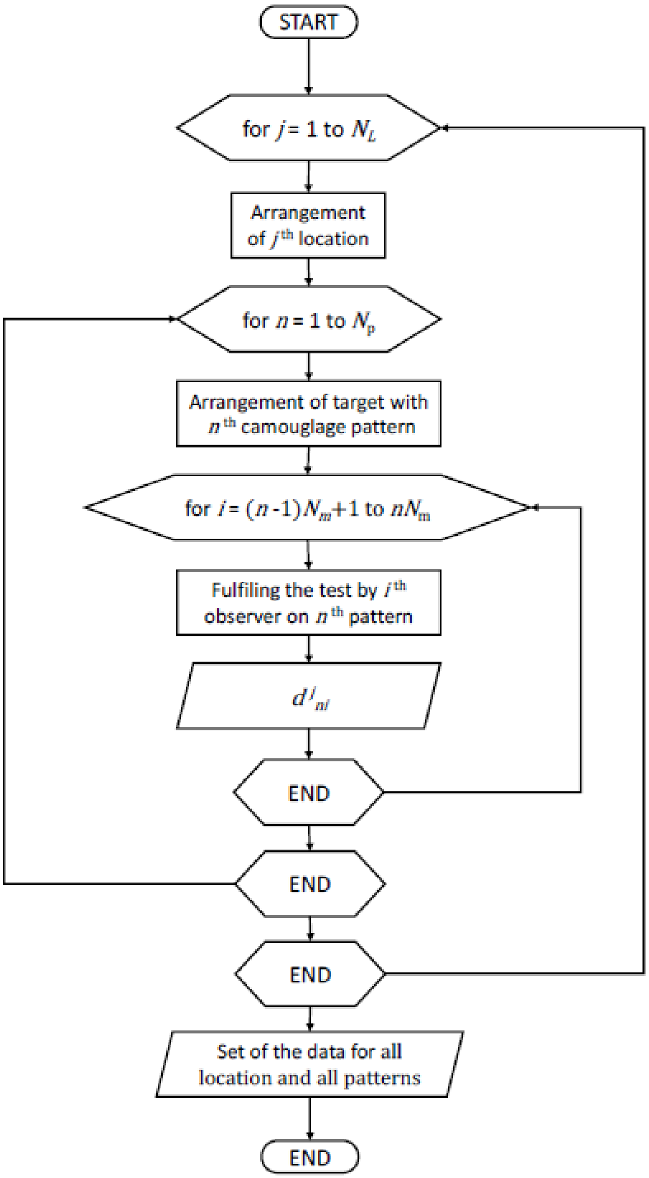

Figure 4: Flow chart of the field test organization.

The organization of the laboratory test with capturing files is explained in the flowchart provided Figure 6. First, the sequences of unique capturing files are prepared. The condition that applied to the field test also applies to the laboratory test: a unique observer can search the unique camouflaged target in unique scenery only once during the test. The number of observers N_v for the purpose of a photosimulation test is:

$$N_v = N_m \cdot N_S, \tag{3}$$

where N_s is the number of sequencies of images. The possible algorithm [4] to prepare the set of N_s sequences containing the only unique camouflage patterns in unique scenery is presented in Figure 7. By applying the algorithm from Figure 7, the number of sequences N_S is equal to number of patterns to be tested N_p, and the number of capturing files in one sequence N_E is equal to number of locations N_L.

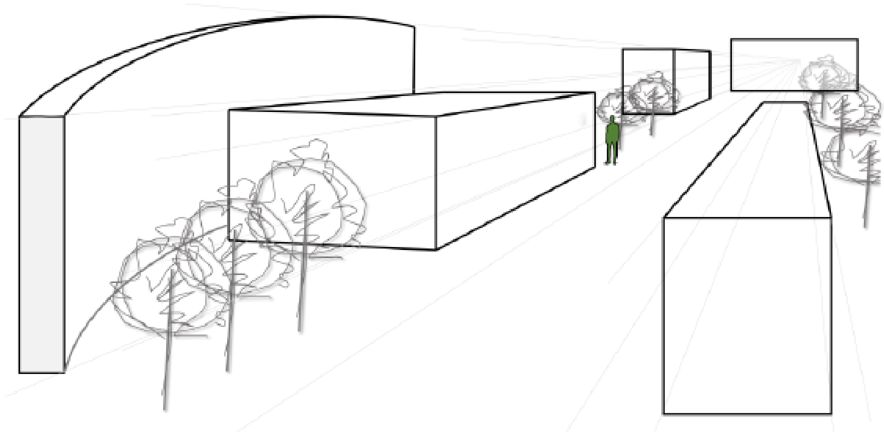

Figure 5: The illustration of observer's view during photosimulation test.

An observer observes the unique capturing file from the sequence assigned to them, turn by turn. For any capturing file, the duration P_{mi}^{k} needed to acquire the camouflaged target is recorded. The symbol P_{mi}^{k} represents unique result of the i^{th} observer on the m^{th} image of the k^{th} sequence, where $k \in \langle 1, N_S \rangle$ and $m \in \langle 1, N_E \rangle$. Thus, the primer data set is acquired. Applying the algorithm from Figure 7 by mapping:

$$P_{mi}^{k} \rightarrow \tau_{ni}^{j} \quad (4)$$

the final data set of times $\boldsymbol{\tau_{ni}^{j}}$ from the laboratory test can be obtained in the form illustrated in Table 2. This way, the data set of time τ_{ni}^{j} from the laboratory test represents the equivalent data set from the field test (see Table 1). All data sets contain the information about the effectiveness of camouflage patterns to be tested. Nonetheless, since the data sets represent different physical quantitities, the results of these two types of tests are not directly comparable.

2.3 Alternative Videosimulation Test Organization

To eliminate the limitation of the two types of tests not being directly comparable, an alternative videosimulation test is suggested. For a videosimulation test, the video recording is captured by a dynamic camera. In this case, it is appropriate to place the camera on a drone that moves at roughly the height of an adult. The recording from the camera thus conveys the possible view of the observer and in this way simulates the way an observer walks. In addition (and this is important for the purposes of this article) it is possible to link the results of the videosimulation test from the dynamic camera with the results from the field test using the transformation function in Equation (6). By moving the camera at a constant known speed, the distance to the target can be determined for each moment of the video recording. It is also possible to determine the distance to the target based on the spatial calibration of the image.

Assume that the capturing file is obtained in the form of videorecording from a dynamic camera taken by the drone moving alongside the same path as the observer during the field test (see Figure 3). the laboratory test (i.e., the alternative videosimulation test) can then be provided by the same processes as the photosimulation and videosimulation tests with a static camera (i.e., following the flowchart in Figure 6). Analogically, the output of the test will be in the same format as the set of times of duration P_{mi}^{k} needed to acquire the target. Again, applying the algorithm from Figure 7 by mapping:

$$P_{mi}^{k} \rightarrow \tau_{ni}^{j} \quad (5)$$

the final data set of times T_{ni}^{j} of the laboratory test can be obtained in the form illustrated in Table 3. To improve clarity, the data set of times given by mapping Equation (5) for the case of videosimulation test with dynamic camera is denoted by capital Greek letter *T*. The significantly important benefit of such a videosimulation test using a dynamic camera is the possibility to transform the data set of T_{ni}^{j} into data set of virtual distances to target D_{ni}^{j} by using:

$$D_{ni}^{j} = f\ (\mathbf{u}, T_{ni}^{j}) \tag{6}$$

where $f\ (\mathbf{u}, T_{ni}^{j})$ is the transformation function of time and $\boldsymbol{u}$ is the vector of parameters of transformation. Using the transformation function Equation (6) the data set of virtual distances D_{ni}^{j} can be determined in the form of table as displayed in Table 4.

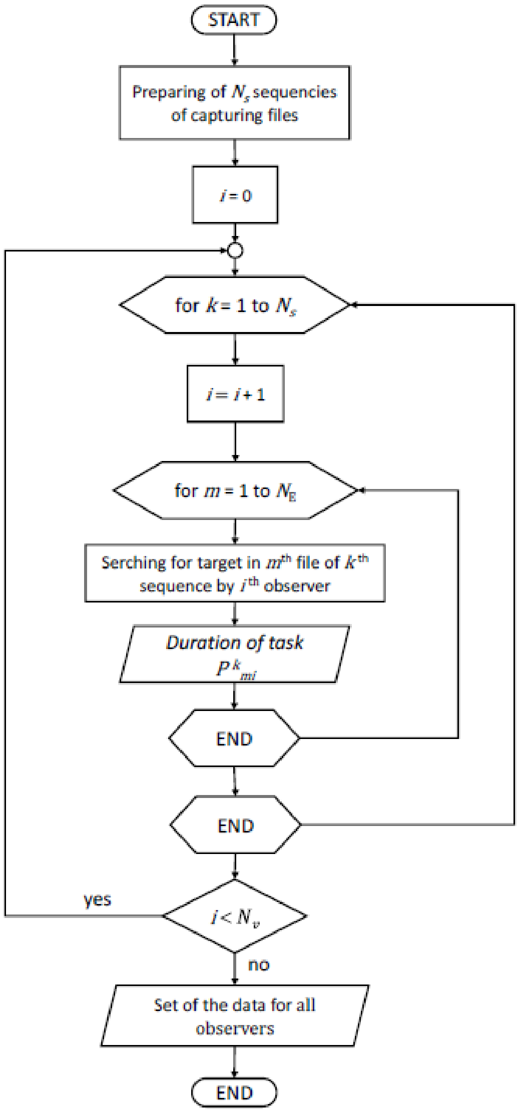

Figure 6: A flowchart showing the organization of a laboratory test.

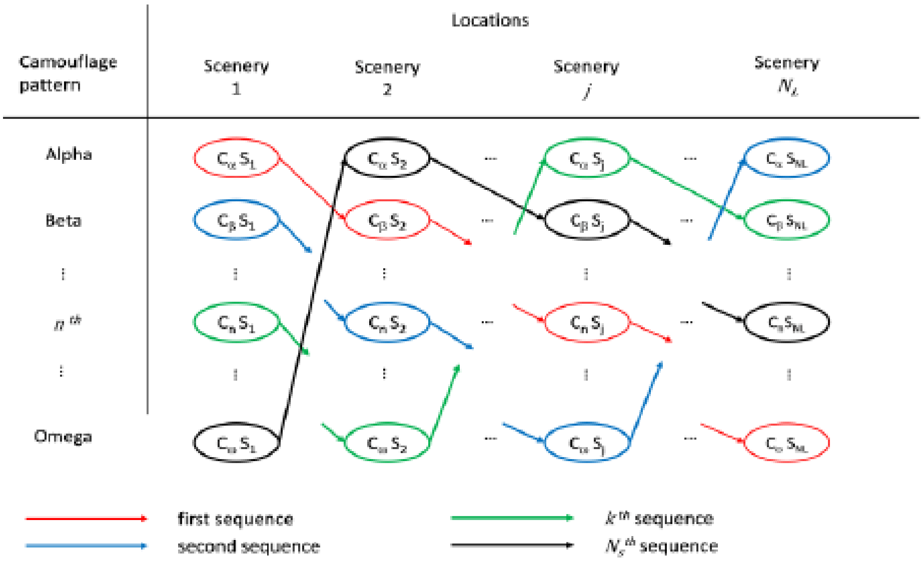

Figure 7: The algorithm of preparing the sequences of capturing files.

Table 2: Set of time-intervals as the result of a laboratory test for j^{th} location.

	Observer's order					
	1	2	...	q^{th}	...	N_m
Camouflage α	$\tau^j_{\alpha 1}$	$\tau^j_{\alpha 2}$				$\tau^j_{\alpha N_m}$
Camouflage β	$\tau^j_{\beta\ N_m+1}$					$\tau^j_{\beta\ 2N_m}$
...						
Camouflage n^{th}	...			τ^j_{ni}		
...						
Camouflage ω	$\tau^j_{\omega\ (N_p-1)N_m+1}$					$\tau^j_{\omega\ N_pN_m}$

Table 3: Set of time-intervals as the result of a laboratory test for j^{th} location.

	Observer's order					
	1	2	...	q^{th}	...	N_m
Camouflage α	$T^j_{\alpha 1}$	$T^j_{\alpha 2}$				$T^j_{\alpha N_m}$
Camouflage β	$T^j_{\beta\ N_m+1}$					$T^j_{\beta\ 2N_m}$
...						
Camouflage n^{th}	...			T^j_{ni}		
...						
Camouflage ω	$T^j_{\omega\ (N_p-1)N_m+1}$					$T^j_{\omega\ N_pN_m}$

Table 4: Set of distances as the result of a laboratory test for j^{th} location.

Observer's order						
	1	2	…	q^{th}	…	N_m
Camouflage α	$D^j_{\alpha 1}$	$D^j_{\alpha 2}$				$D^j_{\alpha N_m}$
Camouflage β	$D^j_{\beta\ N_m+1}$					$D^j_{\beta\ 2N_m}$
…						
Camouflage n^{th}	…			D^j_{ni}		
…						
Camouflage ω	$D^j_{\omega\ (N_p-1)N_m+1}$					$D^j_{\omega\ N_pN_m}$

3.0 DATA PROCESSING AND ANALYSIS

3.1 Determining the Similarity and Difference Among the Patterns

Following the procedure described in the previous section, a huge data set will be obtained that must be statistically processed. We assume each measured or determined quantity (time or distance) of a sample data set x^j_{ni} for a unique location j and a unique camouflage pattern n as a random variable whose properties carry information about the camouflage effectiveness of the given pattern in the conditions of the given location.

The first step in statistical processing is aimed at verifying the hypothesis about the differences of two sample data sets (e.g., $d^j_{\alpha i}$ and $d^j_{\beta i}$). Compared sample data sets come from the same location and differ by camouflage pattern only. Testing is focused on finding the answer for the following question: Are we able to recognize the differences between these two camouflage patterns in terms of camouflage effectiveness? Mathematically, this question can be answered by testing whether the two data sets are from the same distribution using the two sample Kolmogorov-Smirnov test.

The two sample Kolmogorov-Smirnov (K-S) test is a nonparametric hypothesis test that evaluates the difference between the cumulative distribution functions (CDFs) of the distributions of the two sample data sets over the range of x in each data set. The two-sided test uses the maximum absolute difference between the CDFs of the distributions of the two data sets. The test statistic is:

$$D^* = \sup_x |F_1(x) - F_2(x)| \tag{1-7}$$

where F_1 and F_2 are the empirical distribution functions of the first and the second sample respectively, and sup is the supremum function. The null hypothesis is that the two sample data sets are from the same continuous distribution. The alternative hypothesis is that the data are from different continuous distributions. The result of the testing is 1 if the test rejects the null hypothesis, and 0 otherwise. In other words, if the result is 0 the sample data sets come from the same population. In that case, from statistical point of view, we are not able to recognize the difference between camouflage patterns effectiveness. Since the K-S test allows comparing two sample data only, all possible couples of data sets have to be compared for a unique location. An example of a possible result of the K-S test for four camouflage patterns is presented in Table 5. Note that the data in Table 5 are simulations (i.e., fictitious data that do not represent any real measurement or real camouflage patterns). The result inherent in Table 5 is that the camouflage pattern α differs significantly from the other three patterns. On the contrary, the similarity in camouflage effectiveness among the other three patterns is so significant that we cannot state conclusions about their differences and have to evaluate them as being of equal camouflage effectiveness.

Table 5: Example of possible result of K-S test.

	camo-β	camo-γ	camo-δ
camo-α	1	1	1
camo-β		0	0
camo-γ			0

3.2 Determination of Probability Distribution and its Parameters

We assume the acquired data sets as a continuous random variable. Generally, any continuous random variable can be described by its probability distribution. The probability distribution is described by a Probability Density Function (PDF) or CDF. Our task in this step of data processing is to fit the data sets to their distribution. There are plenty of probability distributions into which the data set can be fitted. In distribution fitting, a distribution that suits the data set well has to be found. Not only the type of distribution has to be selected, but the parameters of distribution must also be determined. The parameters of a random variable are appropriately selected numerical data that summarize basic information about the probability distribution of the variable. Assume that we have found the best fitted distribution for any data set D_{ni}^{j} in the form of a PDF described by the function $f_{nj}(\boldsymbol{v}_{nj}, d)$, where $\boldsymbol{v}_{nj}$ is the vector of parameters of distribution and d is the distance. An example of a possible result of fitting the distribution for two data sets of two camouflage patterns is presented in Figure 8. Note that the graph in Figure 8 is a simulation (i.e., it is fictitious and does not represent any real measurement or real camouflage patterns). Knowing the PDF, one can determine the probability that the random variable takes on a value from some interval. In our case, knowledge of the distribution function allows us to calculate the probability p_{nj} for which the camouflage pattern will be acquired for a threshold distance d_t or greater:

$$p_{nj}(d \geq d_t) = \int_{d_t}^{\infty} f_{nj}(\boldsymbol{v}_{nj}, d)dt = 1 - F_{nj}(d_t). \quad (8)$$

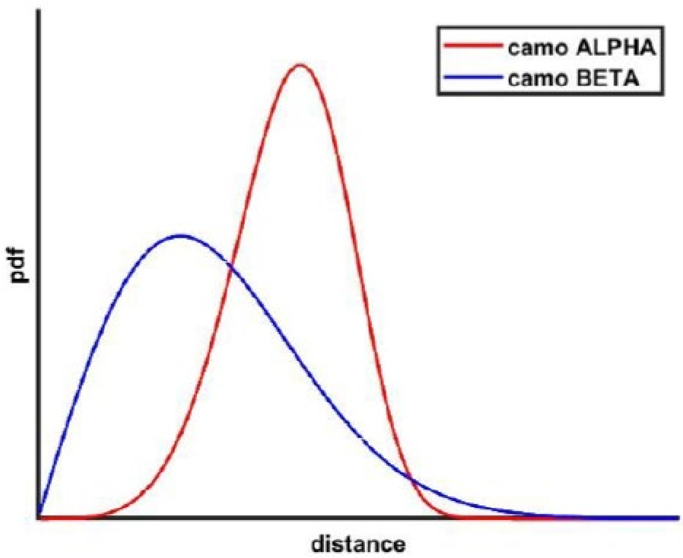

Figure 8: The example of possible distribution for two data sets of two camouflage patterns.

3.3 Analysis of the Camouflage Effectiveness Expressed by Probability of Target Acquisition

The knowledge of the probability distribution is very useful because it is a function according to which the probability distribution of a random variable can be unambiguously described. In our case the camouflage effectiveness can be expressed and be compared among the locations. This way the threshold distance, for example, $d_t = 100$ m, is chosen and the probability of target acquisition can be determined for all the locations. Determined probabilities represent the effectiveness of camouflage patterns. The lower the probability, the higher the camouflage pattern effectiveness. Thus, the probability equal to zero means that for current circumstances of the location the pattern will not be acquired for a distance of 100 m or higher. On the other hand, a probability equal to one means that for current circumstances of the location, the pattern will surely be acquired for a distance of 100 m or higher. This way the results for all locations can be compared as illustrated in Table 6 for hypothetical results of the field test. This is similar to the way that the results of the laboratory test in the form of videosimulation test with dynamic camera are displayed. The hypothetical result of the laboratory test is presented in Table 6. To distinguish laboratory and field test results, the laboratory test results are marked with an asterisk) for the purposes of this report). Since the results in both tables (Table 6 and Table 7) represent the same thing (i.e., the probability that the target will be acquired for distance d_t or greater), the results of field and laboratory test can be compared objectively.

Table 6: Hypothetical results of the field test for all locations.

	Locations					
	1	2	…	j^{th}	…	N_L
Camouflage α	$p_{\alpha 1}$	$p_{\alpha 2}$				$p_{\alpha N_L}$
Camouflage β	$p_{\beta 1}$					$p_{\beta N_L}$
…						
Camouflage n^{th}	…			p_{nj}		
…						
Camouflage ω	$p_{\omega 1}$					$p_{\omega N_L}$

Table 7: Hypothetical results of the laboratory test for all sceneries.

	Locations					
	1	2	…	j^{th}	…	N_L
Camouflage α	$p^*_{\alpha 1}$	$p^*_{\alpha 2}$				$p^*_{\alpha N_L}$
Camouflage β	$p^*_{\beta 1}$					$p^*_{\beta N_L}$
…						
Camouflage n^{th}	…			p^*_{nj}		
…						
Camouflage ω	$p^*_{\omega 1}$					$p^*_{\omega N_L}$

The results of both field and laboratory tests, expressed by probabilities of acquiring in Table 6 and Table 7, allow us to examine the common variability of these data sets and determine common correlations. In the case of evaluating a high degree of correlation, we could accept the hypothesis that the results of one test demonstrate the same camouflage effectiveness as the results of the other test. Such a correlation of results between the field and laboratory tests would allow us to perform a large number of tests in laboratory conditions that ensure a high degree of measurement repeatability. In this way, we could obtain a high number of reliable measurement realizations and, therefore, also a statistically significant data set necessary for an accurate evaluation of camouflage effectiveness. The degree of correlation is numerically expressed by the value of Pearson's product-moment coefficient (e.g., Ref. [5]) and can be also indicated graphically. The example of correlation determination of hypothetical data from Table 6and Table 7 is illustrated in Figure 9.

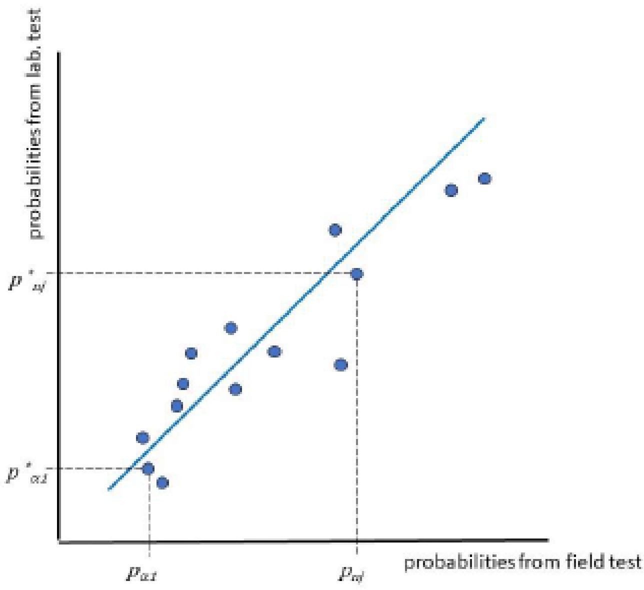

Figure 9: An illustration of indicated level of correlation among the hypothetical data sets from laboratory and field tests.

4.0 CONCLUSION

This paper presents the theoretical possibilities of the usefulness of an alternative videosimulation test using a dynamic camera for testing the camouflage pattern effectiveness. The alternative videosimulation test employs a video captured by a drone that moves alongside the pathway as the observer during the field trial. This way, a capturing file is recorded that can be processed in a similar way as the images in photosimulation test, but the results of the alternative videosimulation test are more comparable to the results of a field trial. The possible properties of an alternative videosimulation test are described from a theoretical point of view, especially with respect to statistical data processing. The theoretical assumptions are not yet supported by the results of actual experimental measurements. The aim of this paper was to express the possibility of new way of evaluating the effectiveness of camouflage patterns. The experimental measurement to evaluate the assumptions presented in the paper is future work for the authors.

ACKNOWLEDGMENT

This research was funded by Ministry of Defence of Czech Republic.

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