Evaluation of Camouflage Effectiveness of Printed Fabrics in Visible and Near Infrared Radiation Spectral Ranges

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The samples of woodland camouflage materials printed of Lithuanian army pattern were developed and investigated seeking to evaluate their camouflage effectiveness both in the visual and near IR radiation spectral ranges. The reflectance of camouflage fabrics with different surface spectral characteristics was first measured with a spectrometer. Later in order to determine near-infrared camouflage protection, the fabrics and prototypes made from these camouflage fabrics were analysed using the night vision goggles. After the investigation the optimum reflectance values in the near IR spectral range for each colour of pattern were determined. Using photo simulation and spectral analysis a camouflage efficiency evaluation method both in the visual and near IR spectral ranges was developed. The proposed method was applied for determination of the efficiency level of various woodland camouflage materials dyed and printed using different technologies.

Keywords: camouflage materials, spectral reflectance, colour fastness, visual and near IR spectral range, camouflage effectiveness.

1. INTRODUCTION

During the past decades the development of surveillance and acquisition devices is proceeding rapidly. Significant investments continue to be made to provide enhancements in these capabilities through improved sensor and processing systems and associated information transfer and fusion technologies. Observation in the visual region (VIS) remains the primary means of military surveillance, however, modern battlefield surveillance devices may operate in one or more wavebands of electromagnetic spectrum, including the ultraviolet (UV), near infrared (NIR), far infrared (FIR), and milimetric or centrimetric radar wavebands [1].

To counter this threat, CCD measures (Camouflage, Concealment and Deception) are applied to mimic targets into the operational background in all the relevant radiation spectral bands.

Textiles are widely used as the camouflage medium, in the form of light flexible nets, covers, garnishing, and clothing items. In the visible waveband it is trying to mimic natural or even artificial backgrounds, not just in terms of colour, but also patterns, gloss, and texture. The NIR region of the spectrum covers the wavelength range from 700 nm to 2000 nm, although current camouflage requirements concentrate on the 700 nm – 1200 nm [2]. In this region objects are still „seen“ by reflection. The attribute, which is required by camouflage to degrade the threat, is related to the reflectance spectrum of leaves, bark, branches, grasses, and other objects of nature in the NIR.

Camouflage efficiency represents the ability of the material to conceal the target or to diminish the detection range of the target. The detectability of a target is determined by differences between the radiative signature of the target and the local background [3].

Considering that increasing distance between the observer and the target differences between colours gradually disappear, next – between their hue and lightness, thinkable that the detection probability of the target mostly depends on colours and their differences between target and background [4]. Consequently concealing ability of textile camouflage in VIS and NIR spectral ranges mostly depend on the surface colour characteristics, particularly on the spectral reflectance distribution in these spectral ranges.

In practice, each military nation has adopted its own visual colours and patterns with definite requirements for colour characteristics, such as spectral reflectance values over VIS spectral range, CIE tristimulus values, colour values – L^* (lightness), a^* and b^* (multicoloured shade) and allowed colour difference – ΔE [5 – 6]. The requirements for surface colour in NIR spectral range are determining under the measurement the reflectance spectrum of natural objects over this range in relevant geographical regions [7, 8].

New materials and techniques offer many opportunities for colour adaptation and controlled variation of the surface reflective characteristics [9]. The parameters describing surface colour characteristics of a camouflage material can be measured in a laboratory using standardised procedures and apparatus and can provide some indication of field performance. The typical measure of effectiveness for a camouflage system is target detectability in a tactical situation. However, there is no laboratory or other readily available measurements for comprehensive detectability. In fact, the finding of NATO Workshop SCI-012 was that – at present time, man-in-the-loop assessment is the robust and effective method to evaluate camouflage detectability [10]. The method to

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evaluate the effectiveness of camouflaged targets using military trained observers is a time consuming, labour intensive, logistically difficult and expensive procedure to use. Any such evaluation is complicated by the fact that many factors such as illumination, location and seemingly random occurrences affect camouflage detection [11]. To reduce the influence of these factors, the camouflage assessments are preferably done in a relative way rather than in an absolute way using such evaluation methods as photosimulation [12]; mathematical theoretical models, based on experimental measurements and observations [4, 13, 14]; predictive software which creates and renders physics based synthetic scenes, with visual and IR modelling capabilities [15].

As this literature survey shows, the evaluation of camouflage efficiency in a wide spectral range is a complicated process and various methods are used for camouflage assessment. The woodland pattern of Lithuanian army camouflage clothing is proprietary [16]. However, there is no full-scale data regarding the requirements for spectral reflectance (over the VIS and NIR spectral range) and other colour characteristics of textile camouflage materials used for outdoor uniforms of Lithuanian army. Also no modern camouflage effectiveness evaluation method is applied for these uniforms.

The aim of the research was:

- to create and investigate the samples of woodland camouflage materials with different surface colour spectral characteristics, printed of Lithuanian army pattern;
- to develop a reasonable alternative method for the evaluation of their camouflage effectiveness both in the visual and near IR radiation spectral ranges;
- to determine optimum spectral reflectance values in the near IR spectral range for each colour of pattern, to ensure required concealing ability of material in this range.

2. MATERIALS AND METHODS OF INVESTIGATION

Woven fabrics produced from polyester (PES)/cotton blended yarns, also fabrics from pure PES printed in 4-colour woodland camouflage pattern of the Lithuanian army were investigated seeking to evaluate their camouflage effectiveness both in the visual and near IR radiation spectral ranges.

The different printing techniques were applied for blended fiber fabrics (Table 1):

- pigment printing using different pigments for relavant colour (I), using three different dye recipes ($1 \div 3$);
- mix of active and disperse dyes with different additives (II), using five different dye recipes ($1 \div 5$);
- mix of vat and disperse dyes (III);
- disperse dyes (IV) for pure PES fabrics.

To achieve required spectral reflectance in the NIR range there were selected special dyes and IR absorbing additives incorporated into printing paste [9].

Experimental investigations were carried out with 12 samples of camouflage fabrics different in VIS and NIR spectral reflectance of relevant surface colours presented in the pattern (light green, green, brown, black), and prototypes made from these fabrics. The identification and description of these fabrics presented in Table 1.

The prototypes were made from the following samples of camouflage fabrics: No. 2, 3, 11, 12.

Table 1. Identification and description of investigated fabrics

Sample No.	Fiber content	Printing technique
1	PES – 65 %, Cotton – 35 %	I, dye recipe 1
2	PES – 70 %, Cotton – 30 %	II, dye recipe 1
3	PES – 65 %, Cotton – 35 %	II, dye recipe 1
4	PES – 65 %, Cotton – 35 %	II, dye recipe 2
5	PES – 65 %, Cotton – 35 %	II, dye recipe 2
6	PES – 65 %, Cotton – 35 %	II, dye recipe 3
7	PES – 65 %, Cotton – 35 %	II, dye recipe 4
8	PES – 65 %, Cotton – 35 %	II, dye recipe 5
9	PES – 65 %, Cotton – 35 %	III
10	PES – 65 %, Cotton – 35 %	I, dye recipe 2
11	PES – 65 %, Cotton – 35 %	I, dye recipe 3
12	PES – 100 %	IV

Spectral reflactance over the VIS and NIR ranges was measured for each surface colour for all prepared samples. For this purpose spectrophotometer Datacolor Microflash MF45NIR was used. The main technical characteristics of this apparatus are the following:

- instrument geometry – 0/45;
- wavelength range of apparatus: 380 nm – 1100 nm; wavelength range used 400 nm – 1100 nm;
- area of view – 3.2 mm;
- illuminant and observer used to calculate the colorimetric values: D65/10°.

The measurements were taken according to the standard – LST EN ISO 105-J01:2000 [17]. The measurement traceability is ensured throught the calibration. The white standard of calibration No.MF45NIR.A40100 is used to calibrate the spectrophotometer. The expanded measurement uncertainty (U) was evaluated for this test – $U = 0.7$ %. The repoted uncertainty is based on a standard uncertainty multiplied by a coverage factor $k = 2$, which provides a level of cofidence of approximately 95 %.

The CMC (Colour Measurement Committee) colour difference ΔE_{CMC} was calculated acording the standard LST EN ISO 105-J03:2000 [18]. The colour difference is a single number defining the total colour difference between a test specimen and its reference specimen.

The pieces of camouflage woven fabrics and prototypes, made from these fabrics were observed in the field conditions (woodland background) and at room conditions, at given different illumination and watching distances, visually by eye obsrevation and through night vision goggles.

During the field trial all camouflage targets were displayed in the same section within a chosen woodland background. The same set of other conditions was used for each camouflage: time of the day – afternoon, time of the year – autumn, detection means, weather conditions – dry and clear, distance from the target – 10 m and 30 m. In each case the photographs were taken of the targets and their backgrounds using Canon A550 digital camera for visible spectral range and for NIR range. There were used a vision scope NV Exelon (model 24101) together with the digital camera.

A photographs of camouflage fabric also were taken at room conditions in VIS and NIR ranges using the same means as in the field trial.

3. RESULTS AND DISCUSSION

In dying and printing it was attempted to obtain such a sample of camouflage fabrics, which would correspond to Lithuanian army technical requirements for woodland outdoor uniforms in respect to the colour and pattern geometry [19]. The requirements for colour are the following: visual colours – green, light green, brown and black, shall match particular indicated colour codes of „PANTONE TEXTILE“ catalogue; the reflectance values in the NIR spectral range (700 nm – 1100 nm) should be within the 5 % – 60 % range.

Whereas no set requirements for separate colours of pattern in the NIR spectral range, which are the mostly important in the respect to the ability of printed material to conceal the target in this spectral range, the tentative tolerance ranges for each colour were determined (Fig. 1). These specified reflectance values were defined in accordance with measurements of NIR reflectance of natural objects [7, 8], which are typical for Lithuanian nature and by means off experience of other countries [5, 6].

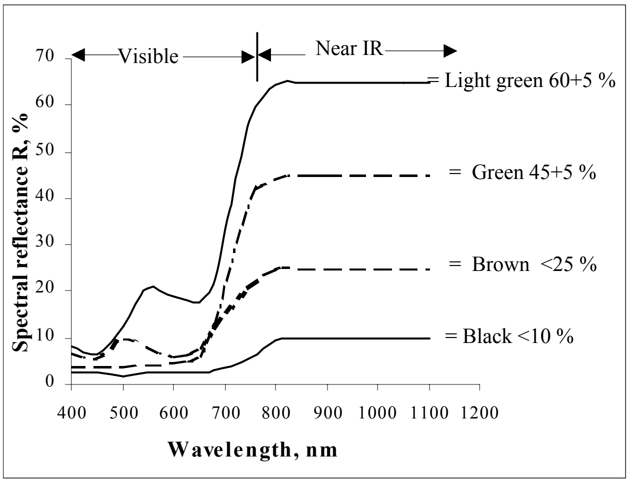

Fig. 1. Tentative requirements for woodland camouflage materials

To determine the level of camouflage efficiency in the VIS and NIR spectral ranges the samples of fabrics were first measured with a spectrometer for reflectance and then compared with results obtained after observations by eye and through night vision goggles in the field, and after the photosimulation (the evaluation photographs by observers in a laboratory settings).

During the field trial and after the photosimulation it was determinated that all tested samples have sufficiently good concealing abilities in the VIS spectral range and existing colour differences $\Delta E_{CMC} \leq 3$ of relevant colours of pattern between various tested samples have no significant influence on their camouflage efficiency.

The analysis of results obtained after observations and photosimulation in the NIR spectral range, showed that camouflage efficiency of the tested samples in this range obviously differ, because of different spectral reflectance values over the NIR range. The data of measuremens for spectral reflectance in the NIR spectral range are presented in Table 2.

Table 2. Values of spectral reflectance in NIR range

Sample No.	Dominant spectral reflectance (*R*, %) in NIR spectral range for different pattern colours:			
	Light green	Green	Brown	Black
1	58	27	13	7
2	62	63	10	7
3	47	48	19	8
4	43	46	16	7
5	37	46	17	8
6	45	47	17	7
7	47	48	19	8
8	44	47	20	8
9	44	48	9	9
10	65	53	6	4
11	64	49	6	4
12	68	53	24	10

After the comparison of results obtained during the field tests and photo modelling in the NIR range with data of measurements of spectral reflectance in NIR range, it can be concluded that samples, distinguished for good concealing properties, have clear different spectral reflectance values for each colour of pattern and these values are in the set limits (Fig. 1). The best results showed sample No. 12, for which the full scale curves of spectral reflectance in NIR range are presented in Figure 2.

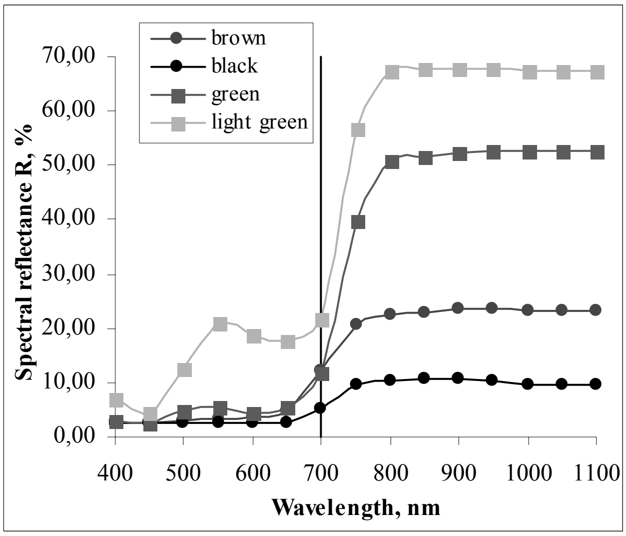

Fig. 2. Spectral reflectance of each colour of sample No. 12

Also sufficiently good results showed samples No. 3 ÷ 8, having obvious differences between values of spectral reflectance in NIR range between main colours of pattern.

Observing samples No. 9 ÷ 11 it was determined that their concealing properties in NIR range are not sufficient, because the contrast between brown and black colours is almost indistinguishable and respectively the values of spectral reflectance of these colours are very similar (see Fig. 3).

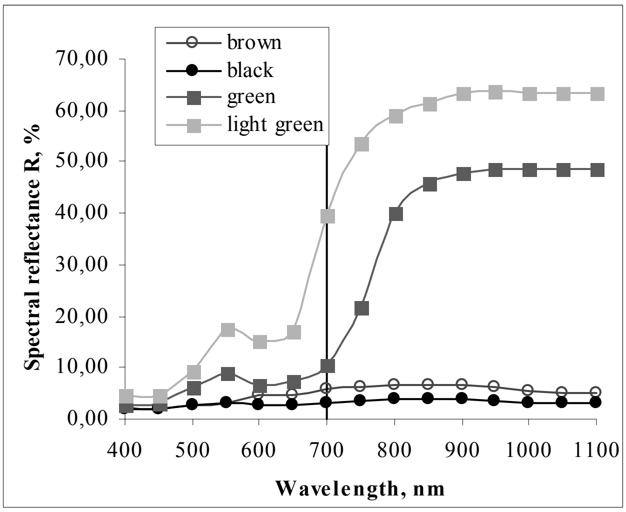

Fig. 3. Spectral reflectance of each colour of sample No.11

With reference to the data obtained, minimum and maximum ranges of spectral reflectance values in the NIR range were determined for different colours of woodland camouflage fabric to ensure optimal concealing properties during the night time (Fig. 4).

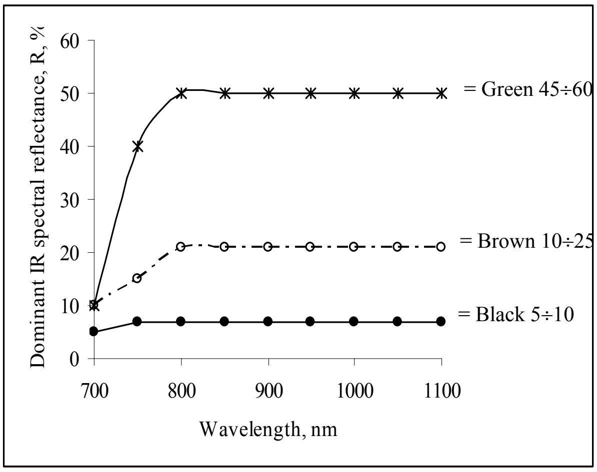

Fig. 4. Optimal values of the spectral reflectance (*R*) in NIR spectral range for different colours of the Lithuanian army's woodland camouflage fabric

In order to obtain satisfactory concealing properties of the woodland camouflage in NIR spectral range, the values of spectral reflectance of the main – green colour must be 40 % ÷ 55 %, of brown colour <25 % and of black colour <10%. The difference between dominant values of spectral reflectance of brown and black colours must be more than 7 %.

During the observation and while taking pictures of the new Lithuanian army woodland camouflage fabrics in the visual and NIR spectral ranges it was determined that the light green colour present in the pattern and covering not more than 1 % of the whole area, has only the esthetical but not the functional-concealing purpose. According to the results of the observations and spectrophotometrical measurements, it can be concluded that should be no strict requirements for the light green colour spectral reflectance in the visible and particularly in the NIR spectral range, as in this case this colour melt into the background of green colour.

Fig. 5. Evaluation of camouflage effectiveness by photo modeling in VIS spectral range

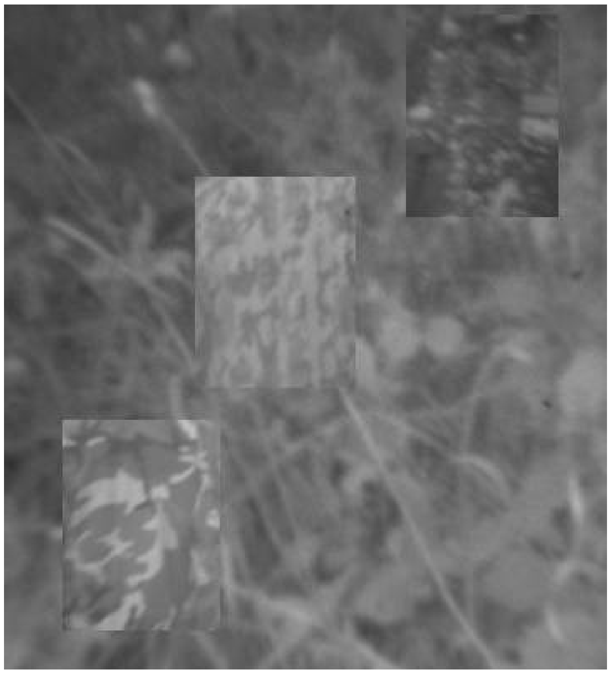

Fig. 6. Evaluation of camouflage effectiveness by photo modeling in NIR spectral range

The evaluation of camouflage effectiveness according to the spectrophotometrical measurements of reflectance properties is rather reliable as the results of it can be easily repeated and restored. This method can be applied to predict the camouflage fabric's characteristics. However for the comprehensive evaluation of the concealing ability of the camouflage materials in particular environment it is purposeful to use a complex effectiveness evaluation method – spectrophotometric measurements (see Figs. 2, 3) together with computer based photo modelling method, loading the pictures of camouflage fabric samples into the photograph of appropriate background. The sample of photo modelling in the visible spectral range is given in the Fig. 5, and for evaluation in the NIR range – in the Fig. 6.

For determining the level of camouflage adaptivity – matching to background, the 5 steps scale was used. A rating of 5 is given only when there is very good matching between the sample and the background. A rating of 1 means that the sample obviously contradistinguish from the background.

4. CONCLUSIONS

1. Samples of woodland camouflage materials having different spectral reflectance values for particular pattern colours were developed and tested for reflectance properties. It was determined, that to achieve camouflage effectiveness in the NIR spectral range, the spectral reflectance of each colour of pattern should match the appropriate spectral reflectance of particular environment and the difference between dominant values of spectral reflectance in this range must be more than 7 % for dissimilar colours

2. Minimum and maximum limits of spectral reflectance values (*R*) were determined for different colours of woodland camouflage pattern ensuring optimal concealing properties of camouflage materials during the daytime and the night time: for visible range – *R* of green colour must be 4 % ÷ 8 %, of light green colour 10 % ÷ 20 %, of brown colour 3 % ÷ 5 % and of black colour 3 % ÷ 5 %; and for NIR range – *R* of green colour must be 40 % ÷ 55 %, of brown colour <25 % and of black colour <10 %.

3. The method for evaluation of camouflage effectiveness in the visible and NIR spectral ranges was developed using photo modeling and spectral analysis of surface colours.

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