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PEAK TASK EFFICIENCY OF OUTDOOR SPORTS LIGHTINGS FOR AIRED AND NON-AIRED EVENTS

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Abstract

This paper presents a method of determining an appropriate luminous intensity distribution of specified luminaires maintaining defined lighting requirements over the task area. In particular, arbitrary light distributions are generated using the introduced reverse calculating, additive algorithm for a sport lighting scenario, where the ratio of illuminance superposition from multiple light sources is weighted in order to be compliant with conditions targeted for obtrusive light. This diversification is based on an automatic and adaptive fractional factorial optimization process. The algorithm considers minimum specified illuminances both in horizontal and vertical planes for multiple sections and increases the luminous intensity towards the specific directions, while keeping the Glare Rating value specified in European Standard EN 12193 at a given level. Using this method results a theoretical lighting design that could achieve up to 45% decrease in energy consumption of a benchmarked sports lighting of a stadium; assuming the same technology and luminaire efficacy as by the existing installation, simply by eliminating wasted light. Another important achievement observable was a drastical decrease of Maximum to Average (M:A) illuminance ratio both for horizonal and vertical illuminance, lower Coefficient of Variation (CV) and better Uniformity. Beisdes optics design, this approach can provide useful input for lighting designers and optimization of existing lighting installations.

Keywords: Lighting, Sports lighting, Light pollution, Illuminance, Glare

1 Introduction

The level of illuminance and the quality of lighting by sporting venues greatly affects the performance of athetes [1], while undoubtly being neccesary for providing safety and easing the actuality of anxiety for the specators, that is a generized effect of mass events [2].

While maintaining the minimum specifications is critical for any given lighting application, another meaningful characteristic derivable is task efficiency, describing the ratio of useful- and total light output. The wasted light factors of sports lighting – especially for Lighting Class II and Lighting Class III events – are usually causing light pollution, light tresspass of obtrusive light. The method introduced in this paper results a theoretical lighting design that has practically zero unwanted btrusive and spill light and thus mimicing this, power consumption can be greatly reduced.

It is important, to simultaneously maintain a certain level of vertical illuminance above the playing field, that is neglected in many lighting designs. The main reason is that for most sports there is an accessory that has a high chance based on the genre of the game to be mid-air for certain amount of time. While percieving the translational movement of these objects is a key in many sports (football, basketball, baseball, ..), in some instances not being able to follow these items clearly means a serious source of danger (javelin).

2 The algorithm prerequireties

In order to understand the algorithm, the data structures used are to be defined. For a start, a task area or task areas need to be defined, whereas the illumination will be optimized. This includes the play area, the specator stand and the volume defined above the playing field, covering the supposed height, that the event will utilize [4].

The first such surface is recommended to be the playing field, where the horizontal illuminance will be measured. Each sport has a playing area defined that is the principle playing area [5]. This is the bounady of the area where legitim actions can happen during the game. As an example, this is the area inside the line marking for a tennis or football field. Also, there must be a total area, that is called the principal playing area. The second set of planes are recommended to be at 1 m height from this floor, where the vertical illuminance will be evaluated. This positioning is

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based on the default specification of European Standard EN 12193 and is mainly used to meet CTV and film systems appropriate lighting requirements. In case if there is only one filming device, it is reasonable to optimize vertical illuminance towards this direction, else multiple planes are recommended to be defined. Also, for each surface, the required minimum illuminances have to be set. This can be acquired typically from European Standard EN 12193. For this introduced method either planar or semi-cylindrical or semi-spherical illuminance was used.

The next resource to be specified is the location of the light sources. It is possible to set restrictions for the extent of light output of these, although it is recommended to use point-like sources and later distribute these results. For most lighting setup, using a whole spherical coordinate system is favorable for the introduced algorithm.

For the lighting of exterior sports fields and facilities, luminaires have to be mounted at a height, so that the floodlight aiming angle shall not be pointing above 70°. Assuming rectangular principal play fields, this determines the minimum mounting height, always adding the plane where vertical illuminance is calculated from.

The last piece of setup is for the dampening functions. For setting the ratios for surface illumination for the ratio of contribution to be shared between light sources, there is a function for which a baseline needs to be set. More on this topic on the corresponding section.

For every light source, an empty luminous intensity I-table will be generated. An I-table contains the luminous intensity values either in absolute [cd] or in relative [cd/klm] values.

After all the input data is stored, an iterative process is to be run.

3 The generator iteration

Given a number of surfaces with specified illuminance requirements and a set of light sources, each assumed to be capable of emitting light in every spatial direction, in the introduced method an iteration steps through every direction of each source. The I-tables created shall have a sufficient resolution for an applicable result. An I(C, γ) = **I**([720],[360]) array was found to be sufficient for further usage.

In the iteration, a function calculates where a ray oriented from the inspected light source, oriented towards the direction (C_n, γ_m) given by the iteration step intercepts the planes. After, the normal direction from the incidence is calculated based on the type of the illuminance requirement. Based on the surface incident angle, it is possible to calculate the light intensity required for any given illuminance level. The corresponding elements of the I-table can be increased until the distribution meets the lighting requirement.

$$I = \frac{r^2 i}{cos\theta} \tag{1}$$

In the next step, a function calculates the luminous intensity required for getting an illuminance of 1 lx for this particular surface position for each light source that is on the positive side of the plane perpendicular to the surface normal. This is then normalized so that the sum of the values becomes one. The ordering means that for the specific coordinate the required illuminance level can be achieved with the lowest energy need if the light intensity is fully provided by this given light source. On the other hand, this concept results glare by the intense veiling luminance.

4 The dampening function

In order to prevent the light sources generating unacceptable glare, there is a dampening applied on the most efficient intensity section out of the sources. This value is to be lowered by some extent by providing the necessary luminous flux from the remaining light sources. This also decreases the task efficiency for meeting the Glare Rating restriction target. For keeping the philosophy of utilizing the source that can be the most efficient, it is reasonable to use the ones that give more for a unit of power, somehow proportionally to its effectiveness. For this process, a single variable was used in each iteration. This dampening factor (D_n) results the new contributory ratios by normalizing the new contribution factors:

$$R_{m,n+1} = {R_{m,n}}^{D_n} \tag{2}$$

Setting the dampening factor initially to the value: 1, results a generator function that calculates the light intensity requirement based on proportionality to the effectiveness of one. Thus if the ratio with two luminaires facing the surface from the positive side of the semispace is 1:1, the illuminance is provided by the two light sources equally. In case if the ratio is 1:2, then two third of the illuminance will come from the source closer and/or in a lower adjacent angle to the given coordinate. There is an outermost iteration for optimizing for glare, which includes the generator iteration and is supposed to change the value of the dampening factor.

5 Optimization for Glare

The iterative method so far can generate an arbitrary light distribution that meets all the illuminant requirements using one single variable. Changing this parameter results very similar illuminance patterns over the task areas, with the same coefficient of utilization while there is a great difference in total lumen requirement.

Additionally, it is important to highlight that this approach simply boosts the luminous intensity to a specific direction until the required illuminance is achieved. This is a method that converges to the target from the lower side but can not reduce the intensity if it is over the requirement. This is analoque to the concept that if a higher level of illuminance is needed on a farther surface, there will necessarily be more lux measurable in a parallel surface that is closer to the source.

The body of the glare optimization iteration calculates UGR in every calculation grid point defined by the user. It is recommended to use the calculation grid specified in the EN 12193 for sports events and EN 12464 for lighting of workplaces [6]. The goal is to reduce this value to an also defined level. The algorithm increases the value of the dampening factor and regenerates the light intensity distributions. Then the UGR is calculated for the new setup and the first value that meets the glare specification interrupts the loop. This will be the highest task efficiency that is achieved with this method [7].

This method considers constant light depreciation. In order to include a calculation for robustness due to the complexity of the maintenance factor regarding sports lighting [4], an additional buffer can be used within the iteration that optimizes for glare. This can work biasing the dampening factor by defining a uniformity calculation with a defined allowed variance in the I-table.

6 Conclusion

It was shown in this paper, that a process could generate a light intensity distribution that meets the lighting requirements of a sports lighting layout with outstanding task efficiency. The glare rating is always a result of the lighting installation and not the luminaires used. By a certain method introduced, the generated arbitrary light intensity distribution can satisfy glare requirements. This approach for lighting design is able to provide major savings in maintenance and upkeep while increasing the quality of the lighting. The resulting illumination of the principal play field gives benefits for airing such events by increased vertical illuminance towards the imaging optics. The generated lighting design provides the least possible amount of light trespass [8] as this conceptual approach disregards spill light.

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