OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 1, No. 4, April 2007, p. 189 - 193

Determination of the efficiency level of the camouflage net

C. PLESA[*], I. E. SANDU[a], L. COSEREANU, D. TURCANU, GH. PLOTUNA[b]
Military Equipment and Technologies Research Agency, PO Box 51-16, Bucharest, Romania
[a]*Armaments Department, MoD, Romania*
[b]*Ministry of Administration and Interior, Romania*

Camouflage net efficiency represents the ability of the net to diminish the detection range of the target. In the paper is developed a theoretical method for the evaluation of the camouflage efficiency. The proposed method was applied to three different camouflage nets and the detection range was estimated by using a thermal camera operating in the wavelength band 8 - 12 µm.

(Received December 19, 2006; received after revision January 25, 2007; second revision February 16, 2007; accepted March 14, 2007)

Keywords: Camouflage net, Thermal detection, Camouflage efficiency

1. Introduction

The detection represents the first level of observation and assumes that something is seen in the visual field of the optoelectronic device, something that is different from background and shows interest for the observer. Detection range represents the measured value from observation point to target in the visual field of optoelectronic device.

The observation stages are: detection, recognition and identification [1-10].

In order to ensure the observation details, the optoelectronic device must work with a well defined resolution. Mathematically, the characterization of these details is given by the ratio *H/M,* where *H* represents de minimum size of the target and, *M* is the observation factor that must be within the following values: detection (M = 1±0.25), recognition (M = 4±0.8) and identification (M = 6.4±1.50).

2. Theoretical model

2.1. Detection probability and range

The probability for a target in the optoelectronic visual field to be discovered is given by the equation [1]:

$$P_{\det} = P_1 \cdot P_2 \cdot \eta \qquad (1)$$

where P_1 is the probability that the observer, looking an area in the tactical field with a potential target, regards with fovea for a certain time (1/3 s) in the target direction, P_2 is the probability that the image shown on the screen, seen with fovea and with no noise, have enough contrast and size to be detected, and η is a constant.

The probability P_1 is difficult to be estimated because it is influenced by solid angle of the visual field with the centre in the eye focal plane of the observer, by confused element number in the tactical field and by the presence of any information regarding the target position in the tactical field.

The equation for P_1 is [8]:

$$P_1 = 1 - e^{-\left(\frac{700}{G}\right)\left(\frac{a_t}{A_s}\right)t} \qquad (2)$$

where, a_t is target area, A_s is area that will be analyzed and is the visual field area in the object plan, t is the observation time, *G* is the congestion coefficient having a value from 1 to 10 for majority targets of interest.

The display object observation time is calculated on the basis of the following assumptions: the approximate time for one looking (integration time) is from 0.1 to 0.3s, the instantaneous visual field one looking is 5°.

The observation time for a display that is seen in a visual field 16° ×16°:

$$t = \frac{16^o}{5^o} \times \frac{16^o}{5^o} \times 0.3 = 3.1s \qquad (3)$$

The probability P_2 for threshold contrast C_p is by definition 50%. The probability P_2 could be calculated using the following equation for the other value of threshold contrast [8]:

$$P_2 \cong \frac{1}{2} \pm \frac{1}{2}\sqrt{1 - e^{-4.2\left(\frac{C}{C_p}-1\right)^2}} \qquad (1)\ (4)$$

Where the sign minus is used for $C < C_p$.

The η factor from eq. (1) is:

$$\eta = \begin{cases} 1 - e^{-(S/Z-1)} & S/Z \geq 1 \\ 0 & S/Z < 1 \end{cases} \qquad (5)$$

where *S/Z* is signal/noise ratio.

Therefore, using eq. (1), (2), (4) and (5), the equation that gives us the mathematics expression for detection probability of a target is:

$$P_d = \left(1 - e^{-\left(\frac{700}{G}\right)\left(\frac{a_t}{A_s}\right)t}\right) \cdot \left(\frac{1}{2} \pm \frac{1}{2}\sqrt{1 - e^{-4.2\left(\frac{C}{C_p}-1\right)^2}}\right) \cdot \left(1 - e^{-(S/Z-1)}\right) \quad (6)$$

The contrast is given by equation:

$$C = \frac{\rho_t - \rho_b}{\rho_t + \rho_b} \quad (7)$$

where ρ_t is target reflection coefficient and ρ_b is the background reflection coefficient.

The contrast for thermal devices is:

$$C = \frac{T_t - T_b}{T_t + T_b} \quad (8)$$

where T_t is the mean temperature of the target and T_b is the background average temperature.

When a night vision device with image intensifier is used for the evaluation of the efficiency of camouflage net, the resolution that must be attained by the optoelectronical system with the certain probability is given by [5]:

$$R_d[lp/mm] = \frac{C}{S/Z \cdot \sqrt{F_A}} \sqrt{\frac{S_{fk}\rho_t T_a T_o E_t t \varepsilon}{2(1+4f_{nr}^2)(1+C)e}} \times 10^{-3} \quad (9)$$

Where S/Z is the signal-noise ratio, T_a is the atmospheric transmission, T_o is the optical transmission of the objective, f_{nr} is the *f* number for objective, t is the eye integration time, ε is the minimum size /maximum target size ratio, S_{fk} is the photocathode sensibility of the image intensifier, E_t is the target illumination, and F_A is the image intensifier noise factor

The limit range, for the detection probability is given by eq. (10):

$$L_d = \frac{H}{M} R_d f_{ob} \quad (10)$$

where f_{ob} is the focal length of the objective.

If you have a thermal device than maximum detection range will be given by eq. (11):

$$L_{d,TIR} = \sqrt{\frac{T_o T_a \sigma \varepsilon' (T_t - T_b)^4 A_t A_{ob} D^*}{\pi \sqrt{A_d \Delta f}}} \quad (11)$$

where σ is the Boltzman constant, ε' is the target emissivity, A_t, A_{ob} A_d are the areas of the target, objective and detector, D^* is the sensor detectivity and Δ f is the bandwidth.

2.2. The efficiency of the camouflage net.

The camouflage net efficiency represents the camouflage net ability to decrease the target detection range into optoelectronical visual field in comparison with the detection range of the same non camouflaged target and in the same atmospheric conditions.

$$\varepsilon_{cam} = \left(1 - \frac{L_{d,cam}}{L_d}\right) \cdot \tau^{\left(\left|L_{d,cam} - L_d\right|\right)} \quad (12)$$

where τ represents atmospheric transmission, $L_{d,cam}$ represents the camouflaged target detection range and L_d is the non camouflaged target detection range.

3. Experimental measurements

The traditional camouflage nets designed for IR spectrum have a high absorption coefficient of solar energy due to their PVC consistency. The camouflage efficiency is given by the level of heat exchange with the background through convection and diffusion. The characteristics of the camouflage net will block the radiation emitted by the camouflaged target. The pattern of the net (leaf shapes) is differently used according to the climate in which the camouflage is required. In woodlands a higher convection rate is required but in desert regions is imposed the smallest possible convection rate. The most important characteristic of the desert regions is that the ground temperature falls down during night under the air temperature.

The measurements regarding of the camouflage nets efficiency has been carried out in the thermal band (8-12 μm) using thermal cameras models A20V and E45.

The atmospheric conditions in the measurement point were:

Atmospheric temperature	26.1 °C
Illumination	2000 lx
Humidity	65.3%
Wind velocity	0.6 m/s
Target temperature at 0.5 m	Cod 1 = 24 °C
	Cod 3 = 28 °C
	Cod 4 = 27 °C

The evaluated camouflage nets are presented in Fig. 1-3.

In order to decrease the efficiency of the surveillance, tracking and sighting devices, the “Code M1” camouflage net is specially designed for multi spectral purposes, lowering the thermal signatures of the target. The net is “rip-stop” type, being made from polyamide fibers of 6.6 micrometers and having in its structure at least 10%

metallic fibers. The infrared pictures appear scattered and detection as e.g. a human being can be successfully avoided. Against corrosion the net is covered with a polymer thin layer, which also has hydrophobic and oleo phobic properties.

The metallic fiber production started with a lower emissivity imposed factor for IR spectrum.

Spectral fields of interest are visible spectrum (VIS – 0.38 μm to 0.70 μm), near infrared spectrum (NIR - 0.70 μm to 1.40 μm) and thermal infrared spectrum (TIR - 3-5 μm and 8-12 μm).

In addition, due to the hydrophobic properties of the net, it gives protection against humidity, rain and against the alternating conditions of the thermal interaction with the background.

Side 1

Side 2

Fig. 1. Camouflage net in the thermal region specially designed for soldiers (Cod M1).

Fig. 2. Camouflage net in the visible spectrum designed for soldiers (Cod M3).

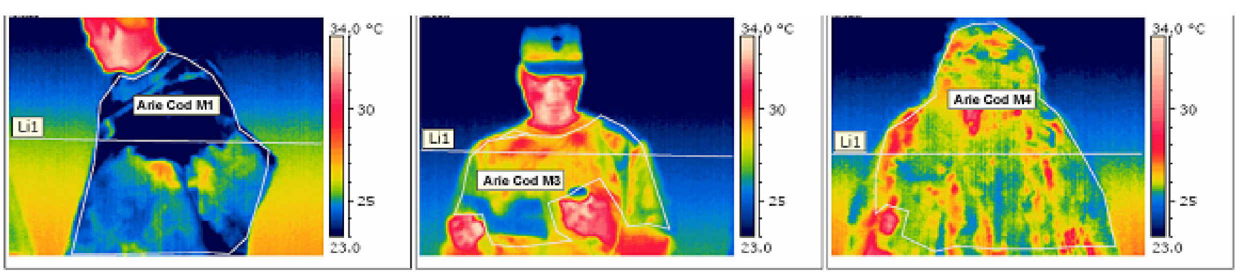
Fig. 3. Camouflage net in the visible spectrum designed for snipers (Cod M4).

The “Cod M3” and “Cod M4” camouflage nets are only designed for visible spectrum, the first being made from “rip-stop” polyamide painted with different colors and the second is made from cotton fiber which doesn’t have any special coating.

The net efficiency has been calculated using eq. (12) by solving successively the probability of detection for both camouflaged and non-camouflaged target in the same atmospheric condition. The distance for the probability of detection is less that 50% and represents the upper limit of the target detection range, camouflaged and non-camouflaged.

4. Results and discussion

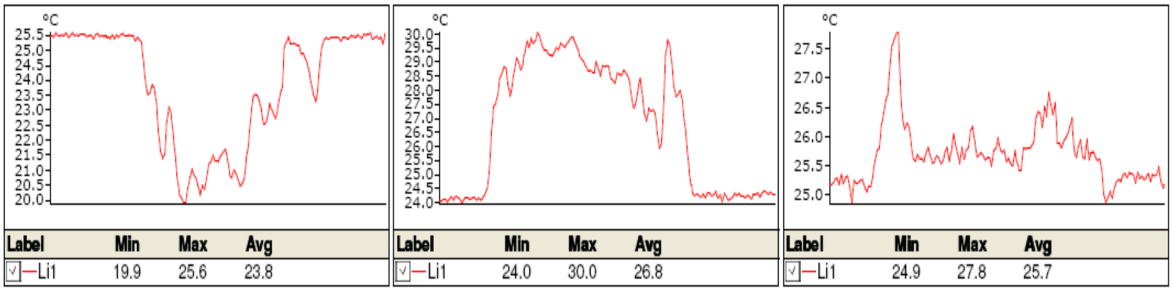
The camouflage net efficiency at the distance from target 5 m, is evidenced on Fig. 4 and 6.



(a) (b) (c)

Fig. 4. Thermal images of the same camouflaged human target with "cod M1" (a), "cod M3" (b) and "cod M4" (c).

The Fig. 5 and 7 shows the temperature variation along line Li1 and we can say that the lowest average temperature of the camouflaged target is for "Cod M1" and also, this target has the lowest thermal contrast. The target camouflaged with "Cod M1" has the lowest probability of detection at 5 m from target.



(a) (b) (c)

Fig. 5. Temperature variation along line Li1 (see Fig. 4) for camouflaged human target with "cod M1" (a), "cod M3" (b) and "cod M4" (c).

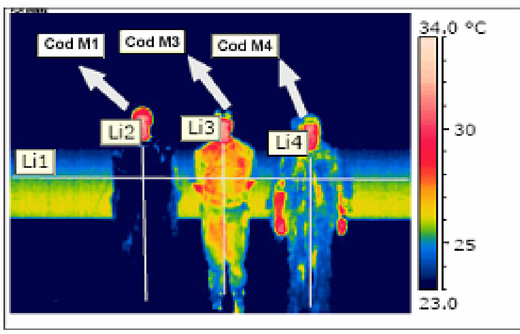


Fig. 6. Thermal image with radiometric camera model E45.

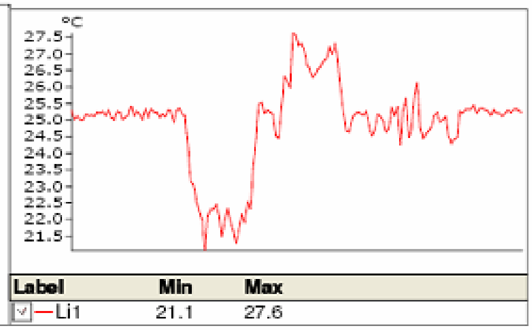


Fig. 7. Temperature variation along Li1 (see Fig. 6).

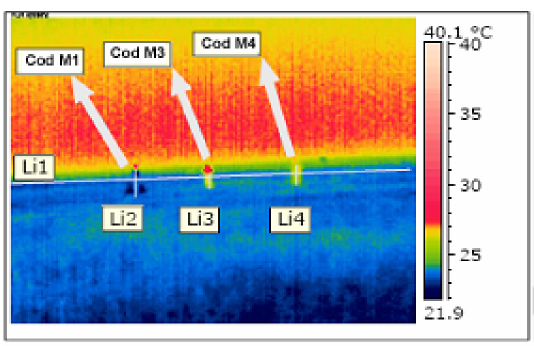


Fig. 8. Thermal image with radiometric camera model E45 (from different range).

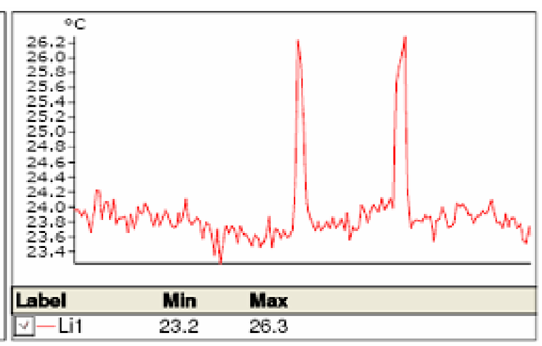


Fig. 9. Temperature variation along Li1 (see Fig. 8).

The analysis of the Fig. 8 and 9, points out to the better diminishing of the detection range due to weaker contact between background and target. The distance from target is 150 m. 150 m represents the upper range for the left camouflaged human target to be seen with a probability higher than 50%. The temperature difference from target to background is minimal for the material "Cod M1".

5. Conclusions

The determination of the efficiency level of camouflage net with the help of the equation (12) is useful to show the detection range, and the camouflage quality. This equation was developed using both experimental measurements and numerical simulations and it is based on the detection range determination of a camouflaged and non-camouflaged targets with a probability better than 50 %. The quality of the determination of the efficiency could be negatively influenced by the atmospheric conditions represented in the eq. (12) only through atmospheric transmission, τ.

Acknowledgement

The research for this work was supported by Romanian Ministry of Education and Science under the

"SECURITY" program, contract no. 27/2005, code S090 and part by Romanian Ministry of Defence.

References

[1] H. H. Bailey, Target Detection Through Visual Recognition: A quantitative Model, Rand Corporation, Santa Monica, Ca., February 1970.

[2] H. Garten, Y. Tal, Y. Swirski, Proc. Soc. Photo-opt. Inst. 5613, 166 (2004).

[3] K. B. Katsaros, A. V. Soloviev, R. M. Weisberg et al. Bound-lay Meteorol, **116**(2), 175 (2005).

[4] S. M. Hsu, J. P. Kerekes, H. H. Burke, proc, 1999 IEEE Radar Conf, p. 218-220 (1999).

[5] C. Pleşa, E. Crețu, "Considerations on the implementation of a recognition model for a target for the modern optoelectronic systems" (in Romanian), Journal of the Military Equipment and Technologies Research Agency (in Romanian), Iss. 2/2003.

[6] C. Pleşa, The use of infrared radiation for thermal signatures determination of ground targets", Communication to the 5th international Balkan Workshop on Applied Physics, Constanta, Romania, July 5-7, 2004.

[7] C. Pleşa, Contributions to the calculation and construction of night vision systems with image intensifiers, Ph. D. Thesis, Military Technical Academy, 2006.

[8] D. A. DeWolf, "Electro-Optics Handbook", p.122.

[9] W. L. Wolfe, G. J. Zissis, The Infrared Handbook, Edited by the Infrared Information and Analysis (IRIA) Center, Environmental Research Institute of Michigan, Ann Arbor, MI (1978).

[10] C. Pleşa, L. Cosereanu D. Turcanu, „Aspects regarding evaluation of the camouflage materials in the thermal domain„ (in Romanian), Symposium of textile products for special domains (in Romanian), Bucharest, 2006.

*Corresponding author: cplesa@acttm.ro