Methodology for Determining of Surveillance Conditions in Relation to Night Vision Devices Performance

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Abstract: Nowadays the devices of night vision are widely used. The working range is one of the most significant night vision device performance parameter. From user point of view, it is interesting to know the external surveillance conditions that correspond to the catalogue data for particular device. Different combinations of the external surveillance conditions complying with certain device performance can be estimated via proposed multi-criteria based methodology. It relies on multi-criteria optimization for defining of boundary points of surveillance conditions for given device performance. The described methodology is numerically verified toward two real night vision devices (goggles and sight). The results show that the described approach can help the user to compensate the missing or incomplete information in the corresponding NVDs datasheet.

Keywords: *night vision devices, external surveillance conditions, methodology, multi-criteria modeling.*

1. INTRODUCTION

Night vision devices (NVDs) give essential advantages to their users during twilight and night time. They allow performing different activities during night time as to observe various objects, to orientate, to conduct aim shooting, to drive transport, to fly aircraft, etc. Depending on application, NVDs can be divided on night vision goggles, night vision binoculars, night vision scopes, night vision rifle scopes, night vision monoculars and night vision bi-oculars. The objects of investigation in the paper are widely used passive NVDs based on image intensifying technology. Currently, the increasing interest of NVDs is associated with a reduction in their prices, with the continuous improvement of their performance and expanding of their application areas. A variety of night vision devices with different parameters are available to meet different applications requirements.

The performance of NVDs depends both on device parameters and surveillance conditions. NVD working range is a complex performance parameter that is influenced by both the device parameters and the surveillance conditions. The working range of a given NVD depends on the image intensifier tube (IIT) parameters, target characteristics, weather conditions and ambient illumination.

AMO - Advanced Modeling and Optimization. ISSN: 1841-4311

The ambient illumination, which may be comprised of lunar, galactic, and/or man-made lighting, strongly affects the ability of IIT to "see" and is essential to determine working ranges [Shirkey, R.]. Object detecting and tracking are important in any night vision-based surveillance system. Various approaches to object detection have been proposed for surveillance [Huang et al., 2008; Li et al., 2004; Monaco et al. 2006]. For outdoor night surveillance, the targets' contrast value limits the NVD working range. In practice, the value of working range given in catalogue datasheets is defined under some fixed external surveillance conditions that are not mentioned in catalogue specifications. The given value of working range in catalogue can be achieved under different combinations of the external surveillance conditions. From the user point of view, it is interesting to know what are these possible combinations corresponding to the given NVDs performance.

The paper describes a methodology for determining of different external surveillance conditions combinations complying with the catalogue data for NVD performance. The methodology is based on multi-criteria optimization to define boundary values of contrast and ambient light illumination for given NVDs performance. These boundary values together with calculated intermediate values are used to plot dependency of different external surveillance conditions for given NVDs performance.

2. NVDs PERFORMANCE

The performance of passive NVDs is a function of internal and external parameters as [Borissova & Mustakerov, 2008; Borissova & Mustakerov, 2009]:

- limiting resolution of IIT – a measure of how many lines of varying intensity (light to dark) can be resolved within a millimeter of screen area;
- signal to noise ratio – determines the low-light resolution capability and measures the light signal reaching the eye, divided by the perceived noise as seen by the eye [Higginbotham, 2006; Riegler et al. 1991];
- IIT photocathode's sensitivity – the ability of photocathode material to produce an electrical response when subjected to light photons [Task, 1992];
- optical system f-number – represents the ratio of the focal length of the lens to the diameter of the entrance pupil (diameter of the aperture) [Borissova & Mustakerov, 2008];
- ambient light illumination – the passive NVD uses available ambient light as starlight, moonlight and sky glow from distant manmade sources – city lights, etc. [Marasco et al., 2003];
- atmospheric transmittance – depends on the air temperature, atmospheric pressure, relative humidity, number and size distribution of atmospheric aerosols, concentration of abnormal atmospheric constituents such as

smoke, dust, exhaust fumes, chemical effluents, and refractive indices of all types of aerosol in the optical path [Indiso, 1970; Ohkawara, 2012];

- contrast between the background and surveillance target – monochromatic contrast difference between the integrated target and background intensities;
- type of surveillance target [Borissova & Mustakerov, 2006; Russell & Lombardo, 1998] .

Most of the internal parameters are shown in catalogue datasheets. The NVD working range mentioned in catalogue is defined under specific external surveillance conditions that in most cases are not specified. It is possible to investigate the combinations of the external surveillance conditions that correspond to the given NVD performance to help the user to compensate the missing or incomplete information.

3. BOUNDARY CONDITIONS MODELING IN RELATION OF NVDs PERFORMANCE

The functional dependence of NVDs performance of internal parameters and external surveillance conditions is expressed analytically via the proposed by the authors' formulation [Borissova & Mustakerov, 2006; Borissova & Mustakerov, 2009]:

$$R^2 = \left(\frac{0.07 D_{in} f_{ob} \tau_{ob} \tau_a S_\Sigma \delta E K A_{target}}{M \Phi_{min.ph}} \right) \tag{1}$$

where: R – working range in m; D_{in} – objective diameter inlet pupil in m; f_{ob} – objective focal length in mm, τ_a, τ_{ob} – atmosphere and objective transmittance, dimensionless; $\Phi_{min.ph}$ – image intensifier tube photocathode limiting light flow in lm; δ – IIT limiting resolution in lp/mm, S_Σ – IIT luminous sensitivity in A/lm, M – IIT' signal-to-noise ratio, dimensionless; E – ambient light illumination in lx; K – contrast, dimensionless; A_{target} – reduced target area in m^2 [Borissova & Mustakerov, 2006; Russell & Lombardo, 1998].

The atmosphere transmittance varies within narrow interval of (0.712 – 0.804) for spectral interval of NVD [Indiso, 1970]. From 1933 to late 1940s, the transmittance remained stable at around 0.74 to 0.75, in the mid-1980s it reached 0.69 and then turned into be increasing till the early 2000s marking the level of 0.71 [Ohkawara, 2012]. Because of that, the atmosphere transmittance could be considered as a constant.

The relation (1) can be used to define different combinations of external surveillance conditions corresponding to given NVDs performance. The values of minimal ambient light illumination and maximal contrast between target and background and vice versa represent two boundary points for particular target and working range. They cannot be determined from (1) because for known NVDs performance this formulation cannot be solved for two unknown variables. The theoretical minimal or maximal values of illumination and contrast in (1) could not be feasible for the given NVDs performance. The two boundaries of illumination and contrast under particular target and working range can be determined by using of multi-criteria problem formulation.

One of the boundary points corresponds to maximum of external ambient light illumination and minimum of contrast between target and background. It can be determined by solving the multi-criteria *Problem 1*:

$$\begin{cases} \max E = \left(\dfrac{R^2 M \Phi_{min.ph}}{0.07 D_{in} f_{ob} \tau_{ob} S_{\Sigma} \delta \tau_a K A_{target}} \right) \\ \min K = \left(\dfrac{R^2 M \Phi_{min.ph}}{0.07 D_{in} f_{ob} \tau_{ob} S_{\Sigma} \delta \tau_a E A_{target}} \right) \end{cases} \quad (2)$$

subject to:

$$E^l \le E \le E^u \quad (3)$$

$$K^l \le K \le K^u \quad (4)$$

$$A^l \le A_{target} \le A^u \quad (5)$$

where E^u, K^u, A^u and E^l, K^l, A^l are upper and lower boundaries for the ambient light illumination, contrast and reduced target area; R is given detection range in meters; M, $\Phi_{min.ph}$, D_{in}, f_{ob}, τ_{ob}, S_{Σ}, and δ are constants that depend on particular NVDs performance.

The other boundary point corresponding to minimal ambient light illumination and maximal contrast can be defined by solution of the *Problem 2:*

$$\begin{cases} \max K = \left(\dfrac{R^2 M \Phi_{min.ph}}{0.07 D_{in} f_{ob} \tau_{ob} S_{\Sigma} \delta \tau_a E A_{target}} \right) \\ \min E = \left(\dfrac{R^2 M \Phi_{min.ph}}{0.07 D_{in} f_{ob} \tau_{ob} S_{\Sigma} \delta \tau_a K A_{target}} \right) \end{cases} \quad (6)$$

subject to (3) – (5).

4. METHODOLOGY FOR DETERMINATION OF SURVEILLANCE CONDITIONS IN RELATION TO NVDs PERFORMANCE

In the paper, a methodology for determination of the surveillance conditions in relation to NVDs performance is proposed (Fig. 1).

The first stage of methodology collects the internal NVDs parameters data from the device datasheet. On the next stage, the values for upper and lower boundaries of ambient light illumination and contrast are to be set up. Next, surveillance target type should be defined, for example – standing man or jeep or tank, etc. Then, the *Problem 1* (for maximum of external ambient light illumination and minimum of contrast between target and background) and *Problem 2* (for minimal ambient light illumination and maximal contrast) are formulated.

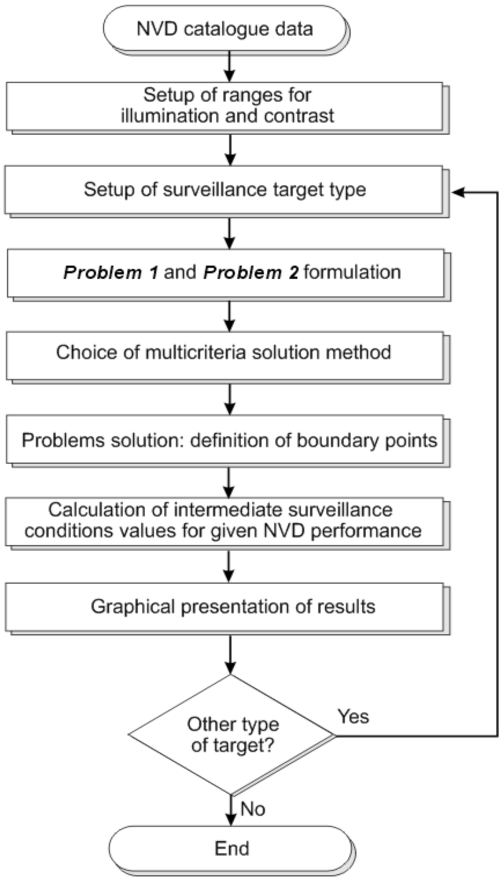

Fig. 1. Methodology for determining of external surveillance conditions in relation to NVDs performance

To solve the formulated problems, a proper multi-criteria optimization solution method has to be chosen. The result of problems solution is definition of two boundary combinations of ambient light illumination and contrast, conforming to the given NVDs performance. The type of curve following the dependency from the equation (1) can be simplified as E ~ 1/K or K ~ 1/E as illustrated in Fig. 2.

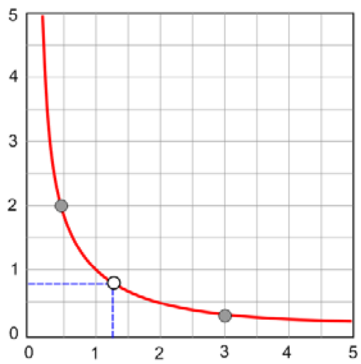

Fig. 2. Simplified dependency for E ~ 1/K (K ~ 1/E)

It is an example of rectangular hyperbola or so called reciprocal function (y=1/x). The defined boundary points and some intermediate points calculated by (1) present graphically all feasible combinations of night illumination and contrast for given NVD performance. This graphical presentation can be used to define particular value for illumination (contrast) for some given value of contrast (illumination) – see Fig. 2.

On the last stage of methodology, NVDs performance can be explored toward other surveillance target types if needed.

The presented methodology allows exploring different combinations of external surveillance conditions complying with the catalogue data for NVD performance.

5. VERIFICATION OF THE PROPOSED METHODOLOGY

The proposed methodology is verified numerically for two types of NVDs – night vision goggles and weapon sight, with catalogue data in Table 1:

Table 1. Night vision devices catalogue data

Limiting resolution *lp/mm*	Signal to noise ratio, *dimensionless*	Photocathode sensitivity, *A/lm*	Objective inlet pupil diameter, *m*	Focal length, *mm*	Detection range, *m*
Night Vision Goggles – MVP-MV14BGP*					
64	21	0.001350	0.018	25	300
Weapon Sight – MV-740**					
64	24	0.001800	0.018	100	425

Internet resources: * http://www.morovision.com/night_vision_goggles/MVP-MV-14BGP.htm
** http://morovision.com/weapons_sights/MVPA-MV-740-3P.htm

For both devices, objective transmittance is considered to be equal to 0.80, the minimal photocathode sensitivity of 3.4x10^{-12} *A/lm* and atmosphere transmittance of 0.71. The external surveillance conditions vary within following boundaries:

- night illumination E is changed within interval from overcast night sky illumination (starlight) to full moon illumination ($0.00013 \le E \le 0.013$ *lux*);
- contrast K between surveillance target type and background is limited within interval of $0.1 \le K \le 0.5$;
- reduced target area according to the Johnson' criteria [Russell & Lombardo, 1998] for different targets: 1) standing man (A_{man} = 0.72 m^2), 2) jeep (A_{jeep} = 2,47 m^2); 3) truck (A_{truck} = 5.9 m^2) and 4) tank (A_{tank} = 10 m^2).

4.1. Formulation of Task 1 and Task 2 for *Problem 1* and *Problem 2*

For the goal of methodology numerical verification, the *weighted sum* method [Marler & Arora, 2010] is chosen to solve the formulated multi-criteria problems. The original *Problem 1* and *Problem 2* are transformed to single criterion tasks as:

***Task 1*:**

$$\max\left(w_1 E' + w_2 K'\right) \quad (7)$$

subject to (3) – (5) and $\sum_i w_i = 1$, where $E' = \frac{E - E^{\min}}{E^{\max} - E^{\min}}$, $K' = \frac{K^{\max} - K}{K^{\max} - K^{\min}}$ are normalized objectives [Marler & Arora, 2010].

***Task 2*:**

$$\max\left(w_1 E' + w_2 K'\right) \tag{8}$$

subject to (3) – (5) and $\sum_i w_i = 1$,

where $K' = \frac{K - K^{\min}}{K^{\max} - K^{\min}}$, $E' = \frac{E^{\max} - E}{E^{\max} - E^{\min}}$ are normalized objectives.

The solutions results of *Task 1* and *Task 2* shown in Table 2 define boundary points for illumination and contrast for 4 type of surveillance targets – standing man, jeep, truck and tank.

Table 2. The solution results for boundary points of night illumination and contrast

NVDs	Target type	Illumination, *lux*	Contrast, *dimensionless*	Given detection range, *m*
Night vision goggles MVP-MV14BGP	*Task 1: (max E, min K, w_1=0.50, w_2=0.50)*			
	standing man (A_{man} = 0.72)	0.0130000	0.44	300
	jeep (A_{jeep} = 2.47)	0.0130000	0.13	300
	truck (A_{truck} = 5.9)	0.0007045	0.10	300
	tank (A_{tank} = 10)	0.0041568	0.10	300
	Task 2: (min E, max K, w_1=0.50, w_2=0.50)			
	standing man (A_{man} = 0.72)	0.011547	0.50	300
	jeep (A_{jeep} = 2.47)	0.003365	0.50	300
	truck (A_{truck} = 5.9)	0.001409	0.50	300
	tank (A_{tank} = 10)	0.000831	0.50	300
Weapon sight MV-740	*Task 1: (max E, min K, w_1=0.50, w_2=0.50)*			
	standing man (A_{man} = 0.72)	0.001000	0.25	425
	jeep (A_{jeep} = 2.47)	0.007237	0.10	425
	truck (A_{truck} = 5.9)	0.003030	0.10	425
	tank (A_{tank} = 10)	0.001787	0.10	425
	Task 2: (min E, max K, w_1=0.50, w_2=0.50)			
	standing man (A_{man} = 0.72)	0.004965	0.50	425
	jeep (A_{jeep} = 2.47)	0.001447	0.50	425
	truck (A_{truck} = 5.9)	0.000606	0.50	425
	tank (A_{tank} = 10)	0.000357	0.50	425

To represent graphically the feasible combinations of illumination and contrast some intermediate points are calculated by relation (1). The results are shown in Table 3.

Table 3. Intermediate points of night illumination and contrast

NVDs	Target type	Illumination, *lux*	Contrast, *dimensionless*	Given detection range, *m*
Night vision goggles MVP-MV14BGP	*standing man (A_{man} = 0.72)*	0.013000	0.44	300
	jeep (A_{target} = 2.47)	0.013000	0.13	300
	truck (A_{target} = 5.9)	0.000705	0.10	300
	tank (A_{target} = 10)	0.004157	0.10	300
Weapon sight MV-740	*standing man (A_{man} = 0.72)*	0.001000	0.25	425
	jeep (A_{jeep} = 2.47)	0.007237	0.10	425
	truck (A_{truck} = 5.9)	0.003030	0.10	425
	tank (A_{tank} = 10)	0.001787	0.10	425

The data from Table 2 and Table 3 are used to represent graphically the dependency of night illumination and contrast for two types of night vision devices under 4 different surveillance target types as shown in Fig. 3.

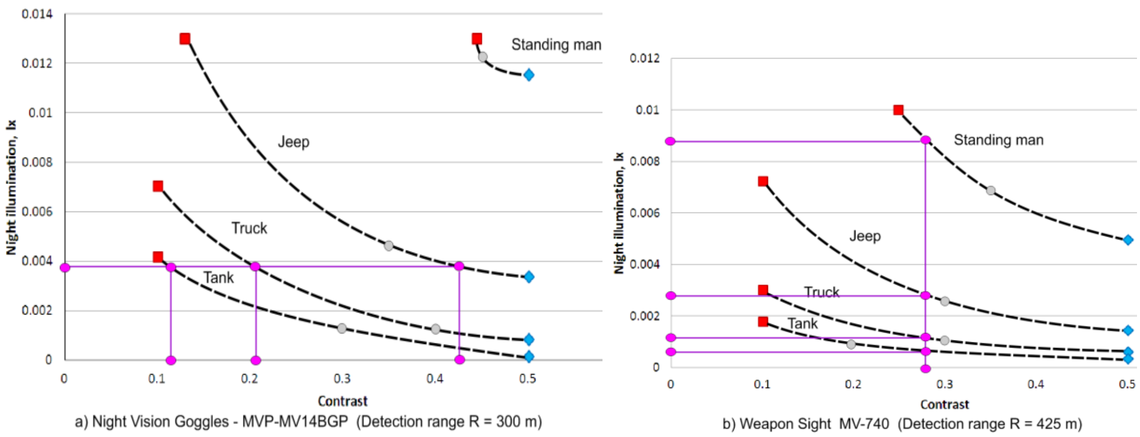

Fig. 3. The dependency of night illumination and contrast for given NVDs performance

As could be seen from Fig. 3, there exist more than one combination of night illumination and contrast for given type of target conforming to the given NVDs performance. Using these curves it is possible to estimate the effectiveness of particular NVD toward different combinations of night illumination and contrast. For example, if night illumination is 0.0038 (Fig. 3a) the goggles detection range of 300 m can be provided for contrast of: 0.12 (tank), 0.21 (truck) and 0.42 (jeep). As it can be seen from Fig. 3a, the detection of standing man is impossible for this value of illumination. If contrast is fixed to 0.28 (Fig. 3b), the weapon sight detection range of 425 m is achieved for illumination of 0.0005 for tank, 0.001 for truck, 0.0024 for jeep and 0.0088 for standing man. If other values of illumination or contrast are to be considered, the performance of given NVD can be estimated roughly in advance by similar graphical representations. The exact estimations can be done by calculation of the corresponding intermediate points using the relation (1).

6. CONCLUSION

In the current paper, a multi-criteria based methodology for defining combinations of external surveillance conditions in relation to NVDs performance is described. Some of NVDs parameters often are given in catalogues with insufficient information about the external surveillance conditions that correspond to the given NVDs performance. Using the proposed methodology, the combinations of external surveillance conditions relevant to the given NVD performance could be explored. The described methodology was numerically verified toward two real NVDs (goggles and sight) with known parameters. For the goal, multi-criteria problems defining boundary points of external surveillance conditions are formulated: *Problem 1*, for maximum of external ambient light illumination and minimum of contrast between target and background and *Problem 2* for the combination of minimal ambient light illumination and maximal contrast. Both multi-criteria problems are solved by *weighted sum* method but there is no limitation to use other multi-criteria solution method. The intermediate points between defined boundary points can be calculated using the relation (1). The numerical verification of the methodology based on real night vision goggles and weapon sight data show that the proposed methodology allows estimation of surveillance conditions combinations complying with given in NVDs datasheets performance. Thus, the described approach can help the user to compensate the missing or incomplete information in the corresponding NVDs datasheet.

Acknowledgment

This work has been supported by the project "*Development of applied optimization models and methods based on single- and multi-objective problems*".

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