BULGARIAN ACADEMY OF SCIENCES

CYBERNETICS AND INFORMATION TECHNOLOGIES • Volume **6**, No 3

Sofia • 2006

A Working Distance Formula for Night Vision Devices Quality Preliminary Information*

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***Abstract**: A night vision devices working distance formula is proposed taking into account essential parameters of the optoelectronic channel elements and the external conditions. Using the Johnson criterion, a parameter "reduced target area" is used. That parameter allows calculating of the different types of working distance – detection, orientation, recognition, identification, for different types of objects. The relevant formulae give a theoretical information about the night vision devices working distance on the design stage before a prototype producing and they reduce testing "trial and error" costs. An experimental comparison between a calculated through the proposed formula standing man detection range and some catalogue data and between the calculated standing man recognition range and a measured recognition range from the night vision goggles "Prilep" testing is shown.*

***Keywords**: night vision devices, working distance– detection, orientation, recognition, identification, preliminary information, theoretical formulae, "reduced target area".*

1. Introduction

Since the first introduction of the night vision devices (NVD) in 1930's their design has been improved and now they are highly efficient devices for both military and civil applications [1, 2]. Especially the night vision devices based on low light level amplifying technology (L^3NVD) has got recently an essential increased usage. All of them are built around optoelectronic channel (or channels), consisting of objective, image intensifier tube (IIT) and eyepiece (ocular). Depending on the construction (binoculars, biocular, monoculars) one or two optoelectronic channels are to be designed. The optoelectronic channel parameters are essential for the parameters of the device itself. One of the most important parameter for the NVD is its working distance (as detection, orientation, recognition or identification range). The usual

* This work is supported by IIT – BAS projects No 010068.

practice for the determining of the NVD working distance is a laboratory or field testing of the built prototypes [3, 4]. If the results of testing are not what are expected a redesign and a new prototype building and testing is needed. That repetitive process of redesign, rebuild and testing of the NVD prototypes trying to satisfy the desired requirements, is money and time consuming process. The theoretical estimation of the NVD working distance on the design stage taking into account as many as possible of the essential parameters of the NVD optoelectronic channel elements and the external parameters would increase the effectiveness of the design process and decrease the costs of the multiple prototypes designing and testing [3, 5]. The paper describes in details the assumptions used in the process of defining of the proposed NVD working range calculation formula [5].

2. Parameters influencing the NVD working distance

There exist a number of parameters that affect the working distance of the NVD. It is evident that the bigger objects are seen on bigger working distance, i.e. the size of object is an important parameter. The external conditions for observation (atmosphere transmittance, ambient light illumination and contrast) including whether conditions (rain, snow, fog, etc.) are also essential for the working distance values. The parameters of the NVD optoelectronic channel – diameter of the inlet pupil, objective focal length, objective transmittance, IIT luminous sensitivity, IIT limiting resolution, IIT signal-to-noise ratio and IIT photocathode limiting light flow, are critical for the working distance value.

A known widely used method for the NVD optoelectronic channel design is based on light energy equations. It is called “energy calculations method” (ECM) [6, 7] and relies on the bigger object-background reflected light energy difference than the IIT photocathode limiting light flow. The ECM method can be used for a theoretical working distance calculation when the NVD parameters and external observing conditions are known or for the NVD parameters determination with a working distance set. Using ECM a formula for theoretical estimation of the NVD working distance is proposed (in m):

(1) $$R = \sqrt{\frac{A_{\mathrm{in}} A_{\mathrm{ob}} \tau_{\mathrm{o}} \tau_{\mathrm{a}} E S_{\Sigma} K}{\pi M \Phi_{\mathrm{min.ph}}}} \,.$$

It takes into account the following parameters: A_{in} – area of the inlet pupil (m^2), A_{ob} – target area (m^2), τ_{a}, τ_{o} – atmosphere and objective transmittance, E – ambient light illumination (lx), S_{Σ} – IIT luminous sensitivity (A/lm), K – contrast, M – IIT signal-to-noise ratio, $\Phi_{\mathrm{min.ph}}$ – IIT photocathode limiting light flow (lm).

A disadvantage of the (1) is not taking into account the NVD resolution. To introduce it in the (1) the definition of the resolution [8] for a real optical system can be used (in angle minutes):

(2) $$\gamma = \frac{140}{D_{\mathrm{in}}} \,,$$

where the D_{in} is the inlet pupil diameter in millimeters.

Taking into account that the area of the circular inlet pupil is (in m^2)

$$A_{\mathrm{in}} = \frac{\pi D_{\mathrm{in}}^2}{4} \tag{3}$$

and rewriting (3) as $A_{\mathrm{in}} = \frac{\pi D_{\mathrm{in}} D_{\mathrm{in}}}{4}$ (in m^2), where D_{in} can be expressed from (2) as

$$D_{\mathrm{in}} = \frac{140}{\gamma},$$

the equation (2) is modified to:

$$A_{in} = \frac{\pi D_{in}}{4}\frac{140}{\gamma}10^3. \tag{3a}$$

In (3) the diameter D_{in} has dimension in meters and in (2) it is dimensioned in millimeters, so the multiplication by 10^3 in (3a) is needed. Using (3a) the formula (1) is transformed to (in m)

$$R = \sqrt{\frac{0.035 D_{\mathrm{in}} A_{\mathrm{ob}} \tau_{\mathrm{o}} \tau_{\mathrm{a}} E S_{\Sigma} K}{\gamma M \varPhi_{\mathrm{min.ph}}}}. \tag{4}$$

That formula takes into account the NVD resolution but the problem is that it is not known until a prototype is produced and its resolution is measured. There exists a similar formula [9] for calculating of the NVD working distance which also uses the overall NVD resolution measured after the prototype testing (in m)

$$R = 3.10^5 \sqrt{\frac{\tau_{\mathrm{o}} \tau_{\mathrm{a}} D_{\mathrm{in}} S_{\Sigma} E K}{M \gamma}}, \tag{4a}$$

where D_{in} is the inlet pupil diameter (m), τ_{o} and τ_{a} – atmosphere and objective transmittance, S_{Σ} – IIT luminous sensitivity (A/lm), E – ambient light illumination (lx), K – contrast, M – IIT signal-to-noise ratio, γ – resolution (rad).

As it was pointed out earlier, it is important to have a formula for the NVD working distance theoretical estimation based on the essential elements parameters on the design stage before the prototype producing and testing. That needs the determination of a theoretical NVD resolution as a function of the parameters of the NVD optoelectronic channel elements (objective, IIT and eyepiece). The eyepieces used in modern NVD are of high quality and their resolution is usually better than the IIT resolution so, the eyepiece could be ignored in the NVD resolution estimation. In practice only the objective and image intensifier tube resolutions are to be considered for the determination of the NVD resolution. The objective resolution δ for an infinitely distanced object is defined as [8]:

$$\delta = \frac{\Delta y'}{f'_{\mathrm{ob}}}, \tag{5}$$

where f'_{ob} is the objective focal length in millimeters (Fig. 1).

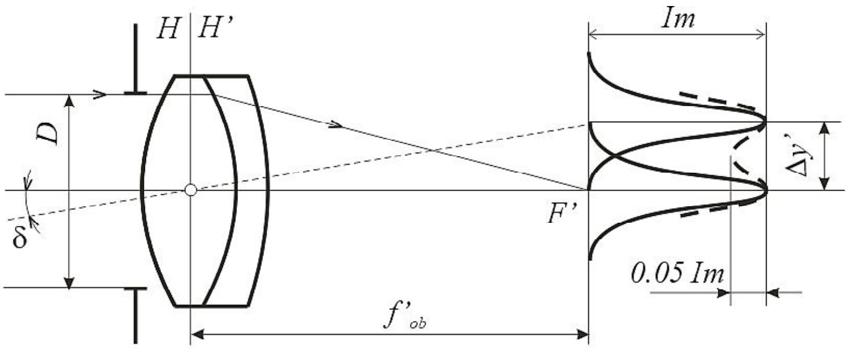

Fig. 1. Defining of the objective resolution

The IIT limiting resolution δ_{IIT} (lp per 1 mm) defines the minimum observed object size as

(6) $$\Delta l = \frac{1}{2\delta_{\mathrm{IIT}}}.$$

For the modern objectives $\Delta l \geq \Delta y'$ and the IIT resolution is the important parameter to be considered for the overall NVD resolution.

Using (5) and (6), the preliminary estimation for the NVD resolution can be defined as

(7) $$\delta_{\mathrm{ob-IIT}} = \frac{\Delta l}{f'_{\mathrm{ob}}} = \frac{1}{2\delta_{\mathrm{IIT}}\, f'_{\mathrm{ob}}},$$

where $\Delta y'$ in (5) is substituted by the Δl from (6).

The parameter $\delta_{\mathrm{ob-IIT}}$ from (7) substitutes γ in (4) and the result is (in m)

(8) $$R = \sqrt{\frac{0.07 D_{\mathrm{in}}\, f'_{\mathrm{ob}} \tau_{\mathrm{o}} \tau_{\mathrm{a}} S_{\Sigma} \delta_{\mathrm{IIT}} E A_{\mathrm{ob}} K}{M \Phi_{\mathrm{min.ph.}}}},$$

where:
D_{in} – diameter of the inlet pupil (m),
f'_{ob} – objective focal length (mm),
τ_{a}, τ_{o} – atmosphere and objective transmittance,
S_{Σ} – IIT luminous sensitivity (A/lm),
δ_{IIT} – IIT limiting resolution (lp per 1 mm),
E – ambient light illumination (lx),
A_{ob} – target area (m^2),
K – contrast,
M – IIT signal-to-noise ratio,
$\Phi_{\mathrm{min.ph}}$ – IIT photocathode limiting light flow (lm).

That way defined formula (8) allows theoretical estimation of the expected working distance on the NVD design stage. It takes into account the essential NVD optoelectronic channel elements parameters (diameter of the inlet pupil, objective focal length, objective transmittance, IIT luminous sensitivity and IIT limiting resolution) as well as the external conditions (atmospheric transmittance, ambient light illumination, target area and the contrast between the target and its background).

3. Estimation of the different types working distance using the Johnson criteria

In the 1950's Johnson proposed a criteria that relates the number of resolution lines across a target critical dimension to the probability of the operator detection, orientation, recognition or identification of the target. The resolutions for minimum dimensions per line pairs for some typical objects and for different types of the working distance defined by Johnson criteria are shown in Table 1 [10].

Table 1. Johnson criteria

Target (Broadside view)	Resolution per minimum dimension in line pairs			
	Detection	Orientation	Recognition	Identification
Truck	0.90	1.25	4.5	8.0
M-48 tank	0.75	1.20	3.5	7.0
Stalin tank	0.75	1.20	3.3	6.0
Centurion tank	0.75	1.20	3.5	6.0
Half-track	1.0	1.50	4.0	5.0
Jeep	1.2	1.50	4.5	5.5
Command car	1.2	1.50	4.3	5.5
Soldier (standing)	1.5	1.80	3.8	8.0
105 Howitzer	1.0	1.50	4.3	6.0
Average	1.0 ±0.25	1.4 ±0.35	4.0±0.35	6.4±1.5

To use that table for the different types working distance estimation a new parameter is introduced – "a reduced target area" A'_{ob} [5], i.e. the target area A'_{ob} is divided by minimal number of the line pairs according to the Johnson criteria and for the chosen type of the working distance – detection, orientation, recognition or identification. Using the reduced target area A'_{ob} in (8) instead of the target area A'_{ob} some formulae for theoretical estimation of the different types NVD working distance can be defined as follows:

for the detection range (in m)

$$R^{\mathrm{d}} = \sqrt{\frac{0.07 D_{\mathrm{in}} f'_{\mathrm{ob}} \tau_{\mathrm{o}} \tau_{\mathrm{a}} S_{\Sigma} \delta_{\mathrm{IIT}} E K A'^{\mathrm{d}}_{\mathrm{ob}}}{M \Phi_{\mathrm{min.ph}}}}, \tag{9a}$$

for the orientation range (in m)

$$R^{\mathrm{or}} = \sqrt{\frac{0.07 D_{\mathrm{in}} f'_{\mathrm{ob}} \tau_{\mathrm{o}} \tau_{\mathrm{a}} S_{\Sigma} \delta_{\mathrm{IIT}} E K A'^{\mathrm{or}}_{\mathrm{ob}}}{M \Phi_{\mathrm{min.ph}}}}, \tag{9b}$$

for the recognition range (in m)

$$R^{r} = \sqrt{\frac{0.07 D_{\mathrm{in}} f'_{\mathrm{ob}} \tau_{\mathrm{o}} \tau_{\mathrm{a}} S_{\Sigma} \delta_{\mathrm{IIT}} E K A'^{\mathrm{r}}_{\mathrm{ob}}}{M \Phi_{\mathrm{min.ph}}}}, \tag{9c}$$

for the identification range (in m)

$$R^{\mathrm{i}} = \sqrt{\frac{0.07 D_{\mathrm{in}} f'_{\mathrm{ob}} \tau_{\mathrm{o}} \tau_{\mathrm{a}} S_{\Sigma} \delta_{\mathrm{IIT}} E K A'^{\mathrm{i}}_{\mathrm{ob}}}{M \Phi_{\mathrm{min.ph}}}}, \tag{9d}$$

where $A'^{\mathrm{d}}_{\mathrm{ob}}$, $A'^{\mathrm{or}}_{\mathrm{ob}}$, $A'^{\mathrm{r}}_{\mathrm{ob}}$, $A'^{\mathrm{i}}_{\mathrm{ob}}$ are the reduced target areas for different types working ranges – detection, orientation, recognition and identification respectively.

4. Experimental testing by comparing of the theoretically calculated different types of the working distance to the real measured ones for night vision goggles (NVG)

Some typical IIT, objective and external conditions parameters are used for the theoretical calculations of the standing man detection range R^{d} by (9a):

- IIT generation II, type Photonis XX1410 (S_{Σ} = 0.00035 A/lm, δ_{IIT} = 32 lp per 1 mm, M = 12),
- IIT generation IV, ITT MX-10160B (S_{Σ} = 0.002100 A/lm, δ_{IIT} = 72 lp per 1 mm, M = 36),
- objective (D_{in} = 0.018 m, f'_{ob} = 25.17 mm, τ_{o} = 0.8),
- external conditions (E = 0.01 lx, τ_{a} = 0.75, K = 0.25, $A'^{\mathrm{d}}_{\mathrm{man}}$ = 0.72 m^2).

The calculated by (9a) R^{d} values and the catalogue data for some real NVG [11, 12] are shown in Table 2.

Table 2. Standing man detection ranges

IIT generation	Target	Illumination E, lx	Catalogue data R^{d}, m	Calculated by (9a) value R^{d}, m	Relative difference $\Delta_1 = \frac{R^{\mathrm{d}}_{(9a)} - R^{\mathrm{d}}}{R^{\mathrm{d}}_{(9a)}} 100\%$
II	Standing man	0.01	300 [11]	282.70	6.12
IV	Standing man	0.01	549 [12]	599.70	8.45

The NVG parameters and the external conditions parameters not shown in table 2 are not shown in the NVG catalogue data and some chosen typical values are used that could explain the differences. The relative difference between man detection range calculated by means of (9a) and the published results [15, 16] are quite close. That means the proposed formulae (9a), (9b), (9c), (9d) can be used for the theoretical estimation of the NVD working range before the NVD prototype producing and testing.

Another experimental results comparison is made by using a theoretical estimation of the standing man recognition range R^{r} calculated by (9c) and the real field measured result for the Bulgarian made NVG "Prilep" [13] (Table 3).

Table 3. Standing man recognition ranges

$A'^{\mathrm{r}}_{\mathrm{ob}}$, m^2	D_{in}, m	f_{ob}, mm	τ_{o}	S_{Σ}, A/lm	δ_{IIT}, lp per 1 mm	M	E, lx	τ_{a}	K	Measured value	Calculated by (9c) value	Δ_2
DEP's IIT: XX1940										R^{r}, m	R^{r}, m	%
0.28	0.018	25.17	0.8	0.00055	50	20	0.035	0.75	0.20	320 [13]	360.74	11

The NVG “Prilep” field testing external conditions are known as:

• weather – cloudy moonless starless winter night, moderate wind, temperature 0 °C and 0.20 m snow,

• measured ambient light illumination 0.035 lx,

• target – a standing on cart-road man (height = 1.8 m, width = 0.6 m) in camouflage clothing at the bush background.

The atmospheric transmittance and the contrast have not been measured during the field test and the closest supposed values are used for the calculation by (9c) which could be explanation for the 11% relative difference. Taking into account that the external conditions parameters are not constant and are dynamically changing through the testing sessions then the difference of 11% could be quite acceptable. On the basis of the results in Table 3 it could also be stated that the proposed formulae (9a), (9b), (9c), and (9d) could be used for a preliminary theoretical estimation of the NVD working range.

5. Conclusions

The modern designing of the NVD includes choice of some elements with known parameters – objective, image intensifier tube, ocular, battery power supply, etc. Some of them directly influence one of the most important NVD parameter – working range. The preliminary theoretical estimation of the NVD working range as a result of the NVD elements choice could reduce costs for the producing and testing of a number of prototypes. The theoretical estimation of the NVD working range as a function of the NVD parameters is also needed for optimizing of the design process by mathematical programming methods. The proposed formulae can be used for a theoretical estimation of the working distance for the different low light level night vision devices. The experimental comparison show that the results calculated by the defined formulae are quite close to the practically measured distances from the real prototypes testing. More real data will be collected and compared with the theoretically calculated ones to prove the practicability of the proposed formulae. Currently they are implemented in a combinatorial choice software system used in the practice of the Bulgarian company “ElkoE”.

References

1. Night Vision Goggles in Civil Helicopter Operations. Aviation research report, B2004/0152, ISBN 1877071943, 2005. 33 p.
2. Koschavtsev, N. F., S. F. Fedorova, V. V. Gorkin. Night-Vision Devices of Civil Purpose. – In: The 16-th Inernational Scientific-and-Technical Conference on Photoelectronics and Night Vision Devices, May 25-27, Moscow, Russia, 2000.
3. Koshchavtsev, N. F., A. N. Koshchavtsev, S. F. Fedotova. About the Recognition Range in Low-Light-Level Visualization System. – Applied Physics, 1999, No 4.
4. Krivoshapkin, I. B., Yu. G. Edelshtain. Handling the Results of Field Tests by a Multiple Correlation Method. – In: The XV International technological conference on photoelectronics, Electronic and Ionic-Plasma Engineering, October 28-30, Moscow, Russia, 1998.
5. Borissova, D. Analytical Calculation of Night Vision Goggles Working Range. – Cybernetics and Information Technologies, Vol. **5**, 2005, No 2, 142-155.
6. Elizarenko, A. S., U. Parvolusov, V. Soldatov, U. Yakushenkov. Optoelectronics Devices Design, Moscow, Mashinostroenie, 1981. 262 p. (in Russian).

7. R a z u m o v s k i y, I. T. Night Vision Devices – e-Book on Special Optical Devices. Sanct-Peterburg National Institute for Precise Mechanics and Optics (in Russian).
http://cde.ifmo.ru/bk_netra/cgi-bin/ebook.cgi?bn=26
8. N i k o l o v, I. Optical Methods and System. Publ. "St. Kl. Ohridski", Sofia, 1993. 272 p. (in Bulgarian).
9. G o e v, A. I. Night Vision Devices Modernization. – Special Techniques, 2002, No 2, 11-14 (in Russian).
10. R u s s e l l, L., J. L o m b a r d o. Target Acquisition: It's not Just for Military Imaging. – Photonics Spectra, July, 1998, 123-126.
11. American Technologies Network Co. ATN NVG7-2 Night Vision Goggles. 2005.
http://cgi.ebay.com/ATN-NVG7-2-Night-Vision-Goggles-w-Headgear-2nd-Gen_W0QQitemZ7197192866QQcategoryZ40970QQcmdZViewItem
12. American Technologies Network Co. How Far Can You See.
http://www.atncorp.com/HowNightVisionWorks
13. NVG "Prilep". Field Test Report, December, 1999.