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Night Vision Devices Choice Taking into Account the External Surveillance Conditions

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Abstract: The current paper defines a new mathematical model of night vision devices choice taking into account the external surveillance conditions. The night vision device working range is an important NVD parameter influenced by the external surveillance conditions. The developed mathematical model is used to formulate multicriteria combinatorial optimization tasks which solutions provide night vision devices choice based on preliminary theoretical estimation of the device working range under expected external surveillance conditions. Additional user requirement about the preferred working range value is used as restriction in optimization tasks. The practical applicability of the proposed night vision devices choice approach is proved by numerical examples based on real night vision goggles and external surveillance conditions data. The multicriteria combinatorial mixed integer optimization tasks are solved by weighted sum method using the software system LINGO v. 11. The proposed approach for night vision goggles choice considering external surveillance conditions can be applied for other types of night vision devices choice taking into account their specifics.

Keywords: *night vision devices choice, external surveillance conditions, multiobjective optimization, numerical examples.*

1. Introduction

Today night vision devices (NVD) are widely used both for military and civil applications. The choosing and evaluation of the most appropriate NVD for specific application could be a complex combinatorial problem [7]. There exist many technological NVD designs with different performance parameters to choose from [13]. In [7] is shown how to implement optimization methods for smart decision making taking into account the devices catalogue data for the essential NVD parameters. All of these parameters data are given for some standardized surveillance conditions. One of the important NVD using specifics is the dependence of their performance of the particular external surveillance conditions [9, 11, 13, 19, 20]. On the other hand, the external surveillance conditions depend on the many related factors as geographical location, weather conditions, environmental parameters, surveillance target type, etc. [12, 17, 23]. That means the intelligent NVD choice should be aware of the expected surveillance conditions in the particular location where they presumably will be used.

The current paper extends the presented in [7] multicriteria optimization approach for NVD choice by defining of a new model taking into account the influence of external surveillance conditions on the NVD performance. The important NVD performance characteristic – its working range calculated as a function of the external surveillance conditions when formulating the optimization choice tasks. Some numerical examples will be solved using real data for night vision goggles parameters and external surveillance conditions.

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2. Night vision and the external surveillance conditions

There exist four external surveillance conditions (ESC) parameters that directly affect the NVD performance – ambient light illumination, atmospheric transmittance, contrast between background and the surveillance target and surveillance target area. The local weather patterns and an understanding of the effects on NVD performance are important for successful night vision observing. It is reasonable to describe shortly the ESC specifics and how they influence the NVD performance.

2.1. Ambient light illumination

The visibility through the NVD is significantly affected by the illumination levels [19]. The current night vision enhancement technology development has significantly improved the needed light-level requirements and the operational light level depends on the used image intensifier tube type. The most popular passive NVD use the natural illumination supplied by the moon and stars and the typical values used are 0.1 lx for full moon, 0.05 lx for half moon, 0.01 lx for quarter moon, 0.001 lx for starlight and 0.0001 lx for overcast [24]. The NVD require some light to operate and provide less benefit in very low ambient light conditions [20].

2.2. Atmospheric Transmittance

Atmospheric conditions and consistence directly reflects to the air transmittance which is important factor to the image enhancement night vision technology. The light is absorbed, scattered, or refracted, either before or after it strikes terrain depending on the aerial media consistence and can reduce the usable energy available to the NVD. The NVD observing distance decreases by the low atmospheric transmittance [20]. The atmospheric transmittance has practically used values in the range of 0.60 to 0.95 [2, 14].

2.3. Contrast between the background and surveillance target

The contrast between the background and surveillance target is important to correctly interpret the NVD image. Any terrain that contains varying albedos (forests, cultivated fields, etc.) will likely increase the level of contrast in a NVD image [19]. The contrast is defined as the difference in brightness between an object and its surrounding background and an object with 5% contrast is defined as “low contrast” and difficult to “see” whereas an object with 90% contrast is “high contrast” and easy to “see” [9]. The contrast between the background and surveillance target varies from 0.05 to 0.50 [2, 14].

2.4. Surveillance target area

Usually the surveillance target area is considered as known value in the cases when the surveillance object is of a particular type. For example, a standing man target area could be calculated using typical man height values between 1.6 m and 1.9 m [27] and width of (0.60÷0.75) m. Generally speaking the different objects have different dimensions and even for the known type of the surveillance targets their area is not fixed constant. The larger object is the easier is to see it. Different types of working range (detection, recognition and identification) are increased when that parameter has bigger values [5, 6].

3. Problem defining

The main aim in the current paper is to choose the most appropriate NVD from the set of available devices considering the influence of ESC on the NVD performance. The NVD choice has to comply with preliminary defined requirements including the expected operational environment conditions. The NVD working range is an important NVD functional characteristic that depends on the ESC [6, 7, 11, 13]. It is possible theoretically to estimate the NVD working range using the developed in [6] formula when the observing conditions, target type and some device parameters are known. Usually most commercial catalogues give the NVD working range based on some fixed values of observing conditions. The proposed approach for NVD choice takes into account the influence of the different ESC and gives the possibility to make a choice based on theoretical estimation of the NVD working range under expected environmental conditions.

When the NVD parameters and the expected ESC data are known the NVD choice can be modeled as combinatorial optimization problem. The efficient satisfaction of desired objectives helps to find the best (optimal) device. As many devices to choose from exist as many possible alternatives should be considered and one overall goal is to determine which of these alternatives best satisfies the user objectives. In practice, there exist more then one and usually conflicting objectives which impose using of a multicriteria optimization approach.

3.1. Model formulation

A NVD choice is usually based on some preliminary user requirements about the NVD performance parameters. The device working range is a function of the ESC and that dependence should be considered when trying to make a smart choice. To take into account the influence of the ESC the developed in [7] model is modified by introducing the device working range as a function of the chosen device parameters and the values of expected ESC instead of choosing of the working range among the known constant values.

$$\begin{aligned} &maximize\ P(x) = (R(x), P_1(x), \ldots,\ P_j(x))^T, \\ &minimize\ N(x) = (N_1(x), N_2(x), \ldots, N_k(x))^T, \end{aligned} \tag{1}$$

subject to

$$\mathrm{R(x)} = \sum_{i=1}^{I} x_i \sqrt{0.07 E \tau_a K A_t^* \frac{D_{in}^i f_{ob}^i \tau_{ob}^i \delta^i S^i}{\Phi_{min}^i M^i}} \tag{2}$$

$$\mathrm{P_j(x)} = \sum_{i=1}^{I} P_{ij} x_i\ , j = 1,2,\ldots,\mathrm{J}, \tag{3}$$

$$\mathrm{N_k(x)} = \sum_{i=1}^{I} N_{ik} x_i\ , k = 1,2,\ldots,\mathrm{K}, \tag{4}$$

$$\sum_{i=1}^{I} x_i = 1,\ x_i \in [0,\ 1] \tag{5}$$

where R(x) is the NVD working range calculated by the formula defined in [6] using the data: E – ambient light illumination in *lx*, τ_a – atmospheric transmittance, K – contrast, A_t^* – reduced target area in m^2 [6], D_{in} – diameter of the inlet pupil in *m*, f_{ob} – objective focal length in *mm*, τ_{ob} – objective transmittance, S – IIT luminous sensitivity in *A/lm*, δ – IIT limiting resolution in *lp/mm*, $\Phi_{min.}$ – IIT photocathode limiting light flow in *lm*, M – IIT signal-to-noise ratio; $P_1(x)$, …, $P_J(x)$ are other the NVD parameters that should be maximized; $N_1(x)$, $N_2(x)$, …, $N_K(x)$ are the NVD parameters that should be minimized; P_{ij} and N_{ik} represents the parameters values of each particular device as known constants; x = ($x_1, x_2, \ldots, x_I$) are binary integer variables corresponding to each device used to realize the choosing mechanism similarly to [7].

Other requirements about the NVD parameters could be added as additional objective functions or restrictions within the formulated model (1)-(5) to reflect different user requirements.

4. Numerical examples for night vision goggles choice

The applicability of the proposed approach for NVD choice will be illustrated on the example of popular binocular type NVG (night vision goggles) choice. The real parameters data of ten particular NVG are shown in Table 1 [3, 4, 10, 26].

Table 1: NVG parameters data

No	Night Vision Goggles	Resolution, lp/mm	Lens system	Objective focal length, mm	Objective transmittance	Signal to noise ratio	IIT luminous sensitivity, A/lm	Field of view	Weight, gr	Price, $
	model	δ	*F#*	f_{ob}	τ_{ob}	*M*	*S*	*FOV*	*W*	*C*
1	Night Optics D-2MV, Gen 1+	40	1:1.2	26	0.78	12	0.00024	40	482	650
2	Rigel 3250, Gen 1+	30	1	35	0.78	12	0.00022	30	430	699
3	ATN Cougar 2, Gen 2	32-40	1:1.4	35	0.78	16	0.00031	30	800	3071
4	ATN Cougar CGTI, Gen 2+	40-51	1:1.4	35	0.78	15	0.00035	30	800	3696
5	ATN Night Cougar-3, Gen 3	64	1:1.4	35	0.78	20	0.00087	30	800	4884
6	ATN Night Cougar-4, Gen 4	68	1:1.4	35	0.8	25	0.00115	30	800	9932
7	ATN PS-23-2, Gen 2	36-45	1:1.2	24	0.8	13	0.0007	40	700	3550
8	ATN PS-23-CGT, Gen. 2+	45-54	1:1.2	24	0.8	17	0.0011	40	700	4195
9	ATN PS-23-3, Gen 3	55-72	1:1.2	24	0.8	22	0.0016	40	700	5895
10	ATN PS-23-4, Gen 4	64-72	1:1.2	24	0.8	24	0.0019	40	700	12995

The example of expected ESC values for ambient light illumination, atmospheric transmittance, contrast between background and target and the target area are shown in Table 2. The target area is calculated for standing man as described in [6] for NVG detection range.

Table 2: Expected external surveillance conditions (ESC)

ESC	Light illumination *E*, lx	Atmospheric transmittance, τ_a	Contrast, *K*	Target area, A_t^* m^2
Set 1	0.01 (¼ moon)	0.75	0.20	0.758
Set 2	0.001 (starlight)	0.80	0.30	

4.1. Multicriteria optimization task formulation

The proposed model (1)-(5) and data from Table 1 and Table 2 are used to define multicriteria optimization tasks. There exist many methods for solution of multicriteria engineering optimization tasks [1, 8, 16, 18, 22, 25]. The *weighted sum* method is the most common when a direct specification of the objectives importance weights are given and can be used for solving of the formulated multicriteria optimization tasks, similarly to [7].

Using of the *weighted sum* method needs *a priori* information about the user's preferences for different objectives importance i.e., the weight coefficients values. The practical experience shows that some of the most preferable from the user point of view objectives are the NVG working range, price and weight [13, 21] and possibly some other NVG parameters (for example – field of view). Two combinations of weight coefficients for those objectives are chosen expressing some user preferences as shown in Table 3.

Table 3: Objectives weight coefficients

Combination	**Objectives weight coefficients**			
	Working range R(x)	**Field of view FOV(x)**	**Price C(x)**	**Weight W(x)**
	w_1	w_2	w_3	w_4
(1)	0.50	0.10	0.30	0.10
(2)	0.25	0.20	0.50	0.05

The weight coefficients combination (1) expresses the user importance ranking as: 1st – working range; 2nd – price; 3rd and 4th field of view and weight. The combination (2) ranking is: 1st – device price; 2nd – working range; 3rd – field of view and 4th – weight. Any other user preferences can be expressed by different weight coefficients.

To use the *weighted sum* method the multiobjective optimization problem should be converted to a single objective problem by introducing weights w_i to each normalized objective function and defining a scalar objective function as:

$$\text{maximize } (w_1R^*(x) + w_2FOV^*(x) + w_3C^*(x) + w_4W^*(x)) \tag{6}$$

subject to

$$R^*(x)=\frac{R(x)-R_{min}}{R_{max}-R_{min}},\ R(x)=\sum_{i=1}^{10}x_i\sqrt{0.07E\tau_a KA_t^*\frac{D_{in}^i f_{ob}^i \tau_{ob}^i \delta^i S^i}{\Phi_{min}^i M^i}} \tag{7}$$

$$FOV^*(x)=\frac{FOV(x)-FOV_{min}}{FOV_{max}-FOV_{min}},\ FOV(x)=\sum_{i=1}^{10}FOV_i x_i\ , \tag{8}$$

$$C^*(x)=\frac{C_{max}-C(x)}{C_{max}-C_{min}},\ C(x)=\sum_{i=1}^{10}C_i x_i\ , \tag{9}$$

$$W^*(x)=\frac{W_{max}-W(x)}{W_{max}-W_{min}},\ W(x)=\sum_{i=1}^{10}W_i x_i\ , \tag{10}$$

$$\sum_{i=1}^{10}x_i=1,\ x_i\in[0,\ 1] \tag{11}$$

$$\sum_{i=1}w_i=1,\ 0\le w_i\le 1, \tag{12}$$

where w_i are objective functions weight coefficients shown in Table 3 and *R*(x), FOV*(x), C*(x)* and *W*(x)* are normalized objective functions defined similarly to [7, 22] using *min* and *max* values calculated for the set 1 and set 2 of ESC.

4.2. Multicriteria optimization task results

Using *weighted sum* method and the information from Tables 1, 2 and 3 four transformed single criterion optimization tasks are solved corresponding to the given ESC and weight coefficients combinations. The tasks solutions and the chosen devices are shown in Table 4.

Table 4: Optimization choice results

External surveillance conditions (ESC)	**Objectives weights**	**R,** m	**FOV,** degree	**C,** $	**W,** gr	**Chosen NVG** of Table 1
Set 1	(1)	748	40	5895	700	**No 9**: ATN PS-23-3, Gen 3
	(2)	335	40	650	482	**No 1**: Night Optics D-2MV, Gen 1+
Set 2	(1)	187	40	5895	700	**No 9**: ATN PS-23-3, Gen 3
	(2)	84	40	650	482	**No 1**: Night Optics D-2MV, Gen 1+

As it is seen from Table 4 the different sets of ESC does not affect the devices choice but define different working ranges under different ESC. It is important to know what working range values to expect when choosing a proper device. If the user does not accept the expected working range values and has for example, some lower limit to consider it could be added as restriction to (6) - (12) similarly the "restricted" choice in [7]. For example, the restriction

$$R(x) \geq 500 \tag{13}$$

added to (6)-(12) leads to choosing of other device for the objective weights combination (2) – see Table 5.

Table 5: Restricted choice results

External surveillance conditions	**Objectives weights**	**R ≥ 500,** m	**FOV,** degree	**C,** $	**W,** gr	**Chosen NVG** of Table 1
Set 1	(1)	748	40	5895	700	**No 9**: ATN PS-23-3, Gen 3
	(2)	623	40	4195	700	**No 8**: ATN PS-23-CGT, Gen. 2+

The choice of the device No 9 for objective weights combination (1) satisfies the restriction (13) and is not affected by adding that restriction.

Changing the objectives weight coefficients and introducing different user preferences as additional restrictions will refine the choice accordingly. Because of the discrete combinatorial nature of the NVG choice it is possible to have unfeasible problem when introducing such kind of restrictions. In cases like that the introduced restrictions should be weakened as needed to get feasibility. For example, the task (6)-(13) is infeasible i.e. it is impossible to satisfy (13) for the set 2 of ESC and the restriction (13) should be changed as $R(x) \geq 100$, for example. The post-optimization analysis provided by the most optimization software packages can be used to help in cases like that.

The LINGO v.11 software system [15] has been used to solve the formulated optimization tasks on PC with 2.6 GHz Intel processor, 1.24 GB RAM and MS Windows XP platform. The computational solutions times depends on the size of the optimization problems and is about few seconds for the described illustrative numerical examples.

Other NVD parameters could be considered as objective functions to reflect the user requirements but the NVD working range is important if the external surveillance conditions are to be considered.

5. Conclusion

The current paper extends the presented in [7] multicriteria optimization approach for NVD choice by defining of a new choice model taking into account the expected external surveillance conditions (ESC). The night vision device working range is directly influenced by the ESC. Nevertheless if the working range is the most important parameter to consider or not the user should be aware of the expected working range values. It makes sense to take into account the worst possible ESC when making the choice to guarantee the minimum NVG performance.

The developed in the paper mathematical model is used to formulate multicriteria combinatorial optimization tasks for intelligent NVD choice. The tasks solutions supply preliminary theoretical estimation of the NVD working range under expected ESC. When the NVD working range is chosen as objective function the optimization task solution provides choice with Pareto optimal value for the working range. If there exists additional user requirement about the preferred working range value under some expected ESC it could be defined as restriction in optimization task formulation. In cases when that requirement is unrealistic it should be modified to get feasible solution. Other NVD parameters can be considered as objective functions or restrictions to comply with different user preferences.

The practical applicability of the proposed NVD choice approach is proved by numerical examples based on real night vision goggles and external surveillance conditions data. The multicriteria combinatorial mixed integer optimization tasks are solved by *weighted sum* method as single criteria scalar problems using the software system LINGO v. 11.

The proposed approach for NVD choice considering external surveillance conditions can be applied for other night vision devices types taking into account their specifics.

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