PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

A field-based method for evaluating thermal properties of static and mobile camouflage

Gorm K. Selj, Daniela H. Heinrich

Gorm K. Selj, Daniela H. Heinrich, "A field-based method for evaluating thermal properties of static and mobile camouflage," Proc. SPIE 10794, Target and Background Signatures IV, 107940B (9 October 2018); doi: 10.1117/12.2326981

Event: SPIE Security + Defence, 2018, Berlin, Germany

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019 Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

A field-based method for evaluating thermal properties of static and mobile camouflage

Gorm K. Selj*[a], Daniela H. Heinrich[a]
[a]Norwegian Defence Research Establishment, P.O.Box 25, N-2027 Kjeller, Norway.

ABSTRACT

Reliable and realistic methods for assessment of thermal infrared signature properties for military purposes are important. With a basis in ongoing developments of imaging technologies, especially towards mass markets, including small handheld cameras or automotive sensors, thermal infrared sensors are expected to pose an increasing detection threat in the future. In this paper, we present a field-based approach that evaluates thermal contrast of camouflage nets, as well as mobile camouflage systems. In the proposed method, relative differences in thermal behavior between target and background are evaluated in a controlled manner in an outdoor environment over extended periods of ten days or more. The camouflage materials under test are mounted identically, in operationally realistic environments, and recorded with a thermal sensor at an image rate of 6 images per hour. Hence, thermal contrast values between each target and selected parts of the scene background are obtained during a full 24 hour period of time. Weather data are collected along with the thermal image data. In the subsequent analysis, average thermal contrasts between targets and selected backgrounds are calculated for certain well-defined time slots, such as night, day and transition between day and night. Only time slots that satisfy weather conditions requirements are analyzed, as changing weather is expected to affect the thermal response to camouflage systems. We believe the proposed method is a good compromise between controlled lab-tests, which are hampered by their lack of transfer value to thermal behavior in theatre, and field measurements during operations, where reproducibility of data can be low.

Keywords: Camouflage, Thermal infrared, Signature management.

1. INTRODUCTION

Signature management and camouflage technology is an increasingly important military capability due to the global distribution of cheaper and smaller sensors with enhanced capabilities in the visible and infra-red wavelengths. It is no longer an obvious assumption that Western nations have a technology advantage, as an increasing number of relatively sophisticated sensors are easily bought from a wide variety of suppliers. In particular, thermal cameras are expected to pose an increasing detection threat in the future, as developments in imaging technology are driven not only towards military users, but also towards mass markets.

The purpose of camouflage is to reduce the probability of detection, recognition or identification, primarily by reducing the revealing contrast between a target and a set of backgrounds in which the target is assumed to operate. Managing signatures properly is known to enhance survivability of military targets significantly. Hence, methods that assess camouflage reliably are as important as are they complex and difficult. Several methods have been developed for evaluation of visual camouflage effectiveness [1-13]. However, evaluation methods for the corresponding thermal properties have not been correspondingly well defined and described as reproducible procedures or methodologies [14].

The lack of methodologies for realistic and reliable evaluation of thermal camouflage might be due to the increasing complexity when moving from the visual to the thermal bands. Camouflage performance is no longer predominantly given by surface properties (spectral reflectance and pattern) and shape, but is also highly affected by material (thermal) properties, of target and background, as well as a number of external meteorological factors that are difficult to control. The goal is still to minimize the contrast between a target and its background, but it is more challenging to control all parameters that influence the measured apparent temperature of an object in a way that is relevant for the application.

To the best of our knowledge there are very few, if any at all, reliable laboratory tests (based on measurements of emissivity, heat capacity, heat sorption properties or other) that are able to entirely close the gap between thermal properties of camouflage materials measured indoor, and the corresponding performance in theatre, although different approaches have been tried out [14-17]. Also, there are few standards in the field of camouflage that are recognized

Target and Background Signatures IV, edited by Karin U. Stein, Ric Schleijpen,
Proc. of SPIE Vol. 10794, 107940B · © 2018 SPIE · CCC code:
0277-786X/18/$18 · doi: 10.1117/12.2326981

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

internationally [18]. Thus, a methodology that assesses apparent thermal contrasts outdoor, over time, and during strictly defined, but still achievable and relevant, environmental conditions should be established, following up earlier ideas and attempts [19].

In this study we propose a methodology for thermal camouflage assessments based on field measurements of apparent temperature contrast, ΔT, between a target and some carefully selected background regions. The methodology is primarily developed for evaluating thermal camouflage performance towards ground-based sensors, but the concept can be expanded to other threats. The aim is to provide an objective and reliable measure of thermal camouflage effectiveness for several targets. By handling meteorological as well as recorded data carefully, targets are not simply ranked by order. The methodology also provides a quantitative relative measure of performance of targets. The quantification is very important, since it narrows the gap between tests and operational performance. In this paper we will focus on the methodology and discuss pitfalls and future improvements and possibilities. Some results from an actual trial will also be presented, for illustration of the methodology.

2. METHODS

2.1 Overall method description

The test method which is presented in this work is based on relative comparisons in performance of different camouflage nets according to the requirements listed in Table 1. The camouflage products are evaluated *outdoors* over time, and their respective, thermal performances are compared with pre-defined, empirical, thermal contrast values relative to a set of selected backgrounds at specific time periods during day and night. In our methodology, two independent sets of requirements are listed, one of which is absolute and as easier to achieve (shall-requirement) and the second is non-absolute, more difficult to achieve, albeit with a higher score when achieved. For a given camouflage net, an overall score is calculated by adding the individual and independently weighted requirements (Table 1), according to the type of background which the net is designed for.

Thermal contrast relative to selected backgrounds – Requirement example:

The surface radiation-temperature of the camouflage net should respond to meteorological conditions in the same way as the natural background.

a) The thermal contrast, ΔT, **shall** be according to Table 1.

b) The thermal contrast, ΔT, **should** be according to Table 1.

Table 1: Individual requirements regarding thermal contrast, ΔT, between camouflage systems and selected background elements.

Background	Time	Shall ΔT (˚C)	Should ΔT (˚C)
Forest	Daytime	T_{11}	T_{12}
	Night	T_{21}	T_{22}
	Transition	T_{31}	T_{32}
Heather	Daytime	T_{41}	T_{42}
	Night	T_{51}	T_{52}
	Transition	T_{61}	T_{62}

As the should-requirements are normally harder to achieve than the corresponding shall-requirement, the following holds

$$|T_{i1}| \geq |T_{i2}|,$$

for $i=1,2,3,..N,$ where N is the number of specific sub-requirements.

The thermal requirements are given as thermal contrast values, ΔTs in Table 1. These values represent the apparent temperature difference between the camouflage net and a well-defined part of the local background. The camouflage net temperature as well as that of the background are temperatures that are averaged both spatially (selected rectangular cuts) and temporally (averaged over a specified time interval). The apparent temperature is used, defined as the

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

temperature an ideal black body must have in order to yield the equivalent camera signal as that achieved from the measured object [20]. Apparent temperatures are extracted from thermal images, here recorded by a calibrated long wave (7,5-14 µm) thermal microbolometer camera (e.g. 480 x 640 pixels; temperature resolution, $\Delta T_{res} \sim 30$ mK).

2.2 Geometry of the camouflage net set-up

All camouflage nets under consideration are to be mounted identically in order to achieve reproducible and reliable results. This means that he nets are aligned in one row which is oriented perpendicular to the TIR sensor. We suggest a large, tilted surface of each camouflage net to be the sample to be evaluated, as shown in Figure 1. It is important that the selected surfaces of all nets are mounted in the same orientation relative to the recording thermal sensor and relative to the sun, since differences in tilt angle (and hence camera viewing angle) may affect the results as the solar load then would be different amongst the nets [20]. This implies that the distance from camera to the camouflage products must be much larger than the distance between the products themselves. We propose a method to control this important issue by constructing identical prototype "garage" scaffolds, onto which the nets are attached and tightened to plane surfaces using purpose-made clips along the scaffold rods. All nets under test are thus mounted in the same geometry, exposing identical surface areas to the recording sensor as well as exposing the same effective area and orientation towards the sun throughout a full 24 h period of time. Similarly, the nets have equal distance and orientation relative to the sensor, reducing the influence of atmospheric damping of the signal to a minimum.

The scene should furthermore be selected from relatively flat terrains (Figure 1 and Figure 2). We suggest the distance between the nets should be minimum 3 m to assure that they do not interact thermally during the measurement period as well as reducing shadowing effects from net onto another. The sensor must have free line of sight to all camouflage nets as well as to all reference background elements (ref. section 2.3)). The distance from the sensor to the samples is recommended to be approximately 100 m, whereas the distance between the products themselves is in the range of 3-5 m. The front surface of each camouflage net facing the sensor should preferably cover a region of about at least 10 pixels square in the image frame of the thermal sensor, in order to yield sufficient pixels for data analysis.

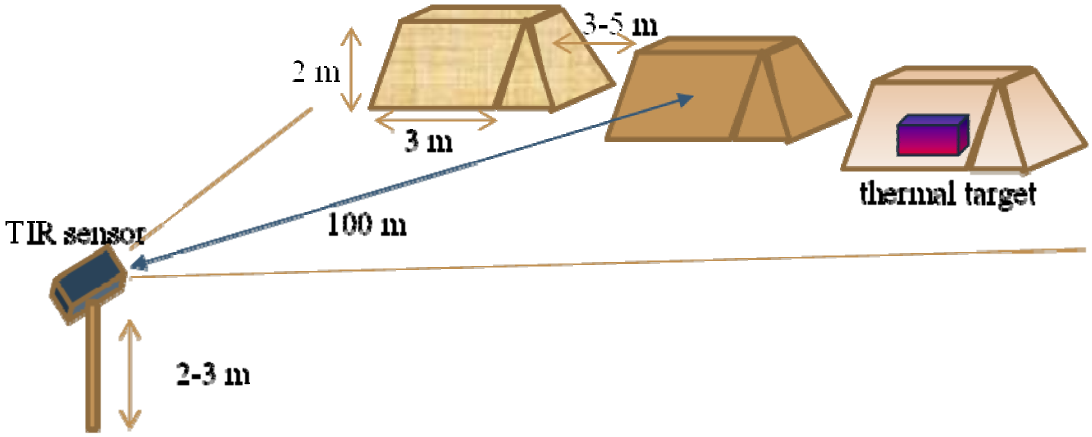

Figure 1. Geometry of the measurement set-up. Optionally, reference thermal targets may be placed inside all net garages during parts of the measurement period.

We implemented the test method following these guidelines:

- The nets are mounted, using purpose-made and identical stiff scaffolds.
- The overall dimension of the camouflage net part facing the sensor at the ground is approx. 5 m. This includes the two oblique sides, perpendicular to the front-side, of the net garage as shown in Fig 1. Furthermore, the front-side facing the senor is tentatively 3 m wide and 2 m high and must be identical for all nets under consideration.

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

- The front-side is oriented to face the sun at midday.
- The angle between the ground and the front-side of the mounted net should be within the range of 60 ± 10 degrees (Figure 1).
- The net is tightened to form plane surfaces.
- The net must be in physical contact with the ground for all sides of the mounted net garage that have a free line of sight to the sensor.
- No parts of the net should be lying on the ground in front of the net garage.

Figure 2. Measurement set-up from a conducted campaign. Sensor for continuous image recording (left) and hot arid scene with mounted scaffolds for fixation of camouflage nets (right).

2.3 Selection of relevant scenes and background types

The background should contain areas representative of the constituents that make up the background type (such as grass, conifers, deciduous trees, heather, snow, sand, and similar), each of the selected elements will be compared to the corresponding thermal response of the nets. We suggest that each background constituent should be selected from preferably more than one region in the scene. It is optimal if the scene consists of an open area in front of the mounted nets, with local vegetation behind directly behind and to the sides.

The background elements should be chosen so that they all are located at a distance not more than ± 20 meters relative to the nets. Each of the background elements must constitute an area of at least 5 by 5 pixels (or preferably larger) when viewed by the thermal sensor. In the following sections we give short descriptions of the different scene categories, more specifically for woodland winter and hot arid.

Woodland

Background elements characterized as woodland (WO) should contain at least two main components; forest vegetation and heather, typical for north European coastal, forest and mountain terrain. Forest front vegetation selected constituents should be foliage/canopy from pine, small birch and other deciduous trees. Trunks should be avoided in the elements, as they are not specified in terms of separate thermal contrast values (ref. Table 1). The foliage must be fully developed in the test scene. The vegetation background element(s) must be chosen so that it is predominantly vertically oriented (i.e. the assumed, albeit not well-defined, surface normal area of the element points towards the thermal sensor). This is to ensure equal sun conditions on the background element and the targets. The green vegetation elements must furthermore be dominated by pixels representing vegetation and not any other unspecified background type caused by transparency of the chosen vegetation-element. Each of the forest background elements must at least cover an area of minimum 5 by 5 pixels (preferably larger). Examples of suggested woodland areas are given in Fig. 3

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

Figure 3. Example of woodland background elements containing forest line (B-1) and heather (B-2) in a scene along with the nets (indicated with T's) that are under evaluation. Note that B-2 in a realistic test should be moved closer to the net garages to ensure equal distances to the sensor. The right image shows a close-up image of heather.

Winter/snow

Winter (WI) scenes should contain at least two main components; snow covered terrain and some areas with forest (leafless deciduous trees or canopy). The scene should be arranged in an open forest/mountain terrain with stable cold winter conditions. The ground must be covered with dry snow thick enough to conceal small details as grass and heather. The regions selected for this background element should normally be in front of the targets and horizontal surfaces with untouched snow (Figure 4) as man-made, or other, cavities are known to influence on thermal signature significantly under the weather conditions that are recommended in this study (ref. section 2.4). Forest background elements (such as smaller pines, birch or other deciduous trees) are considered optional in a test as snow is the most important background in Nordic winter landscapes, and hence snow backgrounds are preferred in this methodology as the aim is to reveal "pure" winter properties of the nets. The vegetation elements must, if such are included in the evaluation, be dominated by pixels representing vegetation and not any other background type caused by transparency of the chosen vegetation-element.

Figure 4. Example of winter background areas containing snow covered regions that are to be compared with the thermal responses of camouflage nets or similar, mounted in the same scene and recorded simultaneously. The two rectangles, 1 and 2, show selected snow surfaces, the remaining rectangles show camouflage nets as well as mobile camouflage systems in the scene.

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

Hot arid

We suggest the hot arid (HA) scenes contain at least three main components; sand, rocks and vegetation. The scene should be arranged in an open, dry and sparsely vegetated region, with long and stable sun-conditions, as shown in Fig. 5. The selected sand background parts should be horizontally oriented areas. A sand background area should be chosen so that it only includes sand which is soil of loose granular material smaller than gravel. Each of the sand background elements should cover large, uniform areas. The rock background elements should be solid rock areas large enough to give a sufficient number of pixels for each element. The arid vegetation background elements should be selected so that they are vertically oriented so that the surface normal points towards the thermal sensor. The green vegetation elements must furthermore be dominated by pixels representing vegetation and not any other unspecified background type caused by transparency of the chosen vegetation-element.

Figure 5. Example of arid background elements containing sand (1), rock (2) and vegetation (3).

2.4 Measurement procedure

The apparent temperatures should be measured in well-defined time intervals and at specified times during a 24 hour period over at least 3 or more days which completely fulfill the weather conditions. The thermal imager camera is calibrated to generate non-uniformity correction (NUC). For the image recording the emissivity is set to 0.92.

Thermal images are recorded every 10th minute:

- during **night**
- during a time interval (“**transition**”, defined by A and B in Fig. 6) of at least 3 hours around sunrise and sunset (Fig. 5)
- during **day**time

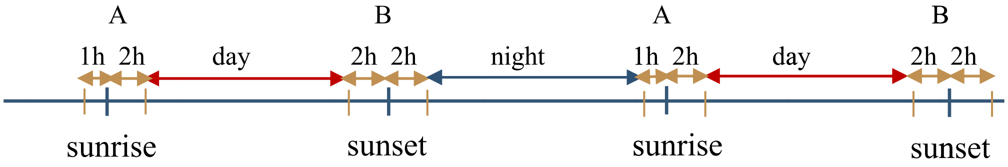

Figure 6. Different time intervals, daytime, transition (sunrise and sunset) and night, in which apparent thermal contrasts are to be compared with pre-defined requirements (ref: Table 1).

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

Image capture procedures

The thermal image recordings are best carried out statically, meaning that both the sensor as well as camouflage nets should be at fixed locations with time. Images can be recorded every 10^{th} minute over a period that normally lasts up to 10 days. This is suggested for practical reasons, as mounting and de-mounting of the nets, sensor and weather monitoring systems is time-consuming, but also to allow the camouflage sufficient time to interact with the local background and thermal loads before image recordings are initiated. Also, this procedure allows for a detailed study on how the nets respond throughout a diurnal period as well as with changes in weather conditions, which are known to affect thermal response of a target significantly. Hence, in our recently conducted measurement campaign, only one scene location was used for testing thermal properties of the nets for each of the three main categories (woodland, winter, hot arid), contrary to field-based studies of visual camouflage effectiveness where a large number of unique scenes are normally used [1, 2, 8, 11]. This means that it is important that the scenes are chosen carefully in order to be representative by containing the most relevant sub-type constituents of such backgrounds.

Weather monitoring during thermal imagery

As the methodology rests upon thermal contrasts between a target and some selected backgrounds, effects that may affect thermal responses of objects, and hence their corresponding contrasts must be monitored carefully during the measurement period. A measured thermal contrast is inextricably intertwined with external factors such as precipitation, temperature, solar irradiation, wind and cloud cover, all of which must be recorded in parallel. As there is also a significant effect of material specific thermal “memories” in targets and background, due to e.g. heat capacities, time periods with rapidly altering weather conditions must be avoided or disregarded in the data analysis.

The required weather conditions during the measurements are given specifically for each category (WO, WI, HA) as they may vary from one climatic zone to the next. In the list below we give, as an example, the conditions for tests in Nordic woodlands:

- Clear sky
- Wind less than 5 m/s (maximum values) and less than 2 m/s (average per hour).
- Periods with precipitation will be disregarded from the analysis

The measurement period should include at least 3 days where all the three weather requirements are met simultaneously. A weather station registers metrological parameters in the vicinity of the mounted camouflage nets, so that it records data under the same conditions as both targets and selected backgrounds. The metrological parameters that should be registered are: air temperature, precipitation, and wind. Solar irradiance (the radiation directly from the sun as well as any diffuse radiation from the sky) should be measured with a pyranometer. The weather station must be located so that it records data under the same conditions as the camouflage net test samples.

3. ANALYSIS OF DATA

In this section the purpose is to give an overview on how the targets under evaluation are ranked and given weighted scores based on time series of thermal contrast measurements. The aim in our methodology is to be able to extract the vital thermal signature information of test products, relative to selected backgrounds by measuring sufficiently long.

3.1 Temperature contrasts - ΔT

Apparent temperatures of selected (rectangular) areas from both nets as well as distinct background elements are captured with time. In this study the apparent temperatures of the chosen areas for both the camouflage net and the backgrounds are treated as uniform, i.e. taking no account of minor temperature fluctuations within a distinct area. An average temperature is calculated for the selected areas of interest (see next paragraph) for each of the nets to be evaluated. Similar averages are found for the background elements.

Subtracting the average background temperature from the average temperature for the nets to be considered leads to an evaluation of the performance of the camouflage materials reduced to a simple factor, ΔT [19]. This subtraction is done individually for each of the background types as defined in section 2.3. It is important that there is full alignment,

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

spatially in the image frame, of the images in a time sequence. Alignment of images in a sequence is ensured either by fixation of the camera station and nets (ref. Figure 2) or by aligning images with respect to a distinct point in the scene such as a small heat source fixed to the ground and fully exposed to the sensor.

Selecting areas for analysis

For the data analysis of the thermal records a rectangular area of minimum 50 pixels is to be chosen from the center of the front-side of the camouflage net garage. The selected area is to be chosen from the central area of the front side of the system as well as largest possible, so that no parts of the scaffold rods affect the measurement signal. From each of the specified background areas (defined in section 2.3)), a number sufficiently high for a solid analysis should be selected. In a recent field trial we selected elements with 30 or more pixels for each element.

Estimation of measured ΔT and comparing measured ΔT with the requirements

Thermal contrasts, ΔT, for the camouflage net systems relative to the selected background element areas are calculated as hourly average values for all time intervals that meet the weather conditions. Hence, an effective average contrast value for a given hour of the day, collected from measurement data over several days, is achieved. Consequently, each sub-requirement (ref. Table 1) is associated with a set of hourly based average contrast values (with standard deviation) that are to be compared with the corresponding requirement contrast limits. A full set of experimentally collected contrast values (separated for all distinct background types as well as all selected diurnal time-intervals) can be used quantitatively in order to find which requirements that are met, to what percentage during a time interval a specific requirement is fulfilled, and similar.

3.2 Finding the overall result and ranking of several targets

In order to find the overall result for each target (over all individual requirements, Table 1), we propose the following procedure:

The overall score, S, associated for a camouflage material in either of the climatic categories WO, WI, AR (or other) is a weighted sum over all requirements, N, that are fulfilled

$S = \sum_{n=1}^{N} w_n R_{nm}$,

where w_n is the weight associated with individual requirements (i.e. rows) in Table 1, and R_{nm} is the score of the corresponding requirement. The index m is 1 or 2 and therefore corresponds to either a shall-requirement or a should-requirement in Table 1. The w_n's are specific for every background element as well as for each of the specified time intervals, that are selected for the evaluation, during a 24 hour period of time. Similarly, the R_{nm}'s are score-functions whose values are decided based on to what degree the two main sets of requirements (shall or should) are met. In this methodology we suggest that all individual shall requirements and should requirements to be assigned only two score values, say A and B (B > A) and then let the weighting factors, w_n, decide the relative impact of each single requirement on the overall score, S.

4. RESULTS – EXAMPLES FROM A RECORDING SERIES

In order to illustrate the methodology we present an example from a recording series conducted over 10 consecutive days. Figure 7 shows the compressed results for one single camouflage system. The figure shows average thermal contrasts, ΔT values, between the system and a selected background constituent during an average 24-hour period of time. The performance requirements, given in terms of maximal acceptable thermal contrasts during a specific time interval, are given between bars colored in green (nighttime), blue (transition times) and red (daytime). Figure 7 shows results relative to one set of requirements (shall or should). The vertically solid lines separate time intervals with specific thermal contrast requirements from one another.

The solid graph shows the performance of the net; where the two dotted lines show the uncertainties in the measurements (given in terms of standard error of the mean). The solid graph consists of average values of thermal contrasts based on simultaneous recording of one specific target and specific background element over several days. From Figure 7 we see that the requirements were fulfilled during the daytime (red), but not during night (green) and one of the transition times (blue).

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

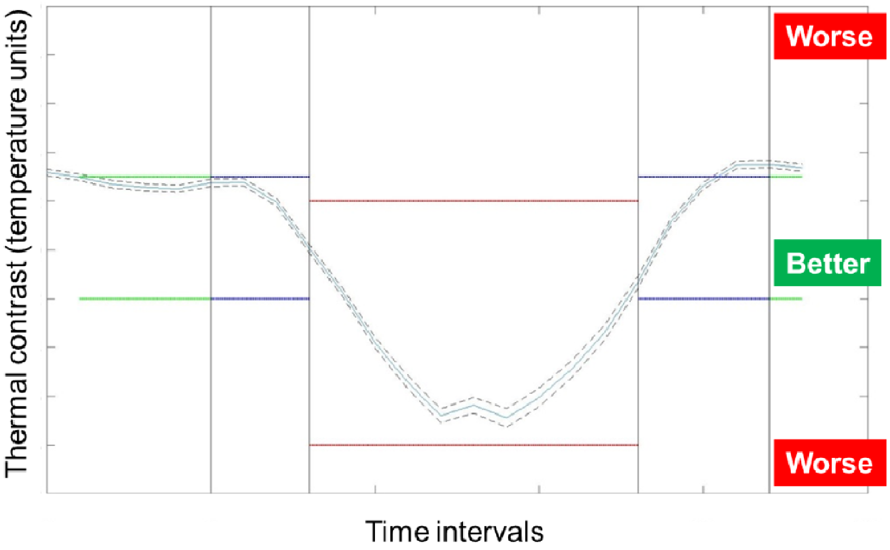

Figure 7. Thermal contrasts, ΔT, between a target and one defined background constituent of an average 24-hour period of time, based on thermal recordings outdoor over 10 consecutive days. Requirements are shown by horizontal pairs of lines for three sets of time intervals; daytime (red), nighttime (green), and transition time (blue) relative to a specified background element. The performance of the camouflage material is better the smaller the absolute value of the thermal contrast.

5. DISCUSSION

In this study we have presented a systematic methodology that evaluates thermal contrasts between camouflage nets (or similar) and selected constituents in the local background in a scene. The methodology allows for relative comparisons of thermal camouflage effectiveness between different targets in a controlled and reproducible way. Furthermore, the proposed methodology is capable of evaluate and rank the targets in a procedure that, as we see it, captures much of the relevant and valuable thermal data of the targets, and hence allows for ranking of camouflage targets.

One strength of the suggested methodology is that it is able to telling us the relative strengths amongst the targets. This can be seen from the example given in Fig. 7. This means that not only do we get to know whether some target performed better than another, but in addition we get numbers on how much better it was. Such kind of relative comparison allows the adding of results (or scores) from several sub-tests, such as contrasts relative to a specific part of the background at different time intervals throughout a diurnal period. This is important as it one is often interested in an overall rank of several camouflage systems that captures the thermal performance over a complete set of relevant sub-requirements as shown in Table 1.

5.1 Test of thermal camouflage effectiveness – lab or field based?

One advantage in the suggested methodology is that it provides detailed information on the thermal performance under various, and realistic conditions outdoor. Diurnal variations are covered as well as are thermal contrasts against a set of realistic background elements. In order to determine the ability of camouflage materials to follow temperature responses in scene backgrounds, thermal contrast measurements of camouflage systems and background elements must be conducted under a variety of (meteorological) conditions, which is possible with our method. One important step, in order to determine the potential of a camouflage system as effective against thermal sensors, is to capture the dynamics of the apparent surface temperature of the system under relevant weather conditions at the same time as the corresponding dynamics of the most likely backgrounds will be recorded under the same weather conditions.

In order to remain a high degree of realistic test results, the apparent temperature of the camouflage systems has to be studied in relation to the corresponding thermal behavior of the selected background elements, such as trees, heather, grass, snow, sand, rock and similar, based on the needs of the end-users. Backgrounds are generally difficult to model,

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

capturing all environmental factors, as well as for all diurnal times, due to complex structures and geometries and also by the fact that some physical processes occurring in vegetation or soil layers are very difficult to describe mathematically and then solve thermodynamically [19,20]. Similarly, camouflage systems, such as camouflage nets, being light weight, thin, textured and perforated, are difficult to model with sufficient accuracy in a dynamic background outdoor. Hence, one important advantage with our methodology over modelling or measurements in the lab is the fact that the desired goal, i.e. the question on how effective a camouflage systems reduces the potentially revealing thermal contrast in theatre, is given an answer since apparent temperature contrasts between target and backgrounds are measured directly in relation with the given weather conditions.

Furthermore, the methodology allows for calculations of camouflage effectiveness, as defined by Jacobs [19] as the percentage of a defined time interval (e.g. daytime, nighttime or similar) in which the contrast between camouflage and background element is below a specified requirement (given as T_i‘s in Table 1). This can be done for multiple requirements of the same physical contrast between a net and a specified background element. Then the achieved score of individual nets for that particular requirement will reflect the operative performance, given by the contrast in apparent temperature between target and background for a thermal sensor. Operative performance in this context is most closely related to reducing the likelihood of being detected thermally as marginal detections are mainly related to enhanced average target signature (thermally) at large distances, whereas recognitions and identifications normally require more details of the target to be revealed such as spatial features (pattern and shape) [19].

Regarding field-based evaluation of thermal camouflage effectiveness, there are important issues that must be handled with caution in order to minimize unwanted effects of outdoor coincidences affecting the results. The geometry of the camouflage systems will generally affect the measured thermal contrasts as differences in geometry of the systems that are to be compared may result in different thermal loads on the systems. Furthermore, it is important that all systems are mounted with identical angles and orientations relative to the sun and the ground in front of the front sides. Also, the exposed front area must be identical for all systems that are under evaluation to reduce artefacts affecting the outcome of an evaluation trial. This is ensured by the scaffold garages which are much easier to mount and align identical outdoor than by support systems or other procedures. Finally, as emissivity may depend on the angle of observation relative to the surface normal [20], it is important not only that the front sides of the individual nets towards the sensor are identically angled with the ground, but also that they are tightened sufficiently to plane surfaces, avoiding wrinkles or local variations in observation angle.

5.2 Background types and how to define them properly

In a test method as suggested in this paper it is obvious that the selection of background element types will have an influence on the score that is achieved by different camouflage products, and therefore also the corresponding rank. Although there has been put some effort in identifying background elements that are representative for the needs of the end-users as well as giving a sufficient coverage of relevant backgrounds or scenarios, there is no simple way of testing that the selected backgrounds are good enough. It is also difficult to standardize the methodology, as backgrounds from one scene to the next are never alike, and therefore comparisons between tests of the same camouflage systems, conducted in different areas, must be carried out with caution. Still, we believe there should be correlations between results collected in studies in different areas, but in similar climatic zones.

5.3 Possible extensions and future work

In the methodology described previous in this paper the camouflage nets (or similar) have been evaluated with no heat source behind or underneath the material surface that is being compared with backgrounds thermally. However, it is also relevant to test a camouflage net, shaped as some kind of garage, and its ability to avoid heat building up, whenever it is being actively heated. We have conducted such a test (not shown in this paper) in series with the test described in this paper. We then used a standardized heat source, in terms of a generator with fixed thermal load, located at identical position, relative height and orientation within all net garages (ref. Fig. 1). In order to conduct also a test of the thermal camouflage effectiveness, measured in thermal contrast units, when being actively heated from within, a new set of experimental data must be used as a basis when requirements are formulated as the heat source may be expected to influence on the thermal response of the nets. Hence, a table similar to Table 1, with corrected values, must be established. This part is difficult and requires a solid data material, just as in the case with no heat source, but has the potential of enhancing the relevance of the evaluation since an important purpose of a camouflage net is to ensure lowest possible contrasts also when vehicles or other heat sources are to be covered.

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

By adding a reference heat source to the test, it is also possible to study effects of thermal transmissions around regions in front of the exhaust plume of the source over time, at different diurnal time intervals, and in locations that are hot, temperate or predominately very cold.

Although the suggested procedure in this study has been developed primarily towards ground-based sensors, the concept can be expanded to other observation angles or sensor platforms. One example is elevated sensors that are thought to be more present in the future along with ongoing developments of low-cost UAVs.

Another addition, which is very similar to the methodology in this paper, is outdoor testing of mobile camouflage systems (MOCS) or similar products. Test set-ups then have to be modified slightly. Also, since MOCS are designed for montage onto vehicles, resulting in new observation angles as well as materials, new specific requirements must be established in order to make it possible to add up individual scores from all sub-tests (background types and time intervals) that are being conducted.

Formulation of requirements and how to weight them properly

The overall evaluation of camouflage products, and their relative rank in performance, rests upon a set of requirements that are weighted individually. The requirements are formulated from empirical data, from similar studies and under identical meteorological conditions so that requirements with lowest possible contrast values can be formulated and still be achievable with leading products in the market. As an example, this is why all requirements are formulated to reject periods of time where there is precipitation as that affects measurements strongly, normally reducing all thermal contrasts, and are generally very difficult to include in a data set and still maintain reproducibility. Also, the question on how to weight all single requirements remains very difficult to answer; both when it comes to the relative importance amongst various background elements as well as identifying diurnal time intervals that are considered more important than others. Still, starting out with a selection of backgrounds and sufficiently long time intervals that both are considered relevant by users and then formulate requirements based on a solid experimental material of similar products seem to be a good approach in order to conduct tests with high relevance and reduced risk of pitfalls.

6. CONCLUSIONS

In this paper we have suggested a field-based methodology for relative assessment of the effectiveness of thermal camouflage. The methodology gives an answer to, unlike modelling or lab-based approaches, questions on how effective a camouflage system is in reducing thermal contrasts in theatre based on long-term measurements of thermal contrasts between targets and backgrounds in direct relation with the given weather conditions. The methodology is capable of evaluate and rank the targets in a procedure that, as we see it, captures much of the relevant and valuable thermal data of the targets, and hence allows for ranking of camouflage targets. A detailed knowledge on the thermal performance of the camouflage materials under different conditions such as meteorological, diurnal and climatic/geographic is also being built up.

REFERENCES

[1] Gretzmacher, F. M., Ruppert, G. S. and Nyberg, S., "Camouflage assessment considering human perception data ," Proc SPIE 3375 (1998).

[2] Toet, A. and Hogervorst, M. A., "Urban camouflage assessment through visual search and computational saliency," Opt Eng 52 (2013).

[3] Toet, A., Bijl, P. and Valeton, J. M., "Image dataset for testing search and detection models," Opt Eng 40(9), 1760-1767, (2001).

[4] 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).

[5] Hecker, R., "CHAMELEON-CAMOUFLAGE ASSESSMENT BY EVALUATION OF LOCAL ENERGY, SPATIAL-FREQUENCY AND ORIENTATION," Proc SPIE 1687, 342-349, (1992).

[6] 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).

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use

[7] Schoene, R., Meidow, J. and Mauer, E.,"Feature evaluation for target/background discrimination in image sequences taken by approaching sensors ," Proc SPIE 7697, (2010).
[8] Selj, G. K. and Heinrich, D., "Search by photo methodology for signature properties assessment by human observers," Proc. SPIE 9474, 947411 (2015).
[9] Nyberg, S. and Bohman, L., "Characterizing low signature targets in background using spatial and spectral features," Proc SPIE 5152, 139-149, (2003).
[10] 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).
[11] 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).
[12] Selj, G. K., Heinrich, D., "Disruptive coloration in woodland camouflage: evaluation of camouflage effectiveness due to minor disruptive patches," Proc SPIE 9997, 99970A (2016).
[13] Toet, A. and Hogervorst, M. A., "Design and evaluation of (urban) camouflage," Proc SPIE 7662, (2010).
[14] Bobo, G., Gonda, T. and Bacon, F., "Thermal camouflage pattern prediction using PRISM and PMO," Proc SPIE 4370, 84-93 (2001).
[15] Skjervold, J. E., "Extensions of the U.S. Night GVision Laboratory static performance model for thermal viewing systems on structural targets and backgrounds in cluttered scenes",
[16] Rodgers, M. L. B., "Development and application of diurnal thermal modelling for camouflage, concealment and deception," Proc SPIE 4029 (2000).
[17] Gonda, T. and Gerhart, G. R., "A comprehensive methodology for thermal signature simulation of targets and background," Proc SPIE 1098 (1989).
[18] Jersblad, J. and Jacobs, P., "Thermal transmission of camouflage nets revisited," Proc SPIE 9997 (2016).
[19] Jacobs, P. A. M., "Experimental evaluation of thermal camouflage effectiveness," Proc SPIE 2469 (1995)
[20] Vollmer, M. and Möllmann, K. P., [Infrared Thermal imaging], Wiley-VCH Verlag, Weinheim, Germany (2010).

*gorm-krogh.selj@ffi.no; phone 004763807615; www.ffi.no

Downloaded From: https://www.spiedigitallibrary.org/conference-proceedings-of-spie on 2/25/2019
Terms of Use: https://www.spiedigitallibrary.org/terms-of-use