DOI: 10.19279/TVZ.PD.2015-3-2-03

FOOTBALL STADIUM FLOODLIGHT AIMING BY USING A GENETIC ALGORITHM WITH MULTI–STEP APPROACH

USMJERAVANJE REFLEKTORSKE RASVJETE NOGOMETNOG STADIONA POMOĆU GENETSKIH ALGORITAMA S VIŠEKORAČNIM PRISTUPOM

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Abstract

Light designer's task is to aim the football stadium floodlight to achieve the required levels of average horizontal and vertical illuminations, as well as their uniformity. At the same time the floodlight aiming for higher demand (for example official games lighting) must incorporate that some reflectors have a fixed aiming obtained by optimizing for lower demand (for example training). It is called the multi–step approach.
In developing of the model and the program GAVRAS are used the mathematical package Matlab with its GA toolbox and own old program for outdoor lighting calculation VRAS.
Implementation of the program GAVRAS is demonstrated by an example.

Keywords: *football stadium, floodlight, genetic algorithm, multi–step.*

Sažetak

Zadatak projektanta rasvjete je da usmjeri reflektore na nogometnom stadionu tako da se postignu potrebni nivoi srednje horizontalne i vertikalne rasvijetljenosti, a također i njihove jednolikosti. Pri tom kod usmjeravanja reflektora za viši zahtjev (npr. rasvjeta utakmica) mora dio reflektora imati fiksno usmjerenje dobiveno optimiranjem za niži zahtjev (npr. rasvjeta treninga). To se zove višekoračni pristup.
Pri izradi modela i programa GAVRAS korišten je matematički paket MATLAB, njegov dio za primjenu genetskih algoritama GA Toolbox i vlastiti stari program za vanjsku rasvjetu VRAS.
Primjena programa GAVRAS je demonstrirana na jednom primjeru.

Ključne riječi: *nogometni stadion, reflektorska rasvjeta, genetski algoritam, višekoračni.*

1. Introduction

1. Uvod

Football pitches lighting must allow playing and monitoring the game (directly at stadium and indirectly via the TV broadcast). Requirements regarding lighting are given in the relevant standard and guides [1, 2, 3]. Aiming of the football stadium reflectors is the longest job which should ensure a high enough horizontal and vertical illuminance with the required uniformity. The development of genetic algorithms methods provides the possibility that this part of the project is left to the computer. The paper will deal with methods of applying genetic algorithms to this activity. The results are demonstrated on a real football stadium and will include numerical and graphical results of the optimal design for a variety of criteria.

Several papers have been already published in this field [4, 5, 6, 7].

Paper [4] deals with genetic algorithm technique that is developed for the optimal design of a supplemental lighting system for greenhouse crop production. The approach uses the evolutionary parallel search capabilities of genetic algorithms to design the pattern layout of the lamps luminaries, their mounting heights and their wattage. The total number and the exact positions of luminaries are not predefined (even though possible positions lay on a fixed grid layout), thus the genetic algorithm system has a large degree of freedom in the designing process. The possibilities of mounting heights and luminaire wattages are limited to four different values for each luminaire in this study.

Paper [5] deals with football stadium lighting optimization by GA methods. The calculation method is based on discrete points on rectangular grid. The reflector data are not included.

Paper [6] proposes a Genetic Algorithm to optimize lighting design parameters integrated with a Computer Aided Design (CAD) application. Genetic Algorithm offers an optimization approach to perform a search to achieve better design solutions, and proposed CAD tool uses innovative concepts of Information Visualization within virtual environments.

Author's paper [7] deals with GA based optimum aiming techniques but without involving past optimization aiming points on lower illumination levels that influence on aiming for the higher illumination levels.

Author uses the possibility to connect the early developed lighting program VRAS [8] to Matlab GA Toolbox. In this way Matlab optimization program GAVRAS, based on genetic algorithms, calls external program VRAS for illuminance calculations as bases for fitness function calculation. In comparison with paper [5] program GAVRAS does not use discrete aiming points. The results cannot be compared with early publish results because of luck of reflector intensity data in published papers.

2. Football stadium lighting

2. Rasvjeta nogometnog stadiona

Lighting requirements are defined by EN 12193 [1]. Additional requirements may be defined by sports governing bodies such as FIFA [2], Olympic Authorities, TV authorities, such as Sky, and by luminaries companies as Philips [2, 3].

Each sport has a playing area that is the principal playing area (the area inside the line marking for tennis or football for example) and the total area which is defined as the principal playing area, plus an additional safety area outside the principal playing area.

Lighting levels for sports are normally defined in terms of the minimum average horizontal illuminance on a reference plane, and the illuminance uniformity. In some instances the illumination plane will be relevant to the sport and the spectator viewing distance, or TV camera–viewing plane. Here, the normal to camera illuminance and vertical illuminance will be relevant.

As some sporting areas are large, they have the need for high illuminance levels, or if they are used for long periods during the day, highly efficient lighting systems are required to keep the energy consumption low. Maintenance is also important to ensure system efficiency and functionality and therefore all lighting equipment should be safely accessible and maintainable throughout its life.

Average maintained horizontal illuminance (E_{hav}) is the average quantity of lux to be achieved over the agreed maintenance cycle period for an installation. Maintenance includes replacement of lamps and cleaning of luminaries. Where there is television coverage, it has become increasingly common for minimum lighting levels to be specified in the regulations. This is also true for the vertical illuminance described below.

This is the amount of light (measured in lux) that is required for the relevant sport to be played. The faster the sport and the smaller the playing object, the higher is the lighting level required. Normally, several different settings or "switching modes" are recommended so that the lighting system can be used efficiently at all levels, from "training mode" (non–televised) right through to "international TV" mode (televised).

Average maintained vertical illuminance (E_{vav}) or camera illuminance is the quantity of light that shines in the direction of a fixed camera position. Calculations should be carried out using the actual angles perpendicular to the camera positions. The side of a player forms the reference for the television camera. The camera illuminance should ideally also be considered for the ball in flight, as this reading will differ from the camera illuminance at ground level. This is generally defined as being 1.5m from the ground.

Table 1 *Illuminance requirements* [1]

Tablica 1 *Zahtjevi na rasvijetljenost* [1]

Lighting class	**Horizontal average illuminance E_{hav} (lx)**	**Uniformity of horizontal illuminance $U_2=E_{hmin}/E_{hav}$**
Training & recreation	75	0,5
Leagues & clubs	200	0,6
National league	500	0,7

The required vertical illuminance for the TV broadcasting of a football game can be found in Figure 1 at curve B depending on the shooting distance.

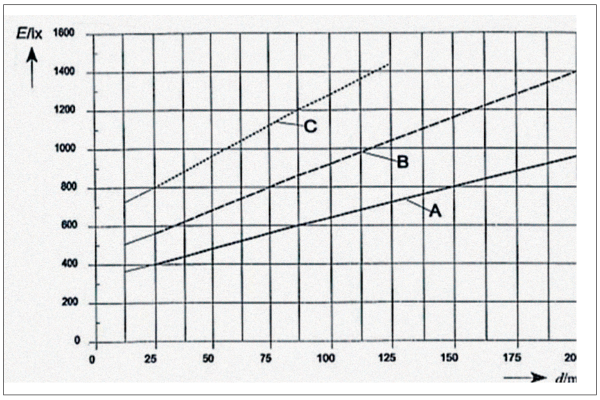

Figure 1 *Required vertical illuminance* [1]

Slika 1 *Zahtijevana vertikalna rasvijetljenost* [1]

For shooting distance around 120m the required vertical illuminance equals to 1000 lx.

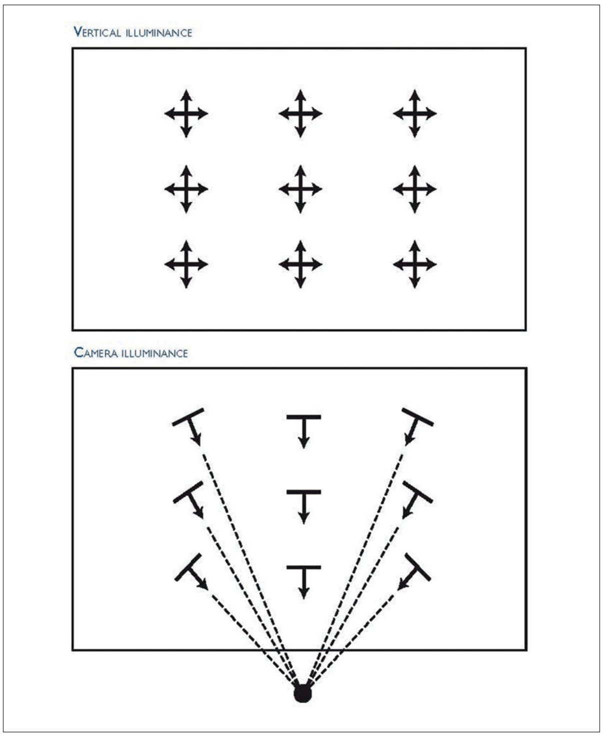

Figure 2 *Vertical and Camera Illuminance* [1]

Slika 2 *Vertikalna rasvijetljenost i rasvijetljenost u smjeru kamere* [1]

Requirements for horizontal and vertical illuminance with TV broadcast are stated in following equations:

$$\frac{E_{v\min}}{E_{v\max}} \geq 0.4 \quad (1)$$

$$0.5 \leq \frac{E_{hav}}{E_{vav}} \leq 2 \quad (2)$$

$$\frac{E_{h\min}}{E_{h\max}} \geq 0.5 \quad (3)$$

where:

E_{vmin} – minimal value of vertical illuminance (lx),
E_{vmax} – maximum value of vertical illuminance (lx),
E_{vav} – average value of vertical illuminance (lx),
E_{hmin} – minimal value of horizontal illuminance (lx),
E_{hmax} – maximum value of horizontal illuminance (lx),
E_{hav} – average value of horizontal illuminance (lx).

Equations for illuminance calculations are:

$$E_h = \frac{I_\alpha}{h^2} \cdot \cos^3 \alpha \quad (4)$$

$$E_v = \frac{I_\alpha}{h^2} \cdot \cos^2 \alpha \cdot \sin \alpha \cdot \cos \beta \quad (5)$$

$$E_{TV} = \frac{I_\alpha}{h^2} \cdot \cos^2 \alpha \cdot \cos \gamma \quad (6)$$

where:

E_h – horizontal illuminance (lx),
E_v – vertical illuminance (lx),
E_{TV} – camera illuminance (towards TV camera) (lx),
I_α – lumens per lamp (intensity) in the direction towards calculation point (cd),
h – height of reflector (m),
α – angle between reflector normal vector and reflector distance vector (°),
β – angle between reflector x-axes and horizontal projection of reflector distance vector (°),
γ – angle between reflector distance vector and TV camera distance vector (°).

Calculation points are placed on rectangular grid with maximum distances p between nodes:

$$p = 0.2 \cdot 5^{\log d} \tag{7}$$

where d equals the longest side of football field. For length of 105m d equals 5m.

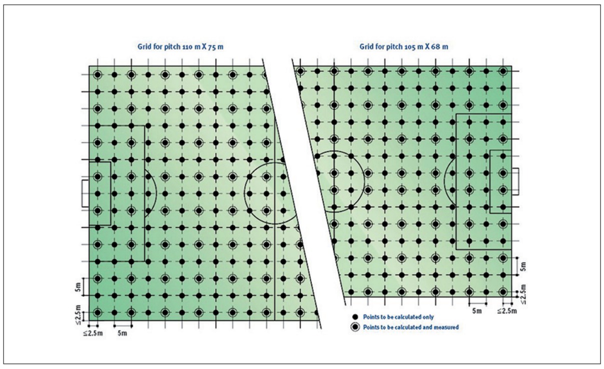

***Figure 3** Calculation Grid Points* [2]

***Slika 3** Proračunska mreža točaka* [2]

One of the popular ways of the reflectors placement is arrangement with 4 towers in the corners of the football stadium. Aiming of reflectors is than mirrored over x and y axes.

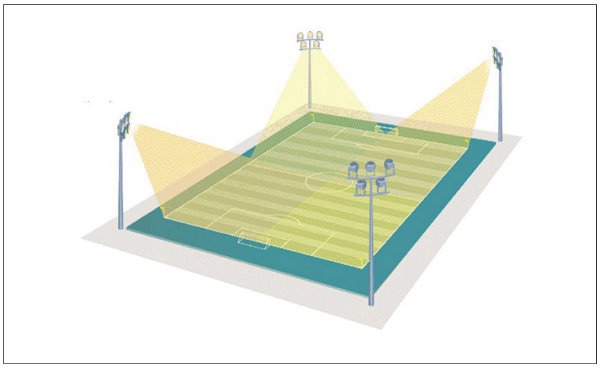

***Figure 4** Four Lighting Tower Arrangement* [2]

***Slika 4** Izvedba s četiri rasvjetna stupa* [2]

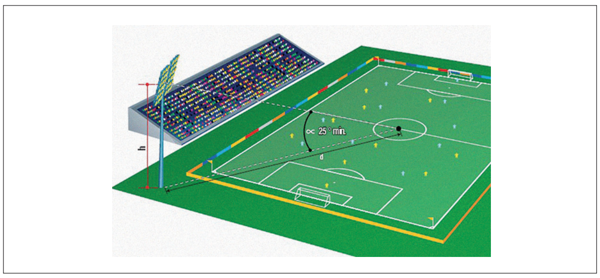

***Figure 5** Minimum Lighting Tower Height* [2]

***Slika 5** Minimalna visina rasvjetnog stupa* [2]

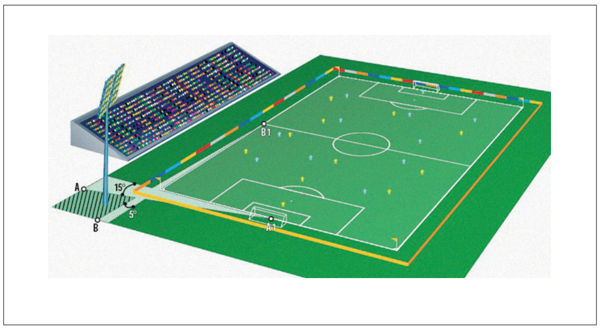

***Figure 6** Lighting Tower Sitting* [2]

***Slika 6** Smještaj rasvjetnog stupa* [2]

3. Implementation of the GA method

3. Primjena GA metode

A genetic algorithm technique is developed for aiming of the optimal design of a football stadium lighting system. The approach uses the evolutionary parallel search capabilities of genetic algorithms.

The real–value chromosomes were used representing the x and y coordinates of aiming points on the football field.

Program GAVRAS (written in MATLAB) randomly selects aiming points on a playing area and call VRAS lighting program [7] for calculation of illuminance as base for fitness function calculation.

Fitness (objective) functions were a mix of illuminance level and uniformity requirements. Huge penalties are implemented for violation of constraints (required illuminance level or uniformity).

Fitness function, for levels I, II and III, must correspond to the requirements in Chapter II (E_{hav} and U_2) and their values:

$$f_1 = k_1 \cdot \left(E_{hav} - E'_{hav}\right) + k_2 \cdot \frac{E_{hav}}{U_2} \cdot \left(U_2 - U'_2\right) \tag{8}$$

where:

f_1 – fitness function,
k_1, k_2 – factors of satisfying requirements,
E_{hav} – required horizontal illuminance (lx),
E'_{hav} – current average horizontal illuminance (lx),
U_2 – required uniformity factor,
U'_2 – current uniformity factor.

Factor k_1 and k_2 equal 1 if requirements are satisfied or 1000 if requirements are not satisfied. In such a way the optimization (minimization) process is moved to the satisfactory solution. For unsatisfied aiming points fitness function is positive and for satisfied aiming points negative.

For TV transmission of a football game the requirements in Chapter II must be satisfied in the similar way as in equation (8) but simultaneously the horizontal and vertical illuminance must be tracked as well as their uniformity factors in equations (1), (2) and (3).

4. Example

4. Primjer

GA method shall be presented on a football stadium with the playing field (or principal area) equal to 105m x 68m. Longer size is parallel with x-axes. Central point of playing area is at point (0; 0), towers with reflectors are at points (70; 45), (70; -45), (-70; 45) and (-70; -45). Towers height equals 40m.
Check of towers sitting:

$$\alpha_B = arctg\frac{45-34}{70} = 8{,}9° > 5°$$

$$\alpha_A = arctg\frac{70-52{,}5}{45} = 21{,}5° > 15°$$

Check for towers height:

$$\alpha = arctg\frac{40}{\sqrt{70^2+45^2}} = 26° > 25°$$

Calculation grid:

$$p = 0{,}2 \cdot 5^{\log d} = 0{,}2 \cdot 5^{\log 105} = 5m$$

Calculation grid has 21x14 calculation points.

Reflector type is MAGNUM LVR-10 2000 TS, TEP with lighting source HQI 2000 W, 183.000 lm. Photo of reflector is given at Figure 7 and Cartesian intensity diagram is given at Figure 8. Cartesian intensity diagram is also given in datasheet view in Table 2.

For all calculations (Levels I, II, III and IV) the following GA parameters have been used:

PopulationSize: 20
EliteCount: 2

***Figure** 7 Reflector MAGNUM LVR-10 2000 TS*

***Slika** 7 Reflektor MAGNUM LVR-10 2000 TS*

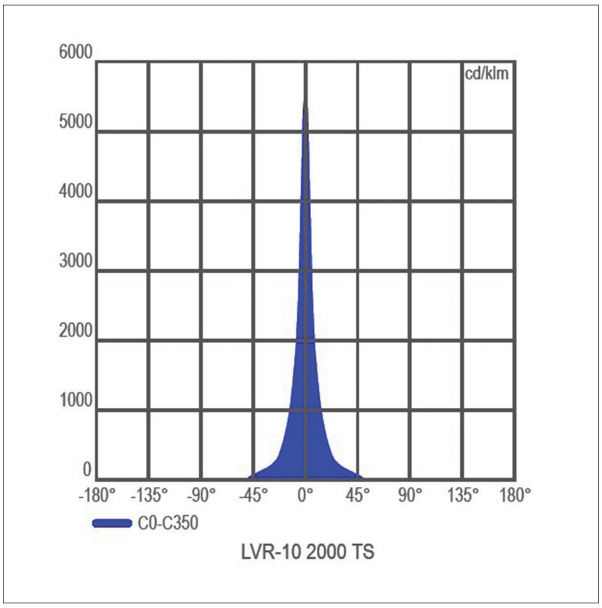

***Figure 8** Cartesian intensity diagram*

***Slika 8** Krivulja intenziteta rasvjete*

CrossoverFraction: 0.8000
Generations: 50
TimeLimit: Inf
FitnessLimit: -Inf
StallGenLimit: 50
StallTimeLimit: 100
TolFun: 0
TolCon: 1.0000e-006
CreationFcn: @gacreationuniform

Table 2 *Cartesian intensity diagram*

Tablica 2 *Dijagram intenziteta rasvjete*

α (°)	I_α (cd/klm)
0	5667
5	3311
10	1422
15	804
20	456
25	267
30	185
35	146
40	106
45	55
50	2
55	0
180	0

FitnessScalingFcn: @fitscalingrank
SelectionFcn: @selectionstochunif
CrossoverFcn: @crossoverscattered
MutationFcn: @mutationadaptfeasible

Level I – Training & recreational

Number of reflectors used in this calculation equals to 12 (4 towers with 3 reflectors). Optimization process is shown at Figure 9 and results are given in Tables 3 and 4.

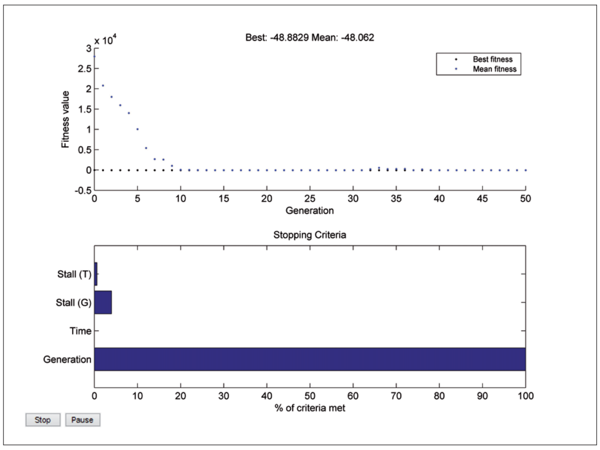

Figure 9 *Optimization Process – Level I*

Slika 9 *Optimizacijski proces – Nivo I*

Aiming points are for reflectors on tower at location (70; 45). The programme GAVRAS automatically generates aiming points for other reflectors on other three towers due to x and y symmetrically arrangement.

Table 3 *Level I – Results*

Tablica 3 *Nivo I - rezultati*

Variable	Required value	Calculated value
E_{hav} (lx)	75	113,9
U_2	0,5	0,57

Table 4 *Level I – Reflector aiming points*

Tablica 4 *Nivo I - točke usmjerenja reflektora*

No.	X (m)	Y (m)
1	29.5	12.9
2	9.8	26.0
3	45.4	15.0

Level II – Leagues & clubs

Number of reflectors used in this calculation equals to 24 (4 towers with 6 reflectors). Three reflectors are already aimed. Optimization process is shown at Figure 10 and results are given in Tables 5 and 6.

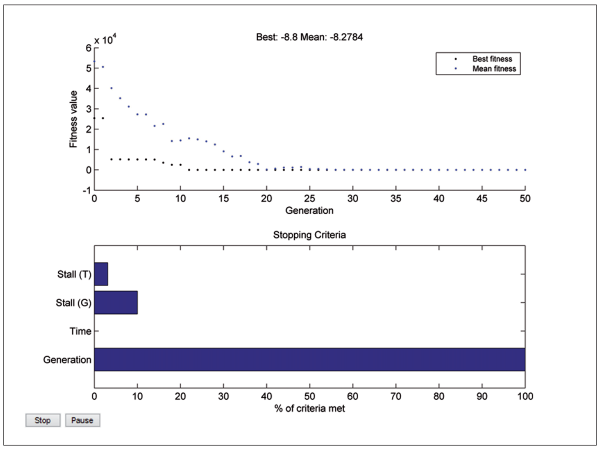

Figure 10 *Optimization Process – Level II*

Slika 10 *Optimizacijski proces – Nivo II*

Table 5 *Level II – Results*

Tablica 5 *Nivo II - rezultati*

Variable	Required value	Calculated value
E_{hav} (lx)	200	200
U_2	0,6	0,63

Table 6 *Level II – Reflector aiming points*

Tablica 6 *Nivo II – točke usmjerenja reflektora*

No.	X (m)	Y (m)
1	29.5	12.9
2	9.8	26.0
3	45.4	15.0
4	4.7	11.1
5	20.3	33.0
6	47.8	-25.4

The first three reflectors are already aimed in previous step.

Level III – National games

Number of reflectors used in this calculation equals to 64 (4 towers with 16 reflectors). Six reflectors are already aimed. Optimization process is shown at Figure 11 and results are given in Tables 7 and 8.

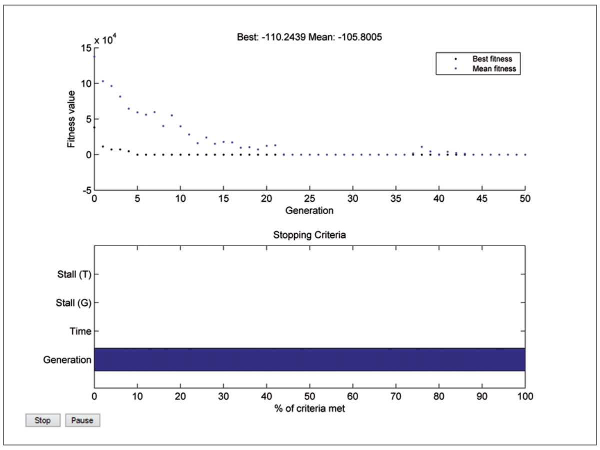

Figure 11 *Optimization Process – Level III*

Slika 11 *Optimizacijski proces – Nivo III*

Table 7 *Level III – Results*

Tablica 7 *Nivo III – rezultati*

Variable	Required value	Calculated value
E_{hav} (lx)	500	524,5
U_2	0,7	0,82

The first six reflectors are already aimed in previous step.

Table 8 *Level III – Reflector aiming points*

Tablica 8 *Nivo III – točke usmjerenja reflektora*

No.	X (m)	Y (m)
1	29.5	12.9
2	9.8	26.0
3	45.4	15.0
4	4.7	11.1
5	20.3	33.0
6	47.8	-25.4
7	22.5	-3.5
8	42.2	33.6
9	9.7	32.6
10	-8.0	14.1
11	45.5	25.3
12	2.0	33.9
13	48.8	0.6
14	11.3	14.6
15	49.6	19.0
16	5.1	15.8

Level IV – International with CTV

Number of reflectors used in this calculation equals to 236 (4 towers with 59 reflectors). Sixteen reflectors are already aimed. Optimization process is shown at Figure 12 and results are given in Table 6.

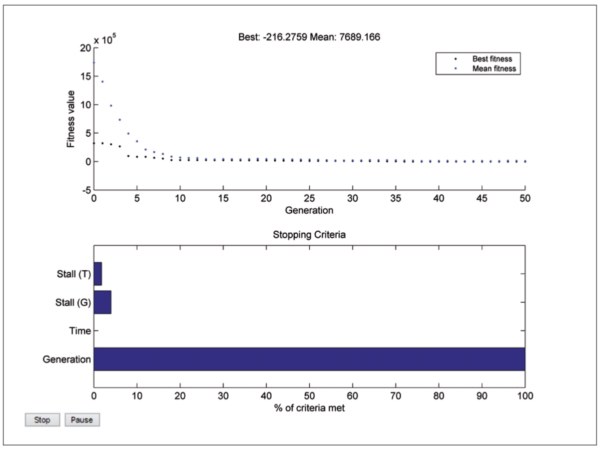

Figure 12 *Optimization Process – Level IV*

Slika 12 *Optimizacijski proces – Nivo IV*

***Table 9** Level IV – Results*
***Tablica 9** Nivo IV – rezultati*

Variable	Required value	Calculated value
E_{hav} (lx)	500	1782
E_{hmin} (lx)	-	2119
E_{hmax} (lx)	-	1254
E_{hmin}/E_{hmax}	0,5	0,59
E_{vav} (lx)	1000	1016
E_{vmin} (lx)	-	557
E_{vmax} (lx)	-	1370
E_{vmin}/E_{vmax}	0,4	0,41
E_{hav}/E_{vav}	<2	1,56
E_{hav}/E_{vav}	>0,5	1,56

***Table 10** Level IV – Reflector aiming points*
***Tablica 10** Nivo IV – točke usmjerenja reflektora*

No.	X (m)	Y (m)
1	29.5	12.9
2	9.8	26.0
3	45.4	15.0
4	4.7	11.1
5	20.3	33.0
6	47.8	-25.4
7	22.5	-3.5
8	42.2	33.6
9	9.7	32.6
10	-8.0	14.1
11	45.5	25.3
12	2.0	33.9
13	48.8	0.6
14	11.3	14.6
15	49.6	19.0
16	5.1	15.8
17	52.5	-2.6
18	25.6	-10.7
19	-8.3	-0.1
20	-25.8	2.9
21	-52.5	-0.9
22	2.3	-25.1
23	10.6	-8.7
24	-24.5	10.3
25	18.2	-8.5
26	20.6	24.7
27	-28.7	13.1
28	15.5	0.0
29	-15.1	-19.5
30	-39.4	20.6
31	-21.1	27.8
32	24.9	-26.0
33	-12.7	5.6
34	-33.8	12.8
35	52.5	-23.5
36	29.1	15.0
37	-49.2	-22.0
38	-42.2	-8.2
39	-52.5	25.3
40	-5.9	14.2
41	32.0	20.2
42	46.7	-16.9
43	26.6	2.7
44	52.5	30.5
45	33.2	-16.5
46	-30.5	29.2
47	-32.8	-13.9
48	-34.5	14.6
49	-25.7	-15.9
50	6.6	-19.2
51	52.5	0.4
52	-32.8	6.4
53	-40.4	3.8
54	-45.1	-24.0
55	-50.7	-17.0
56	-50.6	34.0
57	46.2	20.9
58	-52.5	14.7
59	-32.4	-17.6

The first sixteen reflectors are already aimed in previous step.

5. Discussion

5. Diskusija

The results for all four illumination levels (I, II, III and IV) show that the described GA method gives optimum results. Low resulting (negative) values of fitness function meant that there is no room for smaller number of reflectors.

Due to symmetric arrangement of towers, number of calculated reflectors is only one quarter of total reflector's number.

The described method free illumination designer of time–consuming and boring work of reflectors aiming.

6. Conclusion

6. Zaključak

The paper describes the method for football stadium reflector aiming by means of GA implementation. The real–value chromosomes were used representing the coordinates of aiming points on the football field. The reason for the GA choice is the description simplicity of the stated problem and easy connection to the VRAS lighting program. Value of fitness (objective) function depends on satisfying of illuminance level and illuminance uniformity requirements. Penalties are implemented for violation of constraints (required illuminance level or uniformity).

Improvement to last author's paper is multi-step optimization process with fixed and variable aiming points. The fixed aiming points are optimal aiming points on previous optimization process for a lower illumination level.

The future work might be divided into several tasks - connection of the GA model to the professional lighting programs (i.e. RELUX, CALCULUX,...), simultaneous usage of several reflector types and selection of reflector quantity.

8. References

8. Reference

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