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Multicriteria Choice of the NVG Optoelectronic Channel Elements

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1. Introduction

The night vision goggles (NVG) are getting cheaper and are spreading widely in different application areas recently. That is a consequence of technological development and mass production. The process of the NVG design involves choice of optoelectronic channel elements (objectives, image intensifier tubes – IIT, oculars) among their subsets. The chosen elements must fulfill specific requirements of the NVG optoelectronic channel and it has to meet user's expectations. As a result, a need for the development of some relevant optimization models exists. A single-criteria optimization model has been developed and tested showing good practical workability [1]. The defined objective function includes the most common practically demanded components such as price, weight, working range, field of view, etc. To be more precise in real live modeling it should be mentioned that some of the criterion components are incompatible and conflicting. Using optimization for more adequate describing real engineering problems, it is natural to look for multi-criteria optimization problems definition [2, 3]. Considering each criterion component of the formulated single-criterion problem [1] as unique criterion, the single-criterion problem can be transformed to a multicriteria problem as described in the current paper.

2. Formulation of quality criteria of NVG

The parameters of the NVG optoelectronic channel are crucial for the quality of NVG itself. The practical expertise shows that the most important of them are [1]:

$Q_1 = R$ – the working range,
$Q_2 = W_{\text{ob}}$ – the field of view,
$Q_3 = (1/F_{\text{n}})$ – the objective *F*-number,

$Q_4 = -F$ – the objective focus range,

$Q_5 = -\mathrm{AD}_{\mathrm{ab}}$ – objective (distortion),

$Q_6 = \mathrm{ER}$ – the eye relief ,

$Q_7 = -L$ – the weight of NVG optoelectronic channel,

$Q_8 = -P$ – the price of NVG optoelectronic channel,

A multi-criteria optimization model of the NVG optoelectronic channel could be formulated as follows:

(1) $\max \{Q_1, Q_2, Q_3, Q_4, Q_5, Q_6, Q_7, Q_8\}$,

subject to constraints describing the specifics of the NVG optoelectronic channel [1]:

(2) $\sum_{j=1}^{n} y_j F_j^{\mathrm{ob}} = \sum_{k=1}^{l} z_k F_k^{\mathrm{oc}}$ – equality of the objective and ocular focal length for NVG magnification 1?,

(3) $\sum_{j=1}^{n} y_j W_j^{\mathrm{ob}} \le \sum_{k=1}^{l} z_k W_k^{\mathrm{oc}}$ – objective field of view ≤ ocular field of view,

(4) $R^{\mathrm{d}} = \sqrt{0.07 \tau_a E K A'^{\mathrm{d}}_{\mathrm{ob}} K_{\mathrm{IIT}} K_{\mathrm{ob}}}$ – detection range for a standing man [4],

(5) $K_{\mathrm{IIT}} = \sum_{i=1}^{m} x_i K_i^{\mathrm{IIT}}$ – IIT quality parameter,

(6) $K_{\mathrm{ob}} = \sum_{j=1}^{n} y_j K_j^{\mathrm{ob}}$ – objective quality parameter,

(7) $\mathrm{AD}_{\mathrm{ob}} = \sum_{j=1}^{n} y_j \mathrm{AD}_j^{\mathrm{ob}}$ – objective distortion,

(8) $\frac{1}{F_n} = \sum_{j=1}^{n} y_j \frac{1}{F_{\mathrm{n}j}}$ – objective *F*-number,

(9) $F = \sum_{j=1}^{n} y_j F_j$ – objective focus range,

(10) $W_{\mathrm{ob}} = \sum_{j=1}^{n} y_j W_j^{\mathrm{ob}}$ – objective field of view,

(11) $\mathrm{ER} = \sum_{k=1}^{l} z_k \mathrm{ER}_k$ – eye relief,

(12) $W_{\mathrm{oc}} = \sum_{k=1}^{l} y_k W_k^{\mathrm{oc}}$ – ocular field of view,

(13) $L = L_{\mathrm{IIT}} + L_{\mathrm{ob}} + L_{\mathrm{oc}}$ – optoelectronic tract weight,

(14) $P = P_{\mathrm{IIT}} + P_{\mathrm{ob}} + P_{\mathrm{oc}}$ – optoelectronic tract price,

where $x, y, z \in \{0, 1\}$ are binary integer variables for choice of the relevant elements of the NVG optoelectronic channel [1].

The ambient light condition and the target area are constants with known numerical values:

τ_a = 0.7 – atmosphere transmittance,
E = 0.01 lx – ambient light illumination ,
K = 0.2 – contrast between the surveillance target and background,
A'_{ob} = 0.7 m^2 – target area for a standing man [4],

The multicriteria problem solution depends on the optimization strategy [3]. The defined in the current paper deterministic multicriteria nonlinear optimization model has been solved using two approaches – by *e-constraints* approach and by *weighted sum* approach [5, 6, 7].

3. Results of using *e-constraints* approach

As source data for problem formulating the parameters of five objectives, five IITs of different generations and five oculars shown in tables 1, 2 and 3 were used.

Table 1. IITs parameters

No	IIT	S_Σ , A/lm	δ, lp/mm	M	L_{IIT}, g	P_{IIT}, $
1	Gen II	0.000450	50	16	85	660
2	SHD-3	0.000600	54	20	80	1500
3	XD-4	0.000700	58	24	80	2000
4	XR-5	0.000800	70	28	80	5600
5	MX-10160B	0.002100	72	36	85	5900

Table 2. Objectives parameters

No	Objective	F_n	F_{ob}, mm	τ_o	W_{ob}, deg	AD_{ob}, %	F, cm	L_{ob}, g	P_{ob}, $
1	NVG “Prilep”	1.20	25.17	0.80	43	7.0	25.0	82	340
2	AN/PVS-5C	1.05	26.80	0.86	40	4,5	25.0	95	380
3	AN/PVS-5A	1.40	25.00	0.81	40	8.0	25.5	83	300
4	NVG-500	1.09	26.60	0.77	40	5.0	25.0	92	290
5	D-2V	1.40	26.00	0.80	37	8.0	25.0	85	300

Table 3. Oculars parameters

No	Ocular	F_{oc}, mm	W_{oc}, deg	ER, mm	L_{oc}, g	P_{oc}, $
1	NVG “Prilep”	25.17	43.0	15	62	150
2	NVG-500	26.60	40,5	15	75	100
3	M-963	26.00	41.0	15	60	160
4	M-953	25.00	40.0	25	68	140
5	M-915	26.80	41.0	15	70	150

The *e-constraints* approach requires one objective to be selected for optimization and the other objectives to be reformulated as constraints, creating in this way scalar subproblems to be solved as single-criterion problems [5, 6, 7].

Scalar subproblem $D(R)$ for detection range:

(15) $\max R^d$,

subject to (2)-(14) with values from Tables 1, 2, 3 and the additional constraints for the rest of criteria from (1):

(16) $35 \le W_{ob}$,

(17) $1 \le (1/F_n)$,

(18) $F \le 30$,

(19) $AD_{ob} \le 9$,

(20) $20 \le ER$,

(21) $L \le 300$,

(22) $P \le 7000$.

The decision of the $D(R)$ will be a constraint for R^d for all other scalar subproblems.

Scalar subproblem $D(W_{ob})$ for objective field of view:

(23) $\max W_{ob}$,

subject to (2)-(14) with values from Tables 1, 2, 3, constraints (17)-(22) for the rest of criteria from (1) and the additional constraint:

(24) $400 \le R^d$,

The $D(W_{ob})$ decision will be a constraint for W_{ob} for other scalar subproblems.

Scalar subproblem $D(1/k)$ for objective F-number:

(25) $\max 1/F_n$,

subject to (2)-(14) with values from Tables 1, 2, 3, constraints (18)-(22), (24) for the rest of criteria from (1) and the additional constraint:

(26) $40 \le W_{ob}$,

The $D(1/F_n)$ decision will be a constraint for $1/F_n$ for other scalar subproblems.

Scalar subproblem $D(F)$ for objective focus range:

(27) $\min F$,

subject to (2)-(14) with values from Tables 1, 2, 3, constraints (19)-(22), (24), (26) for the rest of criteria from (1) and the additional constraint:

(28) $1 \le (1/F_n)$,

The $D(F)$ decision will be a constraint for F for other scalar subproblems.

Scalar subproblem $D(AD_{ob})$ for objective distortion:

(29) $\min AD_{ob}$,

subject to (2)-(14) with values from Tables 1, 2, 3, constraints (20)-(22), (24), (26), (28) for the rest of criteria from (1) and the additional constraint:

(30) $F \le 30$.

The $D(AD_{ob})$ decision will be a constraint for AD_{ob} for other scalar subproblems.

Scalar subproblem D(ER) for eye relief:

(31) $$\max \text{ER},$$

subject to (2)-(14) with values from Tables 1, 2, 3, constraints (21), (22), (24), (26), (28), (30) for the rest of criteria from (1) and the additional constraint:

(32) $$\text{AD}_{ob} \le 7.$$

The D(ER) decision will be a constraint for ER for other scalar subproblems.

Scalar subproblem D(L) for NVG optoelectronic channel weight:

(33) $$\min L,$$

subject to (2)-(14) with values from Tables 1, 2, 3, constraints (22), (24), (26), (28), (30), (32) for the rest of criteria from (1) and the additional constraint:

(34) $$10 \le \text{ER}.$$

The D(L) decision will be a constraint for L for other scalar subproblems.

Scalar subproblem D(P) for NVG optoelectronic channel price:

(35) $$\min P,$$

subject to (2)-(14) with values from Tables 1, 2, 3, constraints (24), (26), (28), (30), (32), (34) for the rest of criteria from (1) and the additional constraint:

(36) $$L \le 250.$$

The results from the decisions of the scalar subproblems $D(R)$, $D(W_{ob})$, $D(1/F_n)$, $D(F)$, $D(\text{AD}_{ob})$, D(ER), $D(L)$, $D(P)$ are shown in Table 4.

Table 4. The results from scalar subproblems and single-criterion optimization problem D1 decisions

Tasks	D1	$D(R)$	$D(W_{ob})$	$D(1/F_n)$	$D(F)$	$D(\text{AD}_{ob})$	D(ER)	$D(L)$	$D(P)$
Criteria	all	1st	2nd	3th	4th	5th	6th	7th	8th
Chosen IIT (from Table 1)	2	5	5	3	2	3	4	5	2
Chosen objective (from Table 2)	2	2	1	2	2	2	4	1	2
Chosen ocular (from Table 3)	5	5	1	5	5	5	2	1	5
Detecting range, m	404	651	552	413	404	413	414	552	404
Field of view, deg	40	40	43	40	40	40	40	43	40
F-number	1.05	1.05	1.2	1.05	1.05	1.05	1.09	1.2	1.05
Objective focus range, cm	25	25	25	25	25	25	25	25	25
Distortion, %	4.5	4.5	7	4.5	4.5	4.5	5	7	4.5
Eye relief, mm	15	15	15	15	15	15	15	15	15
Weight, g	245	250	229	245	245	245	247	229	245
Price, $	2030	6430	6390	2530	2030	2530	5990	6390	2030

A single-criterion optimization nonlinear problem defined as D1 [1]:

(37) $$\max Q = (R + W_{ob} + (1/F_n) - F - \text{AD}_{ob} + \text{ER} - L - P),$$

subject to (2)-(14) with values from Tables 1, 2, 3 and the same boundaries (16)-(22), (24) as in a multicriteria problem, is solved and the results of its decision are shown also in Table 4. The results for optoelectronic channel parameters from the decisions of D1 and the last scalar subproblem $D(P)$ are equal.

The graphical presentation of the obtained detection range values and the optoelectronic channel price by the decisions of the scalar subproblems $D(R)$, $D(W_{ob})$, $D(1/F_n)$, $D(F)$, $D(\mathrm{AD}_{ob})$, $D(\mathrm{ER})$, $D(L)$, $D(P)$ and by decision of the single-criterion problem D1 are shown in Fig. 1 and Fig. 2 respectively.

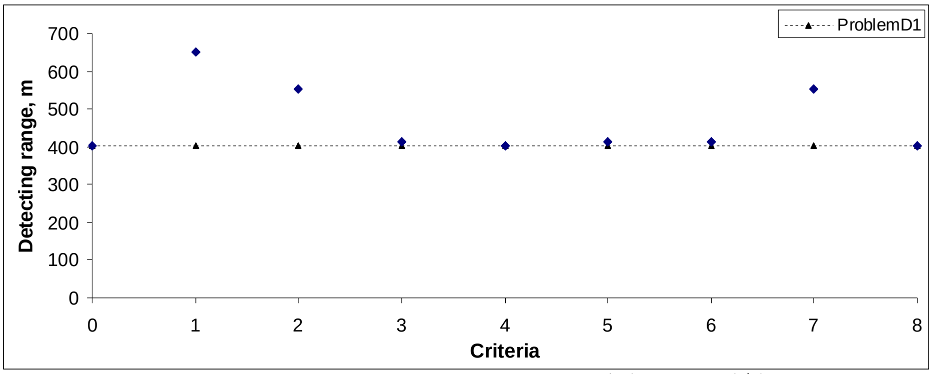

Fig. 1. Detection range values from the scalar subproblems (♦) and D1 (▲) decisions

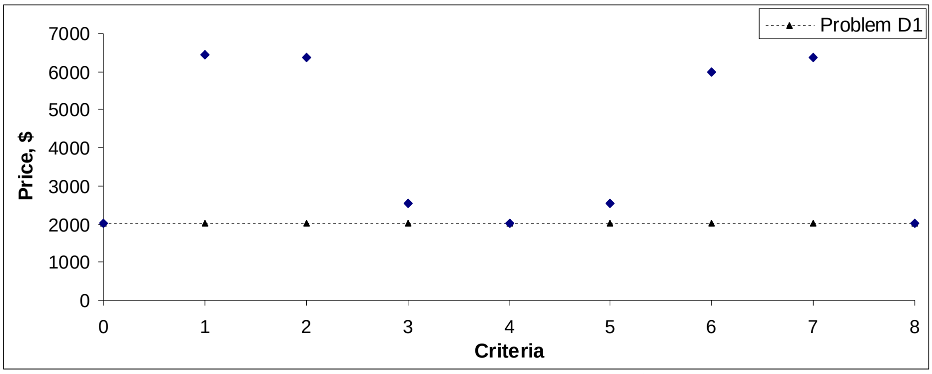

Fig. 2. Price values from the scalar subproblems (♦) and D1 (▲) decisions

4. Results of using *weighted sum* approach

One of the widely used for the multicriteria problems solving is the *weighted sum* approach. The preferences of the decision-maker are taken into account by choosing different weights for the different objectives [5, 6, 7]. Usually the objective functions are of different magnitudes, and should be normalized first. The normalization is done solving maximization and minimization singlecriterion problems for each of the criteria, discarding the rest of the criteria. The obtained maximum and minimum values for each criterion of the formulated in the current paper multicriteria problem are shown in Table 5.

Table 5. The maximum and minimum values for each criterion

Criterion	R, m	W_{ob}, deg	$1/F_n$	F, cm	AD_{ob}, %	ER, cm	L, g	P $
Max	651	43	1/1.09	25.5	8.0	25	252	1050
Min	295	37	1/1.4	25	4.5	15	224	6430

The values from the Table 5 are used to define a normalized single-objective function:

$$(38)\quad \max\{k_1\frac{R-R_{\min}}{R_{\max}-R_{\min}}+k_2\frac{W_{ob}-W^{\min}}{W_{ob}^{\max}-W_{ob}^{\min}}+k_3\frac{(1/F_n)-(1/F_n)_{\min}}{(1/F_n)_{\max}-(1/F_n)_{\min}}+$$

$$+k_4\frac{F_{\max}-F}{F_{\max}-F_{\min}}+k_5\frac{AD_{ob}^{\max}-AD_{ob}}{AD_{ob}^{\max}-AD_{ob}^{\min}}+k_6\frac{ER-ER_{\min}}{ER_{\max}-ER_{\min}}+k_7\frac{L_{\max}-L}{L_{\max}-L_{\min}}+$$

$$+k_8\frac{P_{\max}-P}{P_{\max}-P_{\min}}\}.$$

The *weighted sum* approach transforms multiple criteria to a single-criterion defined as a sum of normalized criteria with proper weight coefficients k_i, where $\sum_i k_i = 1$. Four sets of the weight coefficients k_i have been chosen for using *weighted sum* approach as shown in Table 6.

Table 6. The sets of the weight coefficients

Set	k_1	k_2	k_3	k_4	k_5	k_6	k_7	k_8
(1)	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.2
(2)	0.3	0.1	0.1	0.05	0.1	0.05	0.1	0.2
(3)	0.2	0.1	0.1	0.05	0.1	0.05	0.1	0.3
(4)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125

The decisions of the corresponding transformed single-criterion problems for each set of weighted coefficients are shown in table 7.

Table 7. The results of the multicriteria problem
using four sets of weighted coefficients

Parameter	D(1)	D(2)	D(3)	D(4)
Chosen IIT from Table 1	3	1	1	3
Chosen objective from Table 2	2	2	2	2
Chosen ocular from Table 3	5	5	5	5
Detecting range, m	413	377	377	413
Field of view, deg	40	40	40	40
F-number	1.05	1.05	1.05	1.05
Focus range, cm	25	25	25	25
Distortion, %	4.5	4.5	4.5	4.5
Eye relief, mm	15	15	15	15
Weight, g	245	250	250	245
Price, $	2530	1190	1190	2530

5. Conclusion

Modeling of the NVG optoelectronic channel for the goal of the optimal choice of its elements could be done using single-criterion and multicriteria optimization models. Multicriteria models are closer to the practical requirements for NVG, but are more difficult to solve. The result obtained by using the *e-constraint*s approach suggests that an equivalent single-criterion transformed problem where a sum of the multiple criteria forms a single criterion, could be used for solving the original multicriteria problem in this particular specific case. Using the *weighted sum* approach demands good knowledge about the specifics of the problems and multiple tries for adjusting of the weighted coefficients to get acceptable results.

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Многокритериальный выбор элементов для оптико-электронного канала очков ночного видения

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(Р е з ю м е)

Описана многокритериальная оптимизационная модель для выбора элементов оптико-электронного канала очков ночного видения. Показаны решения соответствующих многокритериальных задач через методов *е-ограничения* и *тегловых сум* и сделаны выводы для практического применения.