Disruptive coloration in woodland camouflage – evaluation of camouflage effectiveness due to minor disruptive patches

Gorm K. Selj*[a] and Daniela H. Heinrich[a]

[a] Norwegian Defence and Research Establishment, PO Box 25, NO-2027 Kjeller, Norway

ABSTRACT

We present results from an observer based photosimulation study of generic camouflage patterns, intended for military uniforms, where three near-identical patterns have been compared. All the patterns were prepared with similar effective color, but were different in how the individual pattern patches were distributed throughout the target. We did this in order to test if high contrast (black) patches along the outline of the target would enhance the survivability when exposed to human observers. In the recent years it has been shown that disruptive coloration in the form of high contrast patches are capable of disturbing an observer by creating false edges of the target and consequently enhance target survivability. This effect has been shown in different forms in the Animal Kingdom, but not to the same extent in camouflaged military targets. The three patterns in this study were i) with no disruptive preference, ii) with a disruptive patch along the outline of the head and iii) with a disruptive patch on the outline of one of the shoulders. We used a high number of human observers to assess the three targets in 16 natural (woodland) backgrounds by showing images of one of the targets at the time on a high definition pc screen. We found that the two patterns that were thought to have a minor disruptive preference to the remaining pattern were more difficult to detect in some (though not all) of the 16 scenes and were also better in overall performance when all the scenes were accounted for.

Keywords: Camouflage, disruptive coloration, search, vision, contrast, human observers, background matching.

1. INTRODUCTION

The ability to achieve effective concealment in natural backgrounds is important in the animal kingdom and in warfare alike. The primary purpose with camouflage is to blend in with the environments and thereby attract a minimum of attention from a given kind of observer or sensor. Effective camouflage in the visual part of the electromagnetic spectrum, and in particular when the searching sensor is the human eye, has primarily been thought to be achieved through spectral as well as spatial fitting to the characteristics of the background [1-3]. Spectrally this means reducing contrast to the local background by mimicking the reflectance properties of the target surroundings ensuring that they reflect light in a similar way over the entire spectrum. Spatial fitting is achieved through frequency and orientation matching [3].

As no local, natural background look entirely alike (spectrally as well as structurally), camouflage patterns normally consist of different colours presented visually through a camouflage pattern that aims to capture the vital structural properties of natural backgrounds. Such a visual appearance of camouflage is thought to be able to operate in a large variety of natural backgrounds and still provide acceptable reductions in contrast [4-6]. In some cases optimized background matching, resulting in high quality concealment can be achieved for specific backgrounds [7]. However, the acceptable animal protection is then typically restricted to the habitat itself, which hampers the animal's operability. From a military point of view camouflage is, on the contrary, often given most value whenever it does not put restrictions to mobility over a large variety of different, adjacent natural backgrounds.

Camouflage patterns have been used in the military for decades – if not centuries – already [8]. From a military point of view the assumption that a camouflage pattern may have the ability to disrupt the shape of a target has been textbook material for decades [8,9]. One particular concealment effect that often is assigned to multi-coloured camouflage patterns is their ability to disturb the visual impression of an observer (human or animal) through some ruption of the revealing outline of the target and consequently make the target less conspicuous. Through carefully located, high contrast patterns, that stand out visually, along the outline of a given target, false edges are thought to emerge when seen from the observer's point of view and hence the shape of the target is disrupted [1,9,10]. The concept of enhanced protection by adding disruptively colored pattern patches on top of an underlying (and background matched) camouflage pattern was

*gorm-krogh.selj@ffi.no; phone 0047 6380 6715; www.ffi.no

postulated already more than hundred years ago [11] and was refined during the World War II [8,12]. Still very little – if any at all – of scientific credibility has been reported on the effect of disruptive camouflage on the concealment effectiveness of a camouflaged human target over the same period of time, although some tests have been carried out in the recent years [13].

Disruptive coloration is normally designed so that high contrast patches – relative to adjacent surface areas of a target – are located along the revealing outline of the target [1, 10]. Since the hypothesis of enhanced protection through disruptive coloration emerged from studies of the Animal Kingdom [11] it took about a hundred years until it again gained increased scientific interest [9]. Careful experimental studies have, in the recent decade, revealed more and more of the nature of disruptive coloration and it has been reported to increase survivability of prey when exposed to predators of some kind in the Animal Kingdom [9,14-19]. However, only a very limited number of studies have been dedicated to assess the concealment effect of disruptive coloration - for camouflage purposes – in human shaped targets when searched for in three dimensional natural, woodland sceneries [10, 13].

Hence, there is a lack of knowledge about the quantitative effect of disruptive coloration as a concealment strategy when compared to the non-disruptive, albeit background matched counterparts. Also, it must be further investigated under what conditions and natural sceneries disruptive coloration for camouflage purposes actually has an effect. Perhaps of equal importance will be to establish more knowledge on under what circumstances disruptive coloration does not increase the survivability of a (human) target, or, at worst, even reduces it. Although we have recently reported that disruptive coloration seemed to enhance the concealment effectiveness for human-shaped targets in arid sceneries [13], it is not obvious that the effect is quantitatively equal – or present at all – in other types of background, or whether or not there are differences between natural and non-natural (such as urban) backgrounds.

Although disruptive coloration has been shown in many cases to enhance survivability of a camouflaged target [9,13-19], it is still much work undone to reveal its generality over a large set of different background types as well as to establish more knowledge on its applicability to military uniforms. The abovementioned two tasks imply, when combined, that any successful disruptive effect, when added to an underlying background matched camouflage pattern, should not work just in some sub-parts of the relevant set of natural backgrounds, but preferably in almost all and give a negative contribution to the concealment effectiveness in a very few. Consequently, we now want to test out if such disruptive camouflage should – in order not to be limited to certain terrain types - contain minor (and perhaps even single) disruptive patches so that it might give a positive, but potentially small, contribution to the camouflage effect in a large set of backgrounds. At the same time the inclusion of disruptive patches should contribute negatively – for example through a too high spectral or spatial mismatch between the target and background – in a minimum of the given backgrounds of interest. It has been reported in previous studies that disruptive coloration might also reveal the target simply by mismatched high contrast patches that stand too much out, making the target too conspicuous to an observer [18].

In this paper results from a preliminary study of disruptive coloration for camouflage purposes in temperate (Nordic) woodland sceneries will be presented. Human-shaped targets were concealed with camouflage patterns that were reasonably matched to the (spectral and spatial) characteristics of woodland backgrounds. In some of the targets disruptive coloration - in terms of a high contrast (black) patch along the targets' outline – was added to the underlying background matched pattern to study the effect of disruptive patches on the overall camouflage effect. We found that, when subject to human observers, the two targets with disruptive patches performed better in overall as when compared to a similar, but non-disruptive target although this effect was not found in each of the single local backgrounds that we used as sceneries for further testing.

2. METHOD

Three generic camouflage patterns were compared in this study and are shown in Figure 1. The patterns are from now referred to as target 1 (T1), target 2 (T2) and target 3 (T3). The corresponding camouflage effectiveness of the three targets when exposed to human observers were assessed in a variety of Nordic woodland backgrounds. From Figure 1 it is apparent that two of the targets, T2 and T3, were thought to have small disruptive preferences relative to the remaining (and non-disruptive) T1, serving as a reference target in the study. Inspired by recent work [13] we made single disruptive patches on presumably salient parts [1, 9, 10, 20] of the target outline such as the target's head (T2) and shoulder (T3). Furthermore, proper colour representation of the targets in the visual spectrum was ensured by roller printing the desired camouflage patterns onto optically opaque cotton textile (280 g/m^2, Hol-Tex GmbH, Germany) similar to textile used in military combat suits. Human shaped targets were then produced, as shown in Figure 1, ensuring that the shape and size of all targets that were under evaluation were identical. A styrophoam mannequin was finally used so that the targets were given human shape during the image recordings in the field as well as during the subsequent observer trials. The evaluation methodology we used in order to reveal differences in camouflage effectiveness between the targets was a two-step process [21]: 1) Each of the three targets were identically placed and recorded in 16 different woodland scenes in Norway during the time period from July until end of November 2014, and 2) search for camouflaged targets through an observer based photosimulation process.

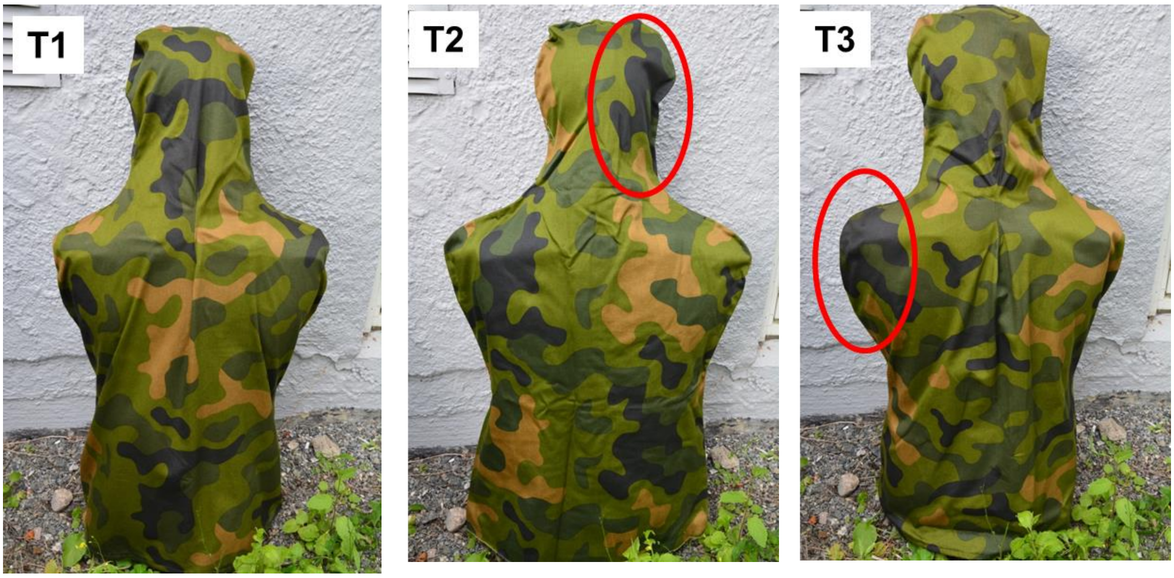

Figure 1. Close-up images of the three near-identical, but still slightly different targets that were under evaluation in woodland sceneries. From left to right we see target T1 with no assumed disruptive preference, target T2 with a (minor) disruptive patch along the head outline and target T3 with a (minor) disruptive patch along the contour of the shoulder part. The disruptive patches, that were black in both T2 and T3 are highlighted in red in this figure for illustration purposes only.

Background data capture of the targets

The 16 scenes that were used to evaluate the three targets in this study were all unique, meaning that they captured different aspects of woodland backgrounds The targets were photographed one by one in identical positions by mounting them, one at the time, to a spear that was fixed to the ground. We put an effort in ensuring as equal conditions during the image capture as possible, regarding the individual target's position, orientation, and visually exposed area as well as illumination conditions, which is important for the observer's perception of target and background contrast, to try to rule out the effect of artifacts during the image capture on the final result. An illustration of one of the 16 scenes is shown in Figure 2. Here, we see the three targets, (T1-T3, highlighted by red circles) exposed in precisely the same natural scenery and located identically in the scene.

In order to be able to assess the three slightly indifferent targets solely based on their camouflage effectiveness in the distinct 16 scenes, targets were recorded within minutes in each scene. We used a digital camera (Nikon D5200) for that purpose. The test methodology we used [21] furthermore rested upon evaluation of one isolated target at a time for every scene. Therefore, only one target was recorded per image, and consequently each scene contained a set of three images. The 16 scenes were chosen to span a broad set of locally different woodland backgrounds. We put an effort in selecting suitable scenes so that the scene nature in itself would not reveal (or attract the observers' attention to) the target position. Consequently, targets were located in different positions in the image frame from one scene to the next, which means the observer should not expect the target to appear at any specific position from one scene to the next. There was a small area in proximity of the center of the image were we did not place the targets during the image capturing process, as an observer tend to start the search process in the center region of an image [22].

The target positions in the 16 scenes were between 11 m and 93 m apart from the camera. The distance range to the targets was chosen sufficiently large to give a reasonable distribution of detection times in the given scenes. On the other hand, the targets were never located farther apart than what an observer was able to detect, meaning that the targets were actually possible to distinguish from the local background whenever an observer focused in the proximity of the target position in the image frame. A manual verification of the detectability of the targets, and thereby also the suitability of each scene, was carried out prior to the observer trial.

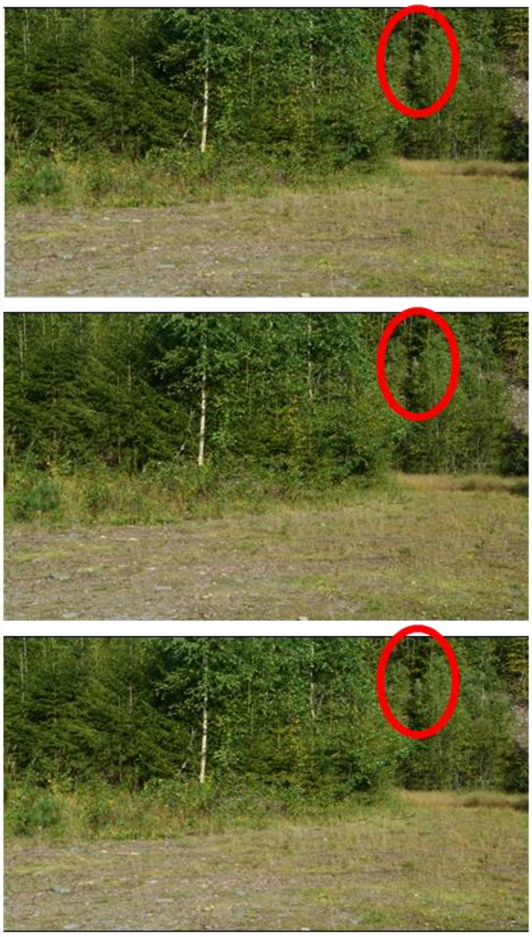

Figure 2. Illustration of a scene (scene 7), showing how the three targets were located at the exact same spot in the local background and then recorded continuously (two still images recorded within a minute). The upper image shows target 1 (no disruptive preference) whereas the lowermost two images shows T2 (disruptive preference, head section), and T3 (disruptive preference, shoulder).

Assessment of the camouflage effectiveness of the targets

We used a purpose made, and human observer based, search by photo methodology (described earlier in Selj et al [21]) to evaluate the camouflage effectiveness of the three targets, T1 (non-disruptive), T2 (disruptive head) and T3 (disruptive shoulder). The targets were then evaluated – through their distribution of time of detection – when subject to the observers. For a given target in a scene 25 human observers were searching for the target and this number was the same for all the three targets (to an accuracy of a single observer) throughout the 16 scenes.

Preparation of human observers

Ahead of the observer trial each observer was given an identical brief by an instructor explaining the steps of the test procedure. The observers carried out the trial singly. Thereafter, the distance from the observer to the widescreen used in the photosimulation part was optimized and set identical for all observers. The distance to the screen was approximately 40 cm, since at such a distance the image frame practically filled the observers's field of view. Further adjustments were then made so that the eyes of the observers were leveling the center of the screen. To prepare the observers for the trial itself, each observer carried out a test run consisting of two practice scenes with a camouflaged target similar to the scenes to be shown later in the observer trial. The observers were allowed to ask questions during the practice images, sorting out potential misunderstandings before the main trial. However, the observers were not allowed to ask whether they had found the proper target or not during the trial itself, as they were supposed to search for camouflaged targets solely by themselves, ensuring that the targets were assessed purely on the observers' performance. Each observer was; however, free to choose any search strategy during the given time interval set for each single search.

The observer trial

In the observer trial itself each observer was shown a randomized sequence of images of the 16 unique scenes. The scene images were shown one at the time by means of a high definition (HD, 2560 x 1600 pixels) in a room that was dimly lit. Each of the images in the sequence was showing a scene with one or no camouflaged (human-shaped) targets in it. The observers were, one at the time, asked to search for a target with a known shape, but unknown camouflage pattern and image frame positioning, and then indicate detection by mouse-clicking on the target as soon as the observer was convinced it was a real target. To filter relevant detection data from anomalies or miss-detections, we established a minor tolerance surrounding each target for each scene. The dimension of the added tolerance around the target was typically lower than the dimension of the target itself, meaning that detection markings just outside the target outline were accepted as proper. This strategy was intentionally chosen by us with the purpose of avoiding the observer spending much time on placing the mouse marker at the center spot of the target torso. For each search the corresponding time of detection was stored for further analysis. The observers were allowed to be exposed to the same targets in more than one scene throughout the 16 scenes in the trial. The observers were never asked to search for more than one target per scene.

Each scene was presented to the observer for no more 50 seconds, giving the observer reasonable search time, but at the same time not so much time that the quality of the search process dropped due to tedious searches for an extremely well hidden target. Whenever the time limit of 50 seconds was exceeded, the target (in the given scene) was stored as a "non-detection". All detection times and all non-detections were stored for further analysis as the non-detections – too – contain valuable information about the camouflage effectiveness if the targets. Finally, we used a purpose-made software tool to carry out the observer trial, showing the 16 scenes in a randomized order to each observer so that each target was assigned the same number of observer searches in each scene.

Method for comparison of signature properties within a certain scene

Ahead of our comparison and subsequent rank by order of the test targets we needed to define our preferred ranking criteria. In this trial we did choose *detection time* as the primary criterion with probability of detection as a possible secondary criterion as has been suggested in previous and similar studies [21] and a short justification is given in in the following.

Generally detection times for a target will be a distribution, that is, a spread of numbers from low to high. Often the spread of detection times is non-symmetric around its mode (*i.e.* the most frequent detection time), but shifted towards higher values (*i.e.* a right-shifted distribution) [23-25]. As detection times can assign only positive values, limited space for deviations exists below the mode. On the contrary, above the mode there is room for large deviations (at least until the fixed search time limit of 50 seconds). A mean value of a test target's detection times can thus be misleading, simply because single outliers potentially will shift the mean detection time towards a high value (but almost never towards a much lower value). The median, however, has the advantage of not being much right-shifted by one or two high detection times (outliers). Hence, in this study we rely our ranking on the median detection time as it is thought to reflect the camouflage effectiveness of a target with higher precision than the [21, 26]. In addition the median also accounts for the non-detections by simply counting them as high, undefined, values.

Handling non-detections

The number of non-detections during our trial was handled carefully to include their value in a rank of the three targets. By definition, the non-detections were not assigned any time value during the trial, but were treated as some undefined value above the search time limit, which was set to 50 seconds. We note that if the non-detections outnumbered the detection times, the median of that particular target turned out to be a "non-detection" which was still possible to use in a comparative test with other two targets. In special cases, if the distinct number of observers for a target was even, in combination with the rare event that the median turned out to be the average of a (well defined) physical detection time and the "first" non-detection, this particular non-detection was assigned the value of 50seconds (the fixed search time), enabling a well-defined median (as the average of those two detections), albeit with a conservative estimate. In any case, the median preserved the valuable information, represented by non-detections, about the test targets.

Finding the overall result and ranking in over all the 16 scenes

In order to find the overall rank for each target (over all 16 scenes), our approach was:

- A normalization of the median detection time for each target in each scene, representing the performance of the target relative to the other targets in a particular scene. A numeric value above 1.0 then reflected camouflage effectiveness above average, whereas a value less than 1.0 reflected the opposite. Such an approach, which is similar to a study we carried out earlier [21], also accounts for the relative difference (and not just their order) of the three targets.
- An assigned weight (higher, equal to or less than one) for each scene. In this study each of the scenes were given equal weight.

3. RESULTS

We present results in full detail from four of the 16 scenes in Figure 3-6. The remaining 12 scenes are summed up in more overall (and with a coarser level of details) in Table 1 as well as Figure 7 at the end of the results section. The four chosen scenes illustrate the spread in our results in a reasonable representative way by i) a case where the two disruptive targets, T2 and T3 came out much better than the non-disruptive T1 (Figure 3), ii) a case where one of the disruptive targets, T2, but not T3, came out better than T1 (Figure 4), iii) a case where none of the three targets were much better than the other, and where the detection times were heavily spread throughout the 50 s time search time interval (Figure 5) and finally iv) a case where there were no preferred target and where most of the detection times were short, giving little information about a target relative to another (Figure 6).

In Figure 3 we see the distribution of detection times for the three targets, T1 (non-disruptive) and T2 (disruptive head section) and T3 (disruptive shoulder), that were under evaluation. The red squares associated with a target indicate the median detection time for that particular target in the given scene. The median times in this case simply counts – chronologically – the detection times as well as the number of non-detections which occurred whenever the search time ran out with no correct detection. The number of non-detections is given as integer numbers in the rectangular square above the corresponding time distributions for each of the targets. Hence, in the case of target 3 in Figure 3, we see that there was no well-defined median time (red square) as the number of non-detections (15) outnumbered the distinct detections, which were only 3 in this case. Consequently, the median time of T3 in scene 1 was some undefined number above 50 seconds, which was the maximal search time per scene.

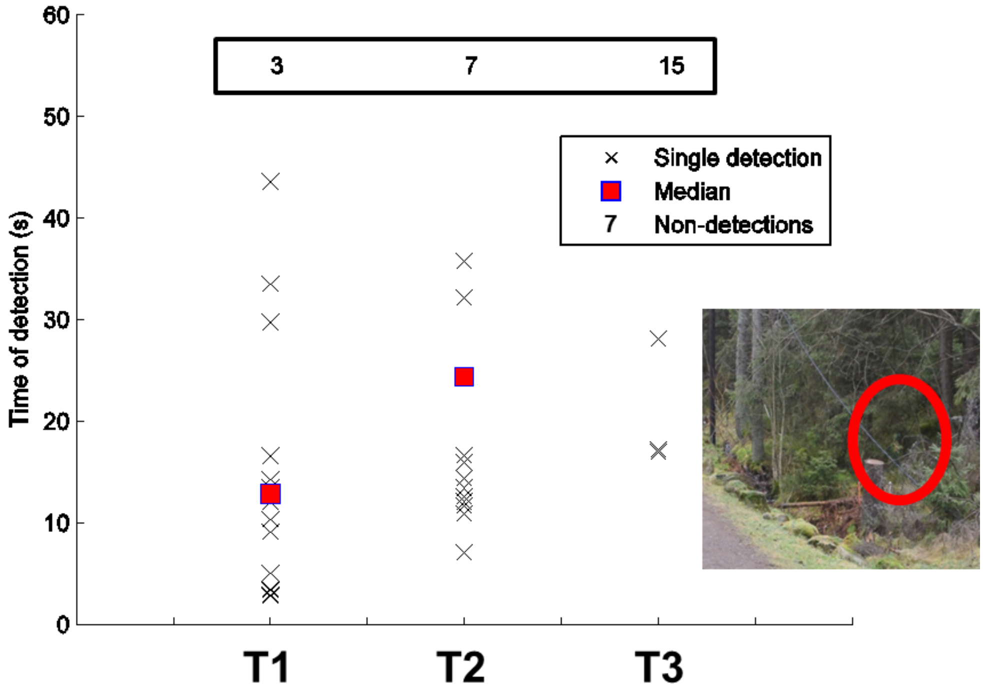

Figure 3. Distribution of detection times for the three targets, T1 (non-disruptive), T2 (disruptive head), and T3 (disruptive shoulder), in scene no 11 of 16. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene. A close-up image of the target and the local background is shown in the inset image. We note that T3 was not assigned a well-defined median time, but was instead some undefined value above 50 seconds as the number of non-detections outnumbered the number of detections.

Correspondingly, Figure 4-6 show the distribution of detection times for target T1-T3 in scene no. 12, 3 and 4. We note that in scene 12 (Figure 4) target T2 (disruptive patch in head section) performed much better than T3 and T2, both when measured by a continuous, temporal parameter (median time) as well as by a discrete parameter (number of non-detections). In Figure 5 and 6 we found few signs of differences in camouflage effectiveness between T1, T2, and T3, when assessed by their respective detection times. However, in scene 4 (Figure 6) target T2 (disruptive head section) achieved a high number of non-detections, indicating good camouflage performance, relative to the remaining two targets.

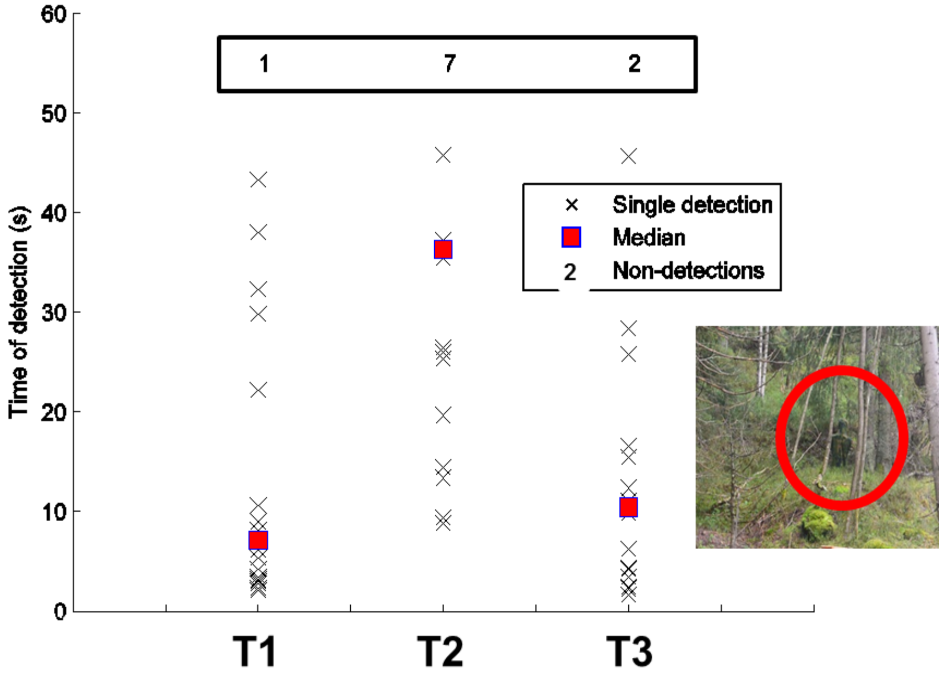

Figure 4. Distribution of detection times for the three targets, T1 (non-disruptive), T2 (disruptive head), and T3 (disruptive shoulder), in scene 12 of 16. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene. A close-up image of the target and the local background is shown in the inset image.

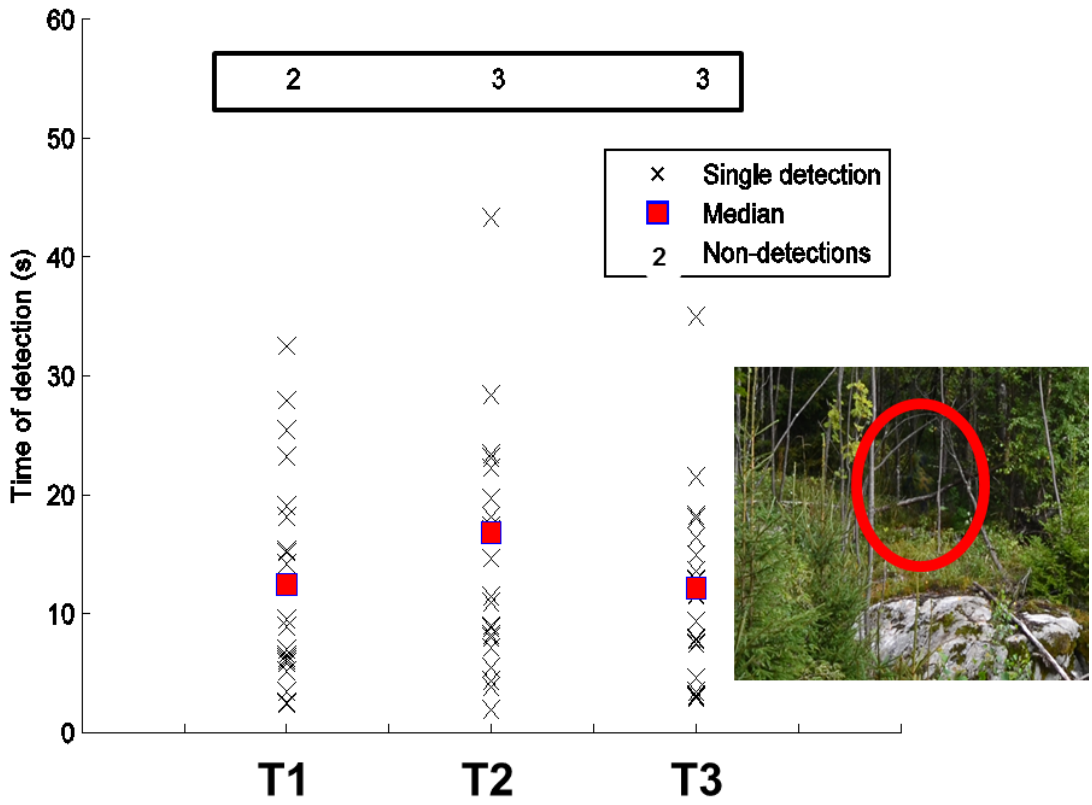

Figure 5 Distribution of detection times for the three targets, T1 (non-disruptive), T2 (disruptive), and T3 (disruptive), in scene 3 of 16. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene. A close-up image of the target and the local background is shown in the inset image.

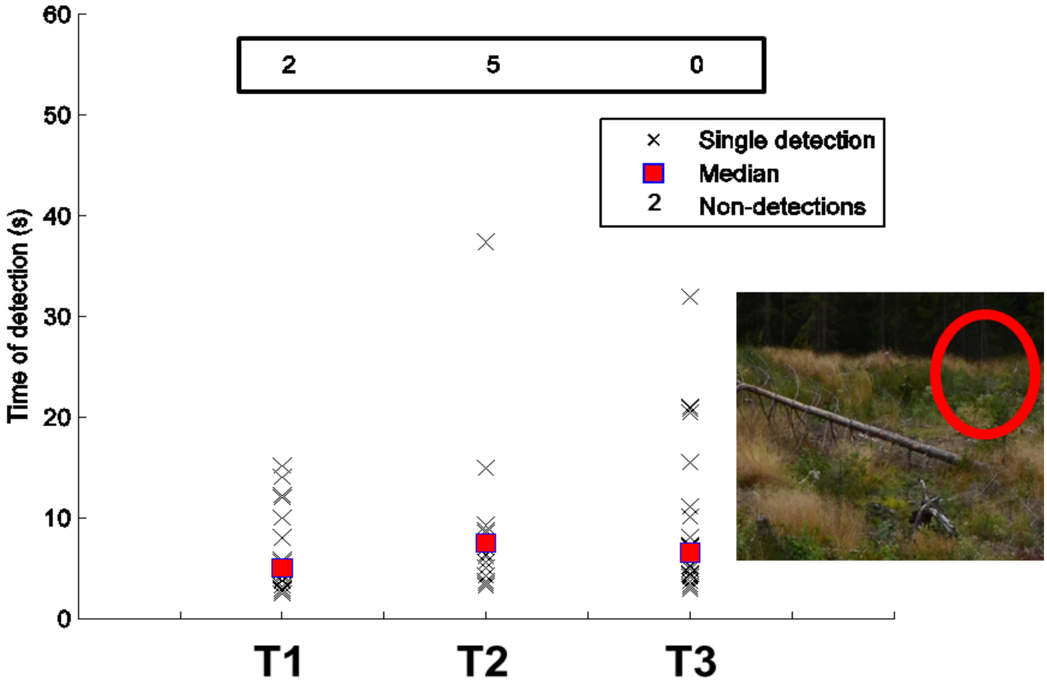

Figure 6. Distribution of detection times for the three targets, T1 (non-disruptive), T2 (disruptive head) and T3 (disruptive shoulder), in scene 4 of 16. The red squares show the median detection time for each target. The rectangular box above the time distributions shows the number of non-detections per target in this scene. A close-up image of one of the targets and the local background is shown in the inset image.

Overall performance of the targets

In Table 1 the normalized medians over all 16 scenes are shown for each of the 16 scenes. In each scene the median of each of the three targets was divided with a common and normalizing factor. This factor was the average median detection time in that scene, serving the role as a difficulty indicator of that particular scene. Consequently, values larger than 1.0 in Table 1 show that the corresponding target performed above average in the given scene, and values below 1.0 show a performance below average. For illustration purposes only (and for the benefit of the reader), in each of the scenes shown in Table 1 we have chosen to mark the best performing target in green and the poorest in red.

We note the large variation in (normalized) median values amongst the targets in many of the scenes, showing that there were large individual differences between the targets regarding their corresponding detection times. In particular scene 5, 11, 12, and 15 showed large differences in performance amongst the three targets with a factor of detection time up to more than 5 (scene 15) and generally in favor of the targets with a disruptive targets (T2 and T3) relatively to the non-disruptive, but visually near identical target T1. There were four scenes where T1 performed better than at least one of the disruptive targets (scene 5 and 13) or better than both (scene 14), meaning that in 13 of the 16 scenes the disruptive target(s) were either indistinguishable or better than the non-disruptive counterpart. In two of the scenes (scene 1 and scene 6) all three of the targets achieved a majority of non-detections, resulting in a numerically un-defined median. In those two scenes all targets were assigned indistinguishable performance, resulting in a value of 1.0 in the respective rows in Table 1.

The normalization of the median detection time values, allow for a summation of characteristic (median) values over the 16 unique scenes. This sum, representing a target's overall performance in the entire observer trial is shown for each of the targets in the lowermost row in Table 1. That particular row shows the overall (performance) score of each target over all scenes in absolute values. We see that target T3 (disruptive shoulder part) came out with the overall highest score, whereas T1 (non-disruptive) achieved the poorest overall score over the 16 scenes.

Table 1. Normalized medians of detection time for each target in each scene. The color coding indicate the best (green) and poorest (red) performing target per scene and is included for illustration purposes only. The bottom row presents the average normalized medians for each target, a parameter indicating the overall, relative performance of a target over all scenes.

Target:	T1	T2	T3	Month	Distance to target (m)
Scene: 1	1,00	1,00	1,00	Mid Aug	22
2	0,84	0,80	1,37	Mid Aug	61
3	0,90	1,22	0,88	Mid Aug	43
4	0,79	1,18	1,03	Mid Aug	53
5	0,96	0,52	1,52	Mid Aug	93
6	1,00	1,00	1,00	Mid Aug	28
7	0,78	1,11	1,11	Late Aug	34
8	0,93	0,99	1,09	Late Aug	25
9	0,84	1,31	0,85	Mid Sept	30
10	0,93	1,00	1,07	Early Nov	32
11	0,44	0,84	1,72	Early Nov	33
12	0,40	2,02	0,58	Early Nov	24
13	0,85	1,44	0,72	Late Nov	32
14	1,22	0,83	0,96	Late Nov	11
15	0,32	0,97	1,71	Late Nov	45
16	0,85	1,06	1,09	Late Nov	22
Tot score	13,04	17,28	17,68		

Combining measures of performance

Figure 7 shows the overall performance of the three targets when evaluated by two different evaluation criteria, detection time and probability of detection. For each of the targets the overall (over all 16 scenes), normalized median time as well as the average probability – over all 16 scenes - of being non-detected during the allotted search time were calculated. The corresponding pairs of coordinates are shown in Figure 7. The upper right corner in the figure corresponds to high performance in both measures whereas the lower left corner corresponds to poor performances as when evaluated by both time and probability of detection. We note a reasonably correspondence between the two measures of performance regarding the overall ranking of the targets, T1 (non-disruptive), T2 (disruptive head) and T3 (disruptive shoulder).

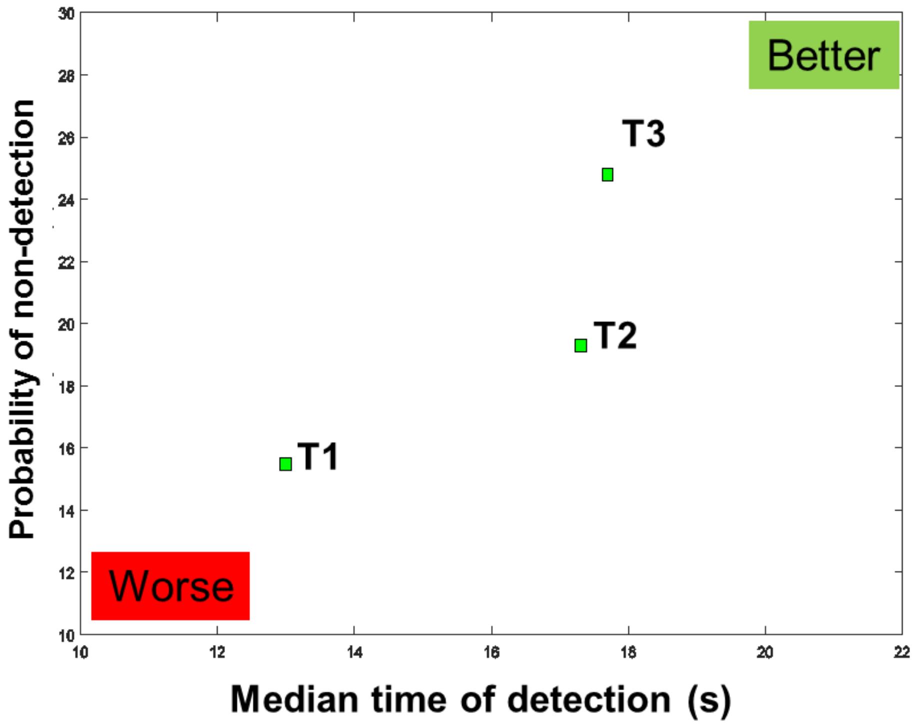

Figure 7. Overall median detection time of the 3 targets plotted relative to the corresponding probability of remaining hidden (i.e. not detected) throughout the 50 seconds of search time allotted per scene. The targets are T1 (non-disruptive), T2 (disruptive head) and T3 (disruptive shoulder). The overall median times of each target are given in terms of normalized median times per scene summed over all the 16 scenes. The probability of remaining hidden is given in terms of the average probability, over all the 16 scenes, of being non-detected throughout the search time.

4. DISCUSSION

In this study the concealment effectiveness of disruptive coloration as an add-on effect to an underlying background matched pattern has been investigated in woodland sceneries. This has been done by comparing two apparently disruptive targets, T2 and T3, with an optically near-similar, but non-disruptive, target, T1, of identical shape and size in 16 distinct natural woodland scenes. A large number of human observers – through a photo simulation methodology [21] - have been used in the search process for targets in natural sceneries.

General findings

The results from Table 1 and Figure 7 show that the overall camouflage performance of the three targets was in favor of the two presumably disruptive (T3 and T2) relative to the near-identical, but preferably non-disruptive target. We found that in 12 of the 16 scenes there was an indistinguishable or positive difference in camouflage effectiveness, given by the median detection times, between at least one of the targets with a disruptive preference (T2 or T3) and the non-disruptive counterpart T1. We found no particular correspondence between distance to target, which varied from 11 m up to 93 m, and the effect of disruptive patches on the observed camouflage effectiveness. We also found that it seemed to be no apparent correlation between the effect of disruptive coloration and the time of the year (August until late Nov).

Combining measures of performance

The results shown in Figure 7 are interesting in that respect as they show the performance of the three targets when assessed by two different (albeit not strictly independent) measures of performance. We see that the two targets that were given a small disruptive preference (T2 and T3) relative to a visually near identical, but still slightly different, target (T1), were given the same rank irrespectively of the two performance measures (detection time vs probability of not being detected). Although the relative differences in camouflage effectiveness were not strictly provided when switching from one measure to the other – which would have been remarkable in itself – the preservation of the rank somehow strengthens the indications that there might actually be a real, positive concealment effect given by the disruptive patches**.**

There is no absolute gold standard regarding the best measure of concealment effectiveness in natural settings. It will in general depend on the primary purpose of the targets under consideration. Consequently, different measures, ranging from detection time [21,27], detectability [3], detection distance [28], probability [27], to subjective measure [29] and psychophysical measures [30] have been used in order to evaluate camouflage effectiveness in earlier studies. One important feature of detection time is that it is a continuous variable, and consequently allows for a detailed (and un-biased) data harvest of signature effectiveness of targets. We speculate that using detection time as the primary measure of performance may have the potential that more of the important information related to the target's concealment effectiveness is captured compared to similar evaluations where the primary measure is either binary, as for detection probability [27], or quantized in some other way, as in [28, 31] where detection distances were recorded in steps rather than continuous.

Interestingly, the results that are reported in this study correlate reasonably well with previously reported works on disruptive coloration where birds searched for flat-bodied prey [9, 14, and 19] as well as human observers searching for prey targets [15-17]. However, on humans searching for other, concealed human-shaped targets in natural sceneries, there is, to the best of the authors' knowledge, not much reported on disruptive coloration although a lot is reported on camouflage effectiveness assessments [3-6, 27-34].

We would like to state that we find it hard to pin down the underlying nature of the observed differences in camouflage performance between the targets with a small disruptive preference (T2 and T3) and the non-disruptive counterpart, T1. Similarly, we are also open that there might not be the two patches (along head outline, T2 and at the outline of one of the shoulder parts, T3) that were the cause of the differences observed in 12 of the 16 scenes. There is always a possibility that the real cause might have been due to some other (and if so, yet unknown) difference between the targets as they were not identical visually, when corrected for the two patches.

Still, as the two targets that were found to perform best, both when ranked in overall (Table 1 and Figure 7) as well as the assumed non-disruptive reference target was given the lowest score, by means of the median time of detection, in 12 of 16 distinct scenes – throughout a time period stretching from August until November - of representative woodland sceneries, we find our results worth reporting as it is likely to be at least a tendency that carefully located disruptive patches might enhance survivability of human shaped targets when faced with human observers in nature. Hence, it would be of great interest to study further the nature of disruptive coloration when used in military uniforms located in three dimensional natural backgrounds. Key topics to be included in such studies should, in our opinion, be to reveal to an even higher accuracy whether or not there is a concealment effect at all using disruptive patches along the outline of a given target. Furthermore, the location of the patches relative to salient target features would be of interest. Similarly would be to investigate the effect varying the number of disruptive patches, their size and shape relative to the characteristic, spatial properties of the background, as well as their local contrast, both to adjacent parts of the target itself, but also relative to the local background to see what the criteria for optimizing the disruptive effect are. Equally important would be to see under what conditions disruptive coloration might reveal the target (rather than concealing it further), for example through too conspicuous high contrast patches combined with the desire to be able to move from one scene to the next.

To sum up, the results reported in this study indicate a potential anomaly effect of the human vision system with a potential evolutionary explanation [11]. Interestingly, it seems that the disruptive effect has not yet been incorporated in mathematical models of human vision [20, 35] as it either i) not well known or ii) not easy to model mathematically.

The latter assumption may be due to the fact that such high contrast effects along the target outline may also be revealing [19]. Obviously more work is needed in order to map the human eyes' responses to disruptive coloration incorporated in targets that are already highly background matched relative to a representative set of natural backgrounds.

5. CONCLUSION

In this study the concealment effect of a disruptive patch along a human-shaped target's head or shoulder outline has been investigated in woodland sceneries. We have seen that this in many cases – though not all - is likely to increase the time of detection by human observers as when compared to an identical target with a visually near-identical camouflage pattern without the disruptive patch. In overall, when summed over 16 distinct woodland scenes, the two disruptive targets performed better than the near-identical, but non-disruptive target. Still, there are a number of unanswered aspects on the effect of disruptive coloration in military uniforms that need further studies.

REFERENCES

[1] Endler, J. A., "Disruptive and cryptic coloration," Proc. R. Soc. B. 273, 2425-2426 (2006).
[2] Lillesæter, O., "Complex contrast, a definition for structured targets and backgrounds," J. Opt. Soc. Am. A. 10, 2453-2457 (1993).
[3] Hecker, R., "CHAMAELEON-CAMOUFLAGE ASSESSMENT BY EVALUATION OF LOCAL ENERGY, SPATIAL-FREQUENCY AND ORIENTATION," Proc. SPIE 1687, 342-349 (1992).
[4] Gretzmacher, F. M., Ruppert, G. S. and Nyberg, S., "Camouflage assessment considering human perception data ," Proc. SPIE 3375 (1998).
[5] Toet, A. and Hogervorst, M. A., "Urban camouflage assessment through visual search and computational saliency," Opt. Eng. 52 (2013).
[6] Boult, T. E., Micheals, R. J., Gao, X. and Eckmann, M., "Into the woods: Visual surveillance of noncooperative and camouflaged targets in complex outdoor settings," Proc. IEEE 89(10), 1382-1402 (2001).
[7] Merilaita, S., Toumi, J. and Jormalainen, V., "Optimization of cryptic coloration in heterogeneous habitats", Biol J Linn Soc 67, 151-161 (1999).
[8] Talaz, L., "The Cultural Evolution of Military Camouflage," PhD dissertation, Bristol University (2015).
[9] Cuthill, I. C., Stevens, M., Sheppard, J., Maddocks, T., Parraga, C. A. and Troscianko, T. S., "Disruptive coloration and background pattern matching," Nature 434, 72-74 (2005).
[10] Stevens, M. and Merilaita, S., "Defining disruptive coloration and distinguishing its functions," Phil. Trans. R. Soc. B 364, 481-488 (2009).
[11] Thayer, A. H., "The law which underlies protective coloration," The Auk. 13, 124-129 (1896).
[12] Cott, H. B., "Adaptive coloration in animals", York, UK, Methuen (1940).
[13] Selj, G. K., "Disruptive camouflage tricks the human eye: a study of detection times of two near-similar targets in natural backgrounds," Proc SPIE 9653, 96530S (2015).
[14] Stevens M., Cuthill I. C., Windsor A. M. M. and Walker H. J., "Disruptive contrast in animal camouflage," Proc. R. Soc. B. 273, 2433-2438 (2006).
[15] Fraser S., Callahan A., Klassen D. and Sherratt T. N., "Empirical tests of the role of disruptive coloration in reducing detectability," Proc. R. Soc. B. Biol. Sci. 274(1615), 1325-1331 (2007).
[16] Webster R., Hassall C., Herdman C. M., Godin J. G. J. and Sherratt T. N., "Disruptive camouflage impairs object recognition," Biol Letters 23, 9(6) (2013).
[17] Troscianko J., Lown A. E., Hughes A. E., Stevens M., "Defeating crypsis: detection and learning of camouflage strategies," PLOS ONE, 8(9) (2013).
[18] Scaefer H. M. and Stobbe N., "Disruptive coloration provides a camouflage independent of background matching," Proc. R. Soc. B. 273, 2427-2432 (2006).
[19] Stevens M., "Predator perception and the interrelation between different forms of protective coloration," Proc. R. Soc. B. 274, 1457-1464 (2007).
[20] Marr, D. and Hildreth, E., "Theory of edge detection," Proc R Soc Lond B, 207, 187-217, (1980).

[21] Selj, G. K. and Heinrich, D., "Search by photo methodology for signature properties assessment by human observers," Proc. SPIE 9474, 947411 (2015).
[22] Mannan, S. K., Ruddock, K. H. and Wooding, D. S., "The relationship between the locations of spatial features and those of fixations made during visual examination of briefly presented images," Spatial Vision 10(3), 165-188,1996.
[23] Toet, A., Bilj, P., Kooi, F. L. and Valeton, J. M. "A high-resolution image data set for testing search and detection models," TNO-report TM-98-A020 1998.
[24] Williams, L. G., "Target conspicuity and visual search," Human Factors, 8, 80-92 1966.
[25] Cooke, K., "The sources of variability in the search process," Search and Target Aquis., RTO-MP-45, 14-1, (2000).
[26] Bickel, P. J. and Doksum, K. A., [Mathematical statistics - Basic ideas and selected topics], Holden-Day, Oakland, USA (1977).
[27] Toet, A. and Hogervorst, M. A., "Urban camouflage assessment through visual search and computational saliency," Opt Eng 52 (2013).
[28] Schoene, R., Meidow, J. and Mauer, E.,"Feature evaluation for target/background discrimination in image sequences taken by approaching sensors ," Proc. SPIE 7697 (2010).
[29] Baumbach, J., "Color and pattern composition to blend objects into a natural environment," Association Internationale de la Couleur, (2008).
[30] Toet, A., Bijl, P., Kooi, F. L. and Valeton, J. M., "Quantifying target distinctness through visual conspicuity," Proc. SPIE 3375, 152-163 (1998).
[31] Mauer, E. and Koffler, P., " A new method for observer-based evaluation of object detectability using image sequences by approaching sensors" Proc. SPIE 7113, 711317 (2008)
[32] Nyberg, S. and Bohman, L., "Assessing camouflage using textural features," Proc. SPIE 4370, 60-71 (2001).
[33] Houlbrook, A. W., Moorhead, I. R., Filbee, D., Stroud, C., Hutchings, G. and Kirk, A., "Scene simulation for camouflage assessment," Proc. SPIE 4029, 247-255 (2000).
[34] Friskovec, M., Gabrijelcic, H. and Simoncic, B., "Design and Evaluation of a Camouflage Pattern for the Slovenian Urban Environment," J. Imag. Sci. Technol. 54(2), (2010).
[35] Heinrich, D. H. and Selj, G. K., "The effect of contrast in camouflage patterns on detectability by human observers and CAMAELEON," Proc. SPIE 9476, 947604 (2015).