

## Applications

### A Multicriteria Approach to Exploring Combinations of External Surveillance Conditions Defining a Given NVD Working Range Value

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**Abstract:** *The working range is one of the most significant night vision devices parameter, given in catalogue datasheets. From user's point of view it is interesting to explore different combinations of external surveillance conditions defining a given working range value of night vision devices. For this purpose, a multicriteria optimization problem is formulated. The optimization problem solutions give combinations of ambient night illumination, atmospheric transmittance and contrast between surveillance target and the background, that define the given detecting range value of night vision goggles by a standing man. The multicriteria nature of the optimization problems allows influencing the solutions by the user's preferences about the expected external surveillance conditions values. The results of a number of numerical experiments using real data are described. It is demonstrated that there exist different external surveillance conditions combinations defining the given device working range.*

**Keywords:** *Night vision devices, working range, external surveillance conditions, multicriteria optimization problem, numerical experiments.*

#### 1. Introduction

Night vision technology, providing the ability for observation at night, is one of the most fascinating technologies in use today [1, 2]. The Night Vision Devices (NVD) have their origin in the military research and development, but it is the non-military applications that have led to the advancement of this technology. Night vision is

becoming more and more popular nowadays. There exist two different night vision technologies each having its own advantages and disadvantages – low-light image intensifying and thermal imaging. The technology, based on the use of electronic image intensifying technology, is used in most of the devices and they are the object of investigation in the paper. A wide range of night vision devices with variety of their parameters are available [3-8] to suit the various requirements for different applications [9].

The working range is one of the most significant NVD parameter. The working range, given in catalogue datasheets, is shown without mentioning the values of the external surveillance conditions for which it is valid. The main goal of the paper is to develop an approach to estimate numerically the possible external surveillance conditions combinations, defining the given working range value. A standing man target is considered and the impact of ambient night illumination, atmospheric transmittance and contrast between the target and background are investigated. Multicriteria task formulation for exploring combinations of external surveillance conditions, defining the given NVD working range value, is used.

## 2. Night vision and external surveillance conditions

The NVD based on electronic image intensifying technology as the most popular type of NVD are chosen for the investigations. There are many night vision devices parameters that characterize their performance, like: working range, field of view, image quality, spectral response, weight, operational battery life, etc. The visual performance through night vision devices is a function of many parameters such as: target contrast, objective and eyepiece lens focus, signal/noise of the image intensifier tube, quality of the image intensifier and NVG output luminance to the eye [10]. The working range value is practically the most important parameter affected significantly by external surveillance conditions – ambient night illumination, atmospheric transmittance, contrast between target and background, target type [11-13]. The influence of the external surveillance conditions on the NVD performance can be described shortly as:

- **Ambient night illumination** – the night vision technology using available light intensifying relies on the ambient light (starlight, moonlight, or sky glow from distant manmade sources, such as city lights, etc.) .

- **Atmospheric transmittance** – depends on the surface terrain and the surroundings, air temperature, atmospheric pressure, relative humidity, number and size distribution of atmospheric aerosols, concentration of abnormal atmospheric constituents in the optical path such as smoke, dust, exhaust fumes, and chemical effluents, and refractive indices of all types of aerosol in the optical path [14].

- **Contrast between the background and surveillance target** – monochromatic contrast difference between the integrated target and background intensities.

- **Surveillance target type** – different objects are to be observed under night conditions and the larger the object is, the easier it is to see.

### 3. Problem formulation

The NVD working range value is a result of a complex dependency of NVD parameters and the external surveillance conditions. This relationship can be expressed analytically using formula as developed and described in [15, 16]:

$$R = \sqrt{\frac{0.07 D_{in} f_{ob} \tau_o \tau_a S_{\Sigma} \delta E K A_{ob}}{M \Phi_{min.ph}}} \text{ m,}$$

where:  $D_{in}$  is the diameter of the objective inlet pupil in m,  $f_{ob}$  – objective focal length in mm,  $\tau_a$ ,  $\tau_o$  – atmosphere and objective transmittance dimensionless parameters,  $\Phi_{min.ph}$  – Image Intensifier Tube (IIT) photocathode limiting light flow in lm,  $\delta$  – IIT limiting resolution in lp/mm,  $S_{\Sigma}$  – IIT luminous sensitivity in A/lm,  $M$  – signal-to-noise ratio of IIT (dimensionless parameter),  $E$  – ambient light illumination in lx,  $K$  – contrast dimensionless parameters also, and  $A_{ob}$  – target (surveillance object) area in  $m^2$ . By substituting the area by the so called “reduced target area”  $A'_{ob}$  in  $m^2$  different types of working range can be calculated – detection range, recognition range and identification range [15].

From user’s point of view it is interesting to know what combinations of the external surveillance conditions values would give the working range data listed in catalogue datasheets. To determine sets of different combinations of the external surveillance conditions values, for which the NVD working range can be achieved, as shown in the catalogue data, a multicriteria optimization problem is formulated:

$$(1) \quad \begin{cases} \min E \\ \min K \\ \min \tau_a \end{cases}$$

subject to:

$$(2) \quad \sqrt{\frac{0.07 D_{in} f_{ob} \tau_o S_{\Sigma} \delta E \tau_a K A'_{ob}}{M \Phi_{min.ph}}} = R^*,$$

$$(3) \quad E^l \leq E \leq E^u,$$

$$(4) \quad \tau_a^l \leq \tau_a \leq \tau_a^u,$$

$$(5) \quad K^l \leq K \leq K^u.$$

where  $R^*$  is the given device catalogue standing man detection range in meters,  $E^u$ ,  $\tau_a^u$ ,  $K^u$  are upper and lower  $E^l$ ,  $\tau_a^l$ ,  $K^l$  limits for the ambient light illumination, atmosphere transmittance and contrast.

### 4. Numerical experiments

The formulated multicriteria nonlinear optimization problem (1)-(5) is used for numerical experiments to get combinations of values of the external surveillance conditions, satisfying equality (2). For the purpose of numerical experiments the

most widely used type NVD, i.e., Night Vision Goggles (NVGs) are considered. Representative NVGs [17] with the following catalogue parameters data are used:

- image intensifier tube *Gen. 3 US* with limiting resolution of  $\delta = 68$  lp/mm, photocathode sensitivity  $S_{\Sigma} = 0.0019$  A/lm, signal to noise ratio  $M = 25$  and photocathode sensitivity  $\Phi_{\min,ph} = 4.10^{-13}$ ;

- objective with inlet pupil diameter of  $D_{in} = 0.018$  m, focal length  $f_{ob} = 26$  mm and objective transmittance  $\tau_o = 0.8$ ;

- NVG detecting range  $R^* = 325$  m.

The practical values of external surveillance conditions parameters are chosen as:

- night illumination  $E$  in the interval  $0.0001 \leq E \leq 0.01$ ;

- atmosphere transmittance  $\tau_a$  in the interval  $0.65 \leq \tau_a \leq 0.80$ ;

- contrast  $K$  between surveillance target and background in the interval  $0.1 \leq K \leq 0.5$ ;

- typical standing men target with reduced target area  $A'_{ob} = 0.72$  m<sup>2</sup>,

The corresponding multicriteria optimization task is

$$(6) \quad \begin{cases} \min E \\ \min K \\ \min \tau_a \end{cases}$$

subject to:

$$(7) \quad \sqrt{\frac{0.07 \times 0.018 \times 26 \times 0.8 \times 1.9 \times 10^{-3} \times 68 \times 0.72 \times E \times K \times \tau_a}{25 \times 4 \times 10^{-13}}} = 325,$$

$$(8) \quad 0.0001 \leq E \leq 0.01,$$

$$(9) \quad 0.1 \leq K \leq 0.5,$$

$$(10) \quad 0.65 \leq \tau_a \leq 0.80.$$

Using the weighted sum method [18], the original problem is transformed to a single criterion problem:

$$(11) \quad \min(w_1 E' + w_2 K' + w_3 \tau'_a)$$

subject to constraints (8)-(10) and

$$(12) \quad \sum_i w_i = 1,$$

where  $E' = \frac{E - 0.01}{0.01 - 0.0001}$ ,  $K' = \frac{K - 0.5}{0.5 - 0.1}$  and  $\tau'_a = \frac{\tau_a - 0.80}{0.80 - 0.065}$  are the

normalized objective functions. The weighted sum method scalarizes a set of objectives into a single objective by pre-multiplying each objective with a user-supplied weight coefficient. The relative importance of each objective function is reflected by those coefficients.

**Experimental results and discussion.** Using a variety of weight coefficients, reflecting user requirements about the external surveillance conditions, three different optimization cases are solved. The first case is based on objective function (11) and restrictions (8)-(10) and (12) and considers the whole practical range of external surveillance conditions values. In the second case some of the external surveillance conditions are limited in given boundaries. The third case is focused on combinations of external surveillance conditions where some of them are fixed with given values. The optimization tasks solutions supply external surveillance conditions combinations defining the given man detection range for each case.

- First case optimization solutions (considering the whole practical range of the external surveillance conditions) – Table 1.

Table 1. Weight coefficients and solution results for Case 1

| No | $w_1$ | $w_2$ | $w_3$ | $E$ , lux | $K$   | $\tau_a$ | $R$ , m |
|----|-------|-------|-------|-----------|-------|----------|---------|
| 1  | 0.34  | 0.33  | 0.33  | 0.00400   | 0.166 | 0.65     | 325     |
| 2  | 0.6   | 0.3   | 0.1   | 0.00287   | 0.232 | 0.65     | 325     |
| 3  | 0.1   | 0.6   | 0.3   | 0.00666   | 0.100 | 0.65     | 325     |
| 4  | 0.3   | 0.1   | 0.6   | 0.00235   | 0.284 | 0.65     | 325     |
| 5  | 0.1   | 0.1   | 0.8   | 0.00406   | 0.164 | 0.65     | 325     |
| 6  | 0.1   | 0.8   | 0.1   | 0.00666   | 0.100 | 0.65     | 325     |
| 7  | 0.8   | 0.1   | 0.1   | 0.00144   | 0.464 | 0.65     | 325     |

The solution results in Table 1 give different combinations for ambient night illumination and contrast between background and target. The atmosphere transmittance has a relatively small feasible interval which defines the lowest possible value. Different weight coefficients (as reflection of user's importance about the external surveillance conditions) lead to a different combination of external surveillance conditions, satisfying the given NVG man detecting range.

- Second case optimization solutions (considering limits for some external surveillance conditions) – Table 2.

Table 2. Weight coefficients and solution results for Case 2  
( $0.15 \leq K \leq 0.45$ ,  $0.7 \leq \tau_a \leq 0.75$ )

| No | $w_1$ | $w_2$ | $w_3$ | $E$ , lux | $K$   | $\tau_a$ | $R$ , m |
|----|-------|-------|-------|-----------|-------|----------|---------|
| 1  | 0.34  | 0.33  | 0.33  | 0.00413   | 0.15  | 0.7      | 325     |
| 2  | 0.6   | 0.3   | 0.1   | 0.00319   | 0.194 | 0.7      | 325     |
| 3  | 0.1   | 0.6   | 0.3   | 0.00413   | 0.15  | 0.7      | 325     |
| 4  | 0.3   | 0.1   | 0.6   | 0.00261   | 0.237 | 0.7      | 325     |
| 5  | 0.1   | 0.1   | 0.8   | 0.00413   | 0.15  | 0.7      | 325     |
| 6  | 0.1   | 0.8   | 0.1   | 0.00413   | 0.15  | 0.7      | 325     |
| 7  | 0.8   | 0.1   | 0.1   | 0.00159   | 0.387 | 0.7      | 325     |

When some preliminary information about the expected values of the external surveillance conditions exists, they can be restricted within some narrower limits. This case is numerically tested, decreasing the feasible intervals for the contrast  $K$

and atmosphere transmittance  $\tau_a$ , using the same sets of weight coefficients as in the first case. This reflects in optimization tasks solutions in Table 2 defining different combinations of the surveillance conditions for the given NVG man detecting range.

- Third case optimization solutions (considering atmospheric transmittance with a fixed value  $\tau_a = 0.73$ ) – Table 3.

Table 3. Weight coefficients and solution results for Case 3 ( $\tau_a = 0.73$ )

| No | $w_1$ | $w_2$ | $w_3$ | $E$ , lux | $K$   | $\tau_a$ | $R$ , m |
|----|-------|-------|-------|-----------|-------|----------|---------|
| 1  | 0.5   | 0.5   | 0     | 0.00383   | 0.153 | 0.73     | 325     |
| 2  | 0.7   | 0.3   | 0     | 0.00251   | 0.236 | 0.73     | 325     |
| 3  | 0.3   | 0.7   | 0     | 0.00585   | 0.100 | 0.73     | 325     |

In some practical cases, some of the external surveillance conditions could be considered as known with fixed values. The approach proposed was tested with a fixed value about the atmospheric transmittance  $\tau_a = 0.73$  using three different combinations of weight coefficients. The solution's results define different combinations of night illumination and contrast values to balance the fixed atmospheric transmittance  $\tau_a$  value (Table 3). It is possible to give fixed values for other external surveillance conditions to investigate the possible combinations satisfying the given NVG working range. Sometimes that could lead to unfeasible optimization task formulation. Changing the given fixed values and experimentation with them will help to overcome such kind of problems.

## 5. Summary and conclusions

The current paper proposes a multicriteria optimization approach for investigating different NVD external surveillance conditions combinations, defining the given NVD working range value. The NVD working range is one of the most significant parameters, given in catalogue datasheets. From user's point of view it is interesting to explore possible combinations of external surveillance conditions satisfying the given NVD working range value. For this purpose a multicriteria optimization approach is developed and described. Three different optimization cases are explored. The first case considers as feasible the whole practical range of external surveillance conditions values; in the second case some of the feasible external surveillance conditions limits are narrowed; the third case is focused on combinations of external surveillance conditions where some of them are fixed with given values. Using a variety of weight coefficients, reflecting user's requirements towards the external surveillance conditions importance, a number of numerical experiments for each case are conducted. The formulated multicriteria optimization problems solutions give combinations of ambient night illumination, atmospheric transmittance and contrast between surveillance target and the background that define the given night vision goggles standing man detecting range value. The multicriteria nature of the optimization problems allows affecting the solutions by

user's preferences about the expected external surveillance conditions values. The numerical experiments, based on real NVG parameters data, demonstrate that there exist different external surveillance conditions combinations, defining the given device working range for each tested case. It should be pointed out that it is possible to get unfeasible optimization task formulation when restricting and fixing values of some external surveillance conditions. Further experimentation with other external surveillance conditions limits and values should be done to overcome the infeasibility. If practically reasoned, the proposed optimization tasks formulations could be modified, weakening equality (2) to inequalities with upper and lower limits. This will lead to external surveillance conditions combinations defining NVD working range within given limits. The multicriteria tasks formulations could be solved by other user preferable methods.

The numerical experimentation shows that the proposed multicriteria optimization approach could be used for determining the reasonable NVD external surveillance conditions combinations, satisfying the given as parameter data NVD working range.

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