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A Single Criterion Combinatorial Optimization Model of the Monocular Night Vision Goggles Battery Power Supply Choice[*]

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1. Introduction

The variety of the night vision devices and its elements recently [1] puts a question for device elements choice to satisfy different requirements. Because of that an appropriate design optimization methods for the device elements choice [2, 3] is necessary for a preliminary theoretical estimation of the designed device parameters. Designing a complex technical system in nowadays conditions is impossible without the use of optimization techniques. The device “quality” can be considered as an optimization criterion that is defined in different ways depending on the usage area and user requirements. There exist a number of quality parameters which can be used in optimization models and amongst them the working ranges (for detection, recognition or identification), weight and price are considered as of essential practical importance [2, 3, 4]. Another essential quality parameter is electrical battery power supply lifetime which also influences significantly on the device weight and price. The device power supply lifetime depends on the type of the used electrical battery. To make an appropriate electrical battery power supply choice on the design stage a mixed-integer problem is formulated involving binary variables. The single criterion optimization mathematical model for the monocular night vision goggles (MNVG) design by a choice of its elements includes practical quality parameters as: working range, weight and price and also electrical battery power supply lifetime and working temperature range.

2. Single criterion nonlinear mixed-integer optimization problem

The practical usage of the NVD shows that a number of device parameters are essential for the device quality. The most practically significant could be listed as follows [2, 3]:

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- working range (detection, recognition or identification),
- weight,
- price.

Another significant from practical point of view is

- electrical battery power supply lifetime.

It depends on the electrical battery type which also reflects on the device weight and price. The most obvious limitation of the electrical battery power supply lifetime will be an electrical load placed on the battery which in our case is IIT electrical current supply IIIT. The electrical battery power supply lifetime LB also depends on the electrical battery capacity CB. The lifetime based on an electrical load can be calculated by dividing the available electrical battery capacity in mAh by the current demand in mA to get the lifetime in hours:

$$L_{\mathrm{B}} = \frac{C_{\mathrm{B}}}{I_{\mathrm{IIT}}}.$$

The electrical battery power supply lifetime parameter demands to develop an optimization model with the possibility of an optimal choice among different electrical battery types. The most popular electrical battery types can be divided on two basic categories depending on their type and supply voltage: AA type with supply voltage 1.5 V and button (coin) cell type with 3.0 V supply voltage. The typical supply voltage needed for MNVG is 3.0 V. Different companies produce variety of electrical battery with different parameters, so an optimization choice is necessary to get the appropriate result. To achieve the device working voltage power supply is necessary to include at least one electrical button cell type battery or at least two AA type batteries. To increase the device electrical battery power supply capacity and respectively its lifetime it is possible to use a number of parallel connected batteries. The different electrical battery combinations for the MNVG electrical battery supply will have different capacity, temperature range, weight and price. The goal of this mathematical model is to find the optimal electrical battery power supply with some requirements about device lifetime, temperature range while is minimizing the device weight and price. The practical requirement for the electrical battery power supply is to include only the electrical batteries of the same type. All of these requirements are to be included in a mathematical optimization model. To express the MNVG quality, the some criterion as in [2, 3] will be used one objective function

$$\max\,\{R^{\mathrm{d}} - H - P\}, \tag{1}$$

subject to:

$$R^{\mathrm{d}} = \sqrt{\frac{2\tau_{\mathrm{a}} EKA^{\mathrm{d}}_{\mathrm{ob}}}{\pi} K_{\mathrm{IIT}} K_{\mathrm{ob}}} \quad \text{– detection range [4];} \tag{2}$$

$$K_{\mathrm{IIT}} = \sum_{i=1}^{m} x_i K^{i}_{\mathrm{IIT}} \qquad \text{– image intensifier tube (IIT) quality,} \tag{3}$$

x_i – binary variable for choice of a single IIT,

$$\sum_{i=1}^{m} x_i = 1, \ x_i \in \{0, 1\}, \qquad \text{– for single IIT choice,} \tag{4}$$

(5) $$K^{i}_{\text{IIT}} = \frac{S^{i}_{\Sigma}\delta^{i}_{\text{IIT}}}{M^{i}\Phi^{i}_{\min.\text{ph}}} \text{ – quality of the } i\text{-th IIT},$$

S_{Σ} – IIT luminous sensitivity (A/lm), δ_{IIT} – IIT limiting resolution (lp/mm), M – IIT signal to noise ratio, $\Phi_{\text{min.ph}}$ – IIT photocathode limiting sensitivity (lm).

The parameters of the MNVG optical system objective-ocular are considered that is preliminary known and objective quality parameter is defined as [2]:

$$K_{\text{ob}} = D_{\text{in}} f_{\text{ob}} \tau_{\text{o}} \text{ – objective quality},$$

D_{in} – diameter of the inlet pupil (m), f_{ob} – objective focal length (mm), τ_{o}– objective transmittance,

For different user requirements the working range type (2) can be changed to the one of other working range types – orientation, recognition or identification as shown in [4].

The parameters of the external surveillance conditions (τ_{a} – atmospheric transmittance,

E – ambient illumination (lx), K – contrast and A^{d}_{ob} – reduced target area (m^2)) are supposed to be known with some determined values.

The device weight is calculated as summarizing of each elements weight:

(6) $$H = H_{\text{IIT}} + H_{\text{ob}} + H_{\text{oc}} + H_{\text{B}},$$

(7) $$H_{\text{IIT}} = \sum_{i=1}^{m} x_i H^{i}_{\text{IIT}} \text{ – image intensifier tube weight},$$

H_{ob} – objective weight,

H_{oc} – ocular weight,

H_{B} – electrical battery power supply weight.

The device price is summarized price of its elements:

(8) $$P = P_{\text{IIT}} + P_{\text{ob}} + P_{\text{oc}} + P_{\text{B}},$$

(9) $$P_{\text{IIT}} = \sum_{i=1}^{m} x_i P^{i}_{\text{IIT}} \text{ – image intensifier tube price},$$

P_{ob} – objective price,

P_{oc} – ocular price,

P_{B} – electrical battery power supply price.

The electrical battery power supply lifetime could be expressed as:

$$L_{\text{B}} = \frac{C_{\text{B}}}{I_{\text{IIT}}}.$$

Let us assume that there are t-types electrical batteries with supply voltage 1.5 V or 3 V. Every t-type battery could have k-subtypes with different capacity to choose from. That means the electrical battery power supply capacity C_{B} could be expressed as (in m.A.h):

(10) $$C_{\text{B}} = n\sum_{p=1}^{t} a_p \sum_{q=1}^{k_p} b^{p}_{q} C^{q}_{\text{B}},$$

n – the number of the connected in parallel batteries to increase capacity,

a_p – binary variable for battery type p,

b^{p}_{q} – binary variable for p-type and q-subtype battery,

C^{q}_{B} – capacity of the q-suptype battery and to have electrical battery power supply one battery is needed at least.

$$n \geq 1. \tag{11}$$

The single choice of the electrical battery type without combining of the different battery types and subtypes for each $p \in \{1, 2, \ldots, t\}$:

$$\sum_{p=1}^{t} a_p = 1, \tag{12}$$

$$\sum_{p=1}^{t} \left(a_p - \sum_{q=1}^{k_p} b_q^p \right) = 0 \,. \tag{13}$$

The chosen IIT input current I_{IIT} is (in mA):

$$I_{\mathrm{IIT}} = \sum_{i=1}^{m} x_i I_{\mathrm{IIT}}^{i} \,, \tag{14}$$

I_i^{IIT} is the input current of the i-th IIT.

There should exist a minimum $L_{\mathrm{B\,min}}$ electrical battery power supply lifetime:

$$L_{\mathrm{B}} \geq L_{\mathrm{B\,min}}. \tag{15}$$

It does not make sense to design a custom electrical battery power supply with lifetime larger than IIT lifetime, so an upper limit is needed:

$$L_{\mathrm{B}} \leq L_{\mathrm{IIT}}, \tag{16}$$

where L_{IIT} in h is

$$L_{\mathrm{IIT}} = \sum_{i=1}^{m} x_i L_{\mathrm{IIT}}^{i} \,, \tag{17}$$

L_i^{IIT} is the lifetime of the i-th IIT.

The electrical battery power supply weight H_{B} and the price P_{B} depend not only on the chosen battery type but on the batteries number also. When the chosen battery type has 1.5 V supply voltage a pair of them have to be connected serially to get the MNVG standard power supply of 3 V;

$$H_{\mathrm{B}} = n \sum_{p=1}^{t} a_p s_p \sum_{q=1}^{k_p} b_q^p H_{\mathrm{B}}^{q}, \tag{18}$$

s_p – constant, where $s = 1$ for the electrical battery with 3 V supply voltage or $s = 2$ for the batteries with 1.5 V supply voltage,

H_{B}^{q} – weight of the p-type and q-subtype electrical battery.

It is also practical to have some upper limit $H_{\mathrm{B}}^{\max}$ for the electrical battery power supply weight:

$$H_{\mathrm{B}} \leq H_{\mathrm{B}}^{\max}. \tag{19}$$

The electrical battery power supply price P_{B} should also be taken in consideration and is defined as:

$$P_{\mathrm{B}} = n \sum_{p=1}^{t} a_p s_p \sum_{q=1}^{k_p} b_q^p P_{\mathrm{B}}^{q}, \tag{20}$$

P_{B}^{q} is the price of the p-type and q-subtype electrical battery.

The electrical battery power supply is also characterized by its working temperature range. It is possible to include the requirements for the electrical batteries temperature working range (T_B^{low} and T_B^{high}) as constraints depending on the battery type choice:

$$T_B^{\mathrm{low}} \le T_B^{\mathrm{low\ min}} \tag{21}$$

T_B^{min}– low battery working temperature boundary,

$$T_B^{\mathrm{high}} \ge T_B^{\mathrm{high\ max}}, \tag{22}$$

T_B^{max}– high battery working temperature boundary,

$$T_B^{\mathrm{low}} = \sum_{p=1}^{t} a_p \sum_{q=1}^{k_p} b_q^p T_B^{\mathrm{low}_q}, \tag{23}$$

$T_B^{\mathrm{low}_q}$ – low working temperature boundary of the p-type and q-subtype battery,

$$T_B^{\mathrm{high}} = \sum_{p=1}^{t} a_p \sum_{q=1}^{k_p} b_q^p T_B^{\mathrm{high}_q}, \tag{24}$$

$T_B^{\mathrm{high}_q}$ – high working temperature boundary of the p-type and q-subtype battery.

The proposed MNVG mathematical optimization model allows formulating of the single criterion nonlinear mixed integer optimization tasks. Their solution is to provide an optimal choice of batteries type to get an electrical battery power supply according to the user requirements, chosen IIT and a given optical system objective-ocular while maximizing the device working range and minimizing its weight and price.

3. Numerical experiments

The optimization task formulation goal is to get a solution where the choice of some IIT and electrical battery type for the MNVG design has to provide:

- a maximum standing man detection range on
- the ambient light condition at j moon with
- minimum of the device price and weight and
- the electrical battery power supply working temperature range (–30 °C, +30 °C)
- and minimum of the electrical battery power supply lifetime 100 h, i.e.:

$$\max \{R^{\mathrm{d}} - H - P\}, \tag{25}$$

subject to 2-24 where the typical values are substituted:

- for the external observing parameters $\tau_{\mathrm{a}} = 0.7$; $E = 0.01$ lx (j moon), $K = 0.2$, $A^{\mathrm{d}}_{\mathrm{ob}} = 0.7$;
- for the objective parameters: $K_{\mathrm{ob}} = 0.42235$; $H_{\mathrm{ob}} = 85$ g; $P_{\mathrm{ob}} = 350$ \$;
- for the ocular parameters: $H_{\mathrm{oc}} = 65$ g; $P_{\mathrm{oc}} = 300$ \$;
- for the electrical battery power supply parameters: $L_{\mathrm{min}} = 100$ h, $T_B^{\mathrm{low}} = -30$ °C, $T_B^{\mathrm{high}} = 30$ °C.

The formulated single criterion nonlinear mixed integer optimization task chooses from the parameters of the five different IIT, for given objective and ocular and three electrical battery types with subtypes shown in Tables 1 and 2.

Table 1. IIT's parameters

No	IIT	S_Σ? A/lm	δ? lp/mm	M	I_{IIT}, m.A.h	L_{IIT}, h	T_{IIT}, g	P_{IIT}, $
1	Gen II [5]	0.000450	50	16	16	2000	85	660
2	SHD-3 [5]	0.000600	54	20	18	10000	80	1500
3	XD-4 [5]	0.000700	58	24	20	15000	80	2000
4	XR-5 [5]	0.000800	70	28	35	15000	80	5600
5	MX-10160A [6]	0.001800	64	21	40	10000	85	4900

Table 2. Battery's parameters

No	Battery	Voltage, V	C_B, m.A.h	H_b, g	T_B^{high}, °C	T_B^{low}, °C	P_b, $
1	Varta Longlife [7]	1.5	1200	23.0	30	– 30	1.00
2	GP Super Alkaline [8]	1.5	2500	24.0	35	– 35	1.40
3	Energizer Ultimate Lithium [9]	1.5	2900	24.0	35	– 35	4.00
4	Renata CR2477N [10]	3.0	950	8.2	35	– 35	7.00
5	Duracell 2450 Long Life Lithium [11]	3.0	560	6.2	30	– 30	2.50
6	CR2477 Sony Lithium Coin Battery [12]	3.0	1000	10.0	30	– 30	4.95

The formulated optimization task is solved by "LINGO" system (LINDO Systems Inc.) and the results are shown in Table 3.

Table 3. Optimization task results

Device elements	Chosen element
IIT (No from Table 1)	1
Battery type (No from Table 2)	5 (3 pc.)
Device parameters	**Calculated value**
Man detection range, m	319.15
Weight, g	253.60
Price, $	1317.50
Electrical battery power supply lifetime, h	105.00

The task solution provides an optimal MNVG design combination of the IIT and electrical battery power supply elements for a given optical system objective-ocular according to the requirements.

4. Conclusion

A single criterion nonlinear mixed integer optimization task for the electrical batteries type and IIT type optimal choice for some given optical system objective-ocular is formulated and solved. The numerical experiments show that the defined optimization model for electrical battery type choice depending on the IIT choice can be used to satisfy practical requirements and also allow preliminary theoretical estimation of the MNVG parameters on the design stage. Using optimization modelling on the design stage decreases costs and time for producing of multiple prototypes and their testing. The proposed mathematical optimization model could be modified if needed to satisfy other practical requirements.

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Оптимизационная модель для выбора батарейного источника питания для монокулярных очков ночного видения

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(Резюме)

Предложена однокритериальная оптимизационная модель для выбора элементов для монокулярных очков ночного видения (МОНВ). Математическая модель включает практические качественные параметры, такие как: дальность действия, вес и цена, а также жизнь и рабочий температурный диапазон батарейного электропитания. Сформулирована однокритериальная нелинейная смешанно-целочисленная задача оптимизации для оптимального выбора типа электрических батарей и типа электронно-оптического преобразувателя при заданной оптической системы объектив–окуляр. Экспериментальные результаты показывают, что предложенная оптимизационная модель может быть использована для проектирования МОНВ и для предварительной теоретической оценки пользовательских требований без создания и испытания множества опытных образцов.