# USING WEIGHTED SUM METHOD FOR THE CHOICE OF THE NIGHT VISION GOGGLES BATTERY POWER SUPPLY

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The paper presents a night vision goggles (NVG) design multicriteria optimization taking into account device working range, weight and price and also electrical battery power supply lifetime, temperature working range and its mechanics. The multicriteria optimization choice of the electrical battery type's and capacity (respectively battery supply lifetime) depends on the image intensifier tube (IIT) choice through its input current. The proposed optimization model is used to formulate multicriteria nonlinear mixed integer problems solved by the weighted sum method to get numerical results. The experimental results show that the proposed optimization model can be used for the IIT and battery power supply choice on the NVG design stage and for some preliminary estimation of the battery power supply lifetime. The optimization model could be modified to satisfy other practical requirements.

## INTRODUCTION

Optimization of the engineering systems and in particular of the NVD design needs optimizing of multiple performance criteria. That is because the real-life engineering optimization problems require simultaneous optimization of more than one objective function [1, 2, 3]. In such cases multicriteria mathematical optimization models can be formulated. The majority of engineering systems can achieve an essential raise of their effectiveness using combinatorial optimization. The appropriate optimization methods for the device elements choice [4, 5, 6, 7] are necessary for a preliminary theoretical estimation of the designed device parameters. The device "quality" can be considered as an optimization criterion defined in different ways depending on the user requirements. There exist a number of quality parameters to be used in optimization models of the NVD and amongst them the working ranges (detection, recognition, identification), weight and price are considered as of essential practical importance [5, 6, 7]. Another essential quality parameter from practical point of view is electrical battery power supply lifetime which also influences significantly on the device weight and price. The device power supply lifetime depends on the used electrical battery type and on the IIT input current. A multicriteria optimization model for the electrical battery type's choice depending on the IIT choice can be used on design stage for preliminary estimation of the device electrical battery power supply lifetime, price and weight.

## THE MULTICRITERIA OPTIMIZATION MODEL OF THE NVG INCLUDING ELECTRICAL BATTERY POWER SUPPLY LIFETIME AND MECHANICS

Most realistic optimization problems, particularly those in design, require the simultaneous optimization of more than one objective function. Some of practically recognized NVG quality parameters could be listed as follows [5, 6, 7]: working range (detection, recognition or identification), weight and price. From practical point of view another significant parameter is electrical battery power supply lifetime depending on the electrical battery's type and capacity and its mechanics that also reflect on the device weight and price.

As the NVG are powered by batteries, the battery supply lifetime becomes an important design consideration. The electrical battery power supply lifetime $L_B$ depends on the electrical battery capacity $C_B$ and the current demand of the used IIT as [7, 8] $L_B = C_B / I_{IIT}$ [hours].

There exists variety of electrical batteries with different parameters that can be divided on two basic categories depending on their type and supply voltage: AA type batteries with supply voltage 1.5 V and button (coin) cell type with 3.0 V supply voltage. The typical supply voltage needed for the IIT of the NVG is 3.0 V. To increase the device electrical battery power supply capacity and respectively its lifetime it is possible to use a number of parallel connected batteries, i.e. to design a custom electrical battery power supply [7]. The custom electrical battery power supply mechanics influences on the device weight and price, so it is necessary to include it in the optimization model also. The requirement for the bigger electrical battery power supply lifetime reflects on its supporting mechanics – the bigger capacity requires the bigger mechanics to pack chosen electrical batteries.

A generalized optimization problem can be defined as maximizing of the NVG working range while minimizing device weight and price, satisfying some requirements about the electrical battery power supply lifetime and temperature range, taking into account electrical battery power supply mechanics:

(1) $$\max \{R^d, -H, -P\},$$

subject to:

(2) $$R^d = \sqrt{\frac{2\tau_a E K A^d_{ob}}{\pi} K_{IIT} K_{ob}}$$ – detection range [9],

(3) $$K_{IIT} = \sum_{i=1}^{m} x_i K^i_{IIT}$$ – IIT quality [4],

(4) $$\sum_{i=1}^{m} x_i = 1, \quad x_i \in \{0, 1\},$$ – for single IIT choice,

(5) $$K_{IIT}^i = \frac{S_\Sigma^i \delta_{IIT}^i}{M^i \Phi^i_{\min.ph}}$$ – quality of the $i^{th}$ IIT,

$S_\Sigma$ – IIT luminous sensitivity, [A/lm], $\delta_{IIT}$ – IIT limiting resolution, [lp/mm],

$M$ – IIT signal to noise ratio, $\Phi_{\min.ph}$ – IIT photocathode limiting sensitivity [lm].

Here the parameters of the NVG optical system objective-ocular are considered as known. The objective quality parameter is defined as [4]:

(6) $$K_{ob} = D_{in} f_{ob} \tau_o,$$

$D_{in}$ – diameter of the inlet pupil [m], $f_{ob}$ – objective focal length [mm], $\tau_o$ – objective transmittance.

A different working range types, for example – orientation, recognition or identification [9] can be used instead (2). The parameters of the external surveillance conditions ($\tau_a$ – atmospheric transmittance, $E$ – ambient illumination [lx], $K$ – contrast and $A_{ob}^d$ – reduced target area [m$^2$]) are also known with some determined values.

The custom electrical battery power supply capacity can be provided by choice of different battery types [7]. A relevant battery power supply packing mechanics depending on the chosen battery type and number is needed and its weight and price has to be considered also. The device weight $H$ is calculated as:

(7) $$H = H_{IIT} + H_{ob} + H_{oc} + H_B,$$

(8) $$H_{IIT} = \sum_{i=1}^{m} x_i H_{IIT}^i$$ – IIT weight,

$H_{ob}$, $H_{oc}$ – objective and ocular weight (fixed), $H_B$ – electrical battery power supply and its mechanics weight.

Let us assume that there are $t$-types electrical batteries with different supply voltage 1.5 V or 3 V respectively. Each $t$-type battery could have $k_p$-subtypes with different capacity to choose from, so the electrical battery power supply weight could be defined as:

(9) $$H_B = n\left(\sum_{p=1}^{t} a_p\left(s_p\sum_{q=1}^{k_p} b_q^p H_B^q + \sum_{p=1}^{t} t_p\right)\right),$$

$n$ – number of the parallel connected batteries accordingly to the capacity requirement,

$a_p$ – binary variable for battery $p$-type,

$b_q^p$ – binary variable for battery $q$-subtype of $p$-type battery,

$$s_p = \begin{cases} 1 & \text{– for the 3 V batteries,} \\ 2 & \text{– for the 1.5 V batteries,} \end{cases}$$

$H_B^q$ – weight of the $p$-type and $q$-subtype electrical battery,

$t_p$ – single $p$-type electrical battery power supply mechanics weight.

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

(10) $$\sum_{p=1}^{t} a_p = 1,$$

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

It is practical to have some upper limit $H_B^{max}$ for the electrical battery power supply weight:

(12) $$H_B \le H_B^{max}.$$

Similarly to (6), the device price is expressed as summarized price of its elements:

(13) $$P = P_{HT} + P_{ob} + P_{oc} + P_B,$$

(14) $$P_{IIT} = \sum_{i=1}^{m} x_i P_{IIT}^i \quad \text{– IIT price,}$$

$P_{ob}$, $P_{oc}$ – objective and ocular price, $P_B$ – electrical battery power supply price.

The electrical battery power supply price $P_B$ depends on the chosen battery type, on the batteries number $n$ and on the battery supply mechanics also:

(15) $$P_B = n\left(\sum_{p=1}^{t} a_p\left(s_p\sum_{q=1}^{k_p} b_q^p P_B^q + \sum_{p=1}^{t} k_p\right)\right),$$

$P_B^p$ – price of the $p$-type and $q$-subtype electrical battery,

$k_p$ – single $p$-type electrical battery power supply mechanics price.

The electrical battery power supply lifetime $L_B$ could be expressed as:

(16) $$L_B = \frac{C_B}{I_{IIT}} \quad [7],$$

where the electrical battery power supply capacity $C_B$ is defined as:

(17) $$C_B = n\sum_{p=1}^{t} a_p \sum_{q=1}^{k_p} b_q^p C_B^q, \ \text{[mAh]},$$

$C_B^q$ – the capacity of the $p$-type and $q$-suptype battery.

The IIT input current $I_{IIT}$ depends on the chosen $i$-type IIT:

(18) $$I_{IIT} = \sum_{i=1}^{m} x_i I_{IIT}^i, \ \text{[mA]}$$

$I_{IIT}^i$ – the input current of the $i^{th}$ IIT.

The minimum battery supply lifetime $L_{Bmin}$ defines the constraint:

(19) $$L_B \geq L_{Bmin}.$$

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

(20) $$L_B \le L_{IIT},$$

where:

(21) $$L_{IIT} = \sum_{i=1}^{m} x_i L_{IIT}^{i}, \text{ [hours]}$$

$L_{IIT}^{i}$ – lifetime of the $i^{th}$ IIT.

The electrical battery power supply is also characterized by its working temperature range and it is good to include the requirements for the electrical batteries temperature working range ($T_B^{low} \div T_B^{high}$) depending on the battery type choice:

(22) $$T_B^{low} \le T_B^{low\,min},$$

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

(23) $$T_B^{high} \ge T_B^{high\,max},$$

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

(24) $$T_B^{low} = \sum_{p=1}^{t} a_p \sum_{q=1}^{k_p} b_q^p T_B^{low_q},$$

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

(25) $$T_B^{high} = \sum_{p=1}^{t} a_p \sum_{q=1}^{k_p} b_q^p T_B^{high_q},$$

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

The proposed NVG optimization model allows formulating of the multicriteria nonlinear mixed integer optimization tasks.

## MULTICRITERIA OPTIMIZATION PROBLEM SOLVING BY THE WEIGHTED SUM METHOD

The proposed multicriteria optimization task formulation should allow IIT and electrical power battery supply choice for the monocular NVG while providing a maximum standing man detection range on the ambient light condition at ¼ moon, minimum of the device price and weight including the electrical battery power supply working temperature range (– 30 °C, + 30 °C) with minimum lifetime 100 h, i.e.:

$$\max\{R^d, -H, -P\}, \quad (26)$$

subject to (2–25) where the used values are:

- the external observing parameters: $\tau_a = 0.7$, $E = 0.01$ lx (¼ moon), $K = 0.2$, $A^d_{ob} = 0.7\ \mathrm{m}^2$;
- the objective parameters: $K_{ob} = 0.42235$, $H_{ob} = 85$ gr, $P_{ob} = 350$ \$;
- the ocular parameters: $H_{oc} = 65$ gr, $P_{oc} = 300$ \$;
- the electrical battery power supply parameters: $L_{B\min} = 100\ \mathrm{h}$, $T_B^{low\min} = -30\ °\mathrm{C}$, $T_B^{high\max} = 30\ °\mathrm{C}$.

The formulated multicriteria nonlinear mixed integer optimization task is solved using the parameters of the 5 different IIT, one fixed pair objective and ocular and 6 battery types shown in *table 1* and *table 2*.

TABLE 1. IIT's parameters
ТАБЛИЦА 1. Параметри на електронно-оптичните преобразуватели

| No | IIT | $S_\Sigma$, A/lm | $\delta$, lp/mm | $M$ | $I_{IIT}$, mAh | $L_{IIT}$, h | $T_{IIT}$, gr | $P_{IIT}$, \$ |
|---|---|---|---|---|---|---|---|---|
| 1 | Gen II [10] | 0.00045 | 50 | 16 | 16 | 2000 | 85 | 660 |
| 2 | SHD-3 [10] | 0.00060 | 54 | 20 | 18 | 10000 | 80 | 1500 |
| 3 | XD-4 [10] | 0.00070 | 58 | 24 | 20 | 15000 | 80 | 2000 |
| 4 | XR-5 [10] | 0.00080 | 70 | 28 | 35 | 15000 | 80 | 5600 |
| 5 | MX-10160A [11] | 0.00180 | 64 | 21 | 40 | 10000 | 85 | 4900 |

TABLE 2. Battery's parameters
ТАБЛИЦА 2. Параметри на батериите

| № | Battery | Voltage, V | $C_B$, mAh | $H_B$, gr | $T_B^{high}$, °C | $T_B^{low}$, °C | $P_B$, $ |
|---|---|---|---|---|---|---|---|
| 1 | Varta Longlife [12] | 1.5 | 1200 | 23.0 | 30 | – 30 | 1.00 |
| 2 | GP Super Alkaline [13] | 1.5 | 2500 | 24.0 | 35 | – 35 | 1.40 |
| 3 | Energizer Ultimate Lithium [14] | 1.5 | 2900 | 24.0 | 35 | – 35 | 4.00 |
| 4 | Renata CR2477N [15] | 3.0 | 950 | 8.2 | 35 | – 35 | 7.00 |
| 5 | Duracell 2450 Long Life Lithium [16] | 3.0 | 560 | 6.2 | 30 | – 30 | 2.50 |
| 6 | CR2477 Sony Lithium Coin Battery [17] | 3.0 | 1000 | 10.0 | 30 | – 30 | 4.95 |

The values for the single mechanics weight and price for the electrical battery types 1, 2 and 3 (*table 2*) are respectively 30 gr and 50 $, for the types 4 and 5 are 20 gr and 25 $, for types 6 are 15 gr and 20 $ and are approximate values.

A widely used and popular method for the multiobjective optimization is the weighted sum method. It takes into account the preferences of the decision-maker by using different weights for the different objectives [1, 6]. The method requires normalization of the objective function by solving maximization and minimization single-criterion problems for the each one of the criteria, discarding the rest of them. The formulated multicriteria problem (26) has maximum and minimum values for each criterion as shown in *table 3*.

TABLE 3. The maximum and minimum values for each criterion
ТАБЛИЦА 3. Максимални и минимални стойности за всеки от критериите

| | $R^d$, m | $H$, gr | $P$, $ |
|---|---|---|---|
| max | 551.56 | 460.60 | 6806.00 |
| min | 319.15 | 286.40 | 1374.00 |

The weighted sum method transforms multiple criteria task to a single-criterion problem defined as a sum of normalized criteria with proper weight coefficients $w_i$, where $\sum_{i=1}^{3} w_i = 1$ and $0 \le w_i \le 1$. The values from the *table 3* are used to define normalized single objective function for the using of the weighted sum method to solve (25):

(27) $$\max\left\{ w_1 \frac{R^d - R^d_{min}}{R^d_{max} - R^d_{min}} + w_2 \frac{H_{max} - H}{H_{max} - H_{min}} + w_3 \frac{P_{max} - P}{P_{max} - P_{min}} \right\}.$$

Four sets of the weight coefficients $w_i$ have been chosen as shown in *tabl. 4*.

TABLE 4. The used sets of the weight coefficients
ТАБЛИЦА 4. Използвани набори от теглови коефициенти

| set | $w_1$ | $w_2$ | $w_3$ |
|---|---|---|---|
| (1) | 0.334 | 0.0333 | 0.333 |
| (2) | 0.450 | 0.450 | 0.100 |
| (3) | 0.100 | 0.100 | 0.800 |
| (4) | 0.900 | 0.050 | 0.050 |

The transformed single criteria problems for the used different sets of the weight coefficients are solved by means of the LINGO software system [18] (LINDO Systems Inc.). The solutions for the each transformed problem are shown in *table 5*.

The results from the *table 5* show the equality of the values of the man detection range, weight and price, for the problems (1) and (3) and for the problems (2) and (4) respectively. The solutions of the problems (1) and (3) are dominated by the price weight coefficients – i.e. 0.333 for the problem (1) and 0.800 for the problem (3), which leads to the cheapest elements combination.

TABLE 5. Transformed problems solutions results
ТАБЛИЦА 5. Резултати от решаването на трансформираните задачи

| **Device elements** | Problem (1) | Problem (2) | Problem (3) | Problem (4) |
|---|---|---|---|---|
| | **Chosen element** | | | |
| Chosen IIT (table 1) | 1 | 5 | 1 | 5 |
| Chosen Battery type (table 2) | 4 (2pc) | 4 (5pc) | 4 (2pc) | 4 (5pc) |
| **Device parameters** | **Calculated value** | | | |
| Man detection range, m | 319.15 | 551.56 | 319.15 | 551.56 |
| Weight, gr | 291.40 | 376.00 | 291.40 | 376.00 |
| Price, $ | 1374.00 | 6710.00 | 1374.00 | 6710.00 |
| Electrical battery power supply lifetime, h | 118.75 | 118.75 | 118.75 | 118.75 |

Note: Because of the fact that not all elements have needed values in their data sheets some practically expected values were used and the results in the *tabl. 5* can be used for some theoretical estimations.

The weight coefficient for the detection range parameter in the problems (2) and (4) are considerably bigger then the price weight coefficients – i.e. 0.450 vs. 0.100 and 0.900 vs. 0.050. As a result the price is ignored and the longest detection ranges are determined. Some further numerical experiments will be done to determine the dependability between the weight coefficients relations and the solution results.

As another extension of current work, some other methods for the formulated NVD design multi-criteria problem solving will be used ("ε-constraint" method, lexicographical methods, etc.) to evaluate their applicability and efficiency.

## CONCLUSION

The obtained results show that the defined multicriteria optimization model taking into account electrical battery power supply lifetime depending on the IIT choice can be used for a preliminary theoretical estimation of the NVG parameters on the design stage. That means decreasing of the device design costs and time as the number of the prototypes to built and test decreases.

The proposed battery power supply for NVG mathematical optimization model could be expanded and modified to estimate other practical requirements on the NVG design stage. For example, the battery power supply packing mechanics depends not only on the batteries type and subtypes but on their mechanics geometrical dimensions. The geometrical dimensions of the chosen IIT could also be taken into consideration for mechanical construction design.

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# ИЗПОЛЗВАНЕ МЕТОДА НА ПРЕТЕГЛЕНАТА СУМА ЗА ИЗБОР НА БАТЕРИЙНО ЗАХРАНВАНЕ ЗА ОЧИЛА ЗА НОЩНО ВИЖДАНЕ

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Резюме

Формулиран е оптимизационен модел на очила за нощно виждане (ОНВ), вземащ предвид разстоянието на действие, теглото и цената, както и времето на непрекъсната работа на батерийното захранване, работния му температурен диапазон и типа на конструкцията му. Изборът на тип и капацитет на батерийното захранване е свързан с избора на електронно-оптичен преобразувател (ЕОП) чрез тока на консумацията му. Оптимизационният модел е използван за формулиране на многокритериална нелинейна смесено-целочислена оптимизационна задача, решавана по метода на претеглената сума. Числените резултати показват, че предложения модел може да бъде използван за избор на ЕОП и батерийно захранване на етапа на проектиране за получаване на теоретична оценка за времето на непрекъсната работа на ОНВ, за теглото и цената на избраните елементи. Предложеният оптимизационен модел може да бъде модифициран и допълван и за други практически изисквания.

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