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Enhanced Human Centric Lighting

Individual automated lighting condition by means of a wearable light dosimeter

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Abstract

The aim of this research is to develop a wearable daytime light dosimeter that can be implemented in a lighting solution, to offer individual, automated and optimized lighting conditions. To do so, the dosimeter is orientated towards the standard CIE S 026/E:2018 *"CIE System for Metrology of Optical radiation for ipRGC-Influenced Responses to Light"*, considering the spectral sensitivities of the different retinal receptors and the impact of the field of view.

For optimized lighting conditions, the luminaire's luminous intensity distribution must be adaptable in spectral power distribution and in direction. If the optimal spectral light incidence distribution for ipRGC-influenced responses to light purposes is known, the required luminous intensity distribution of a luminaire for a certain room geometry with certain room surface reflection values can be calculated. For this purpose, a spectral radiosity algorithm is in development. With a feedback loop between luminaire and dosimeter the light distribution can be continuously adapted as required.

Index Terms: Human Centric Lighting, lighting control, dosimeter

1 Introduction

Research shows, that electromagnetic radiation in the visible spectral range not only enables the human eye and brain to perceive colours, contrasts and forms, but also induces non-image forming (NIF) effects or ipRGC-influenced responses to light (IIL) in the human body, e. g. melatonin suppression, influence on acute alertness and performance or changes in the core body temperature.

A great number of studies on IIL was conducted at night, examining the melatonin level in subjects. While ipRGC cells seems to play a major role in nighttime IIL, the daytime interaction of the different retinal receptor types is still not fully understood. Additionally, the light stimulus is often described insufficiently studies [1], due the interdisciplinary character of the which hampers the progress in IIL research.

Lucas et al. [1] suggest a spectral measurement of the light stimuli at eye level and an integral weighted evaluation of the five sensitivity functions of the human retinal photoreceptors, the so-called action spectra, compare figure 1. This procedure was adapted in the CIE Standard CIE S 026/E:2018 [2] with slightly different terminology. This allows for a homogeneous data acquisition and hence for a better understanding of IIL. If that is not feasible, a complementary guideline was published with recommendations for measurements concerning IIL studies [3]. These recommendations also address the problem that the light incidence angle might play a role in the effect size of IIL due to non-evenly distributed ipRGC cells on the retina or differences in the sensitivity of ipRGC cells. This in turn could result in different findings in similar IIL studies, Broszio et al. [4] illustrate this problem in more detail.

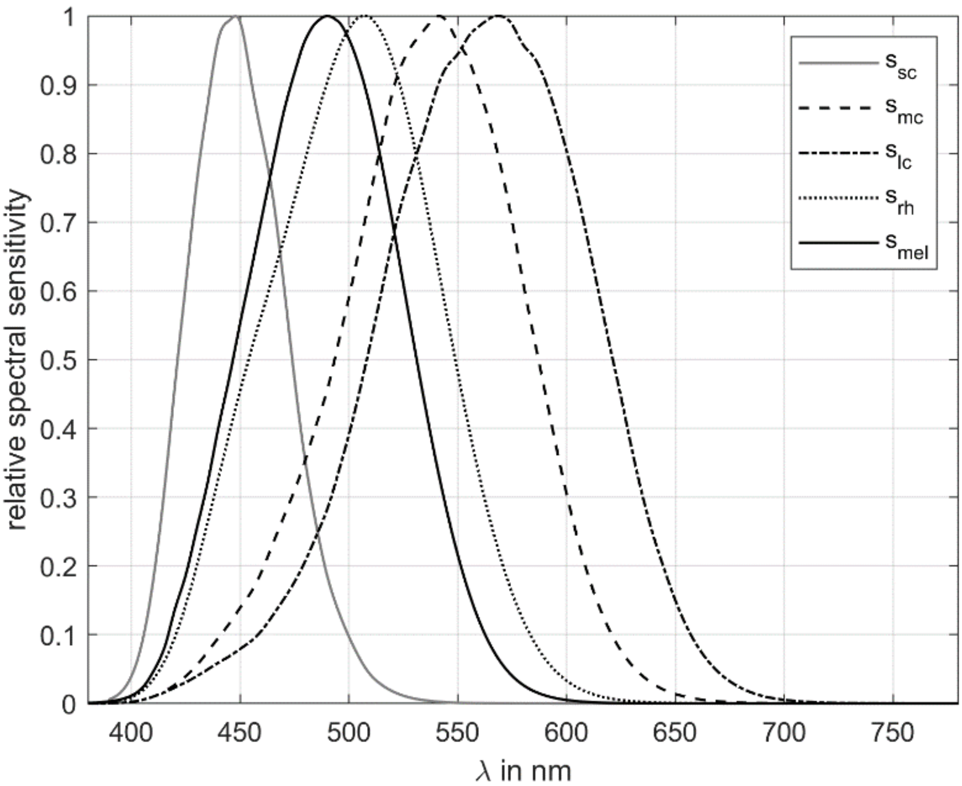

Figure 1: α-opic action spectra of the retinal photoreceptors according to CIE S 026 [2]

Khademagha et al. [5] identified different parameters in an extensive literature review that are believed to influence IIL, see table 1.

Table 1: Parameters for NIF effect analysis [5]

luminous	temporal
spectrum	timing
quantity	duration
directionality	history

To consider the temporal parameters according to Khademagha et al. [5] a wearable measurement device would be suitable. A camera-based system that also considers the integral weighted measurements according to the CIE Standard S 026 [2] by including the action spectra of the five photoreceptors would fulfil the requirements. The measuring system will be henceforth called dosimeter and has the following advantages compared to other devices:

Data that is collected by such a dosimeter could be reassessed for any new insights on IIL, since it contains all necessary information, and thereby accelerate future research and applications. The dosimeter could furthermore be used as a data logger for an automated personal lighting control next to its use as a research tool. This research will focus on the second application in the form of extended human centric lighting.

2 Aims and objectives

For in future known correlations between light stimuli and IIL, an assessment of the temporal and luminous parameters would allow an optimization of an artificial indoor lighting situation for an individual. With an adequate luminaire this process could be automated resulting in an automated and optimized personal wearable lighting control system.

Figure 2 displays the workflow of the lighting control system. The dosimeter collects data and sends it to a compatible luminaire. The lighting control system in the luminaire evaluates the dosimeter data and determines an optimized light stimulus for the participant. A simulation algorithm in the lighting control calculates the necessary luminous intensity distribution curve in dependency of position and viewing direction of the dosimeter and the reflection values of the room. This procedure is repeated continuously.

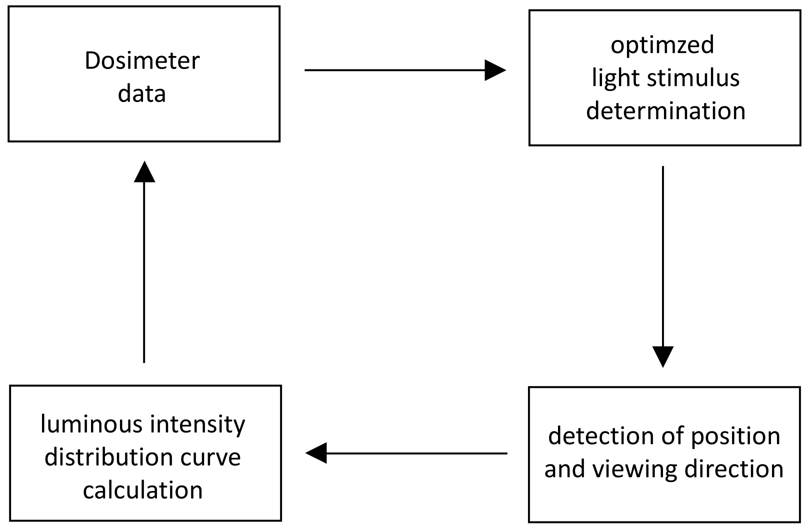

Figure 2: schematic workflow

3 Dosimeter

To collect spatial resolved data over the complete field of view in a short time frame a camera system with a fish-eye lens is suitable, easy to assemble and cost-effective. The images can be separated into different sections of interest which can be weighted with a light incidence factor according to the estimated effect size influence. Each section can be evaluated according to the weighting action spectra and the sections be integrated over the covered area resulting in five values for each measurement. The main problem to solve is the gathering of five different weighted integral measurements with an usual three channel RGB camera system.

Inanici [6] describes a procedure for accurate luminance image acquisition with a normal RGB camera and high dynamic range (HDR) images. This technique was also used with low-cost components controlled by a Raspberry Pi computer [7]. Inanici and Jung [8] extended the HDR luminance image procedure for melanopic irradiance assessments. They also found that the error of the melanopic weighting is linear and can be corrected by a constant factor.

To implement a working dosimeter, an extension of the HDR image approach will be tested. For the necessary additional two channels two different approaches will be pursued.

1. Firstly, an assessment of two imaginary channels from a linear combination of two adjoining RGB channels will be tested. Through the linear combination of two RGB channels the spectral focus will be altered. This would result in five channels using only one camera.

2. Secondly, the field of view can be simplified into two main sections since the photoreceptors are not evenly distributed over the retina: The focus point with colour vision (RGB) and the peripheral field of view comprising roughly of the remaining photoreceptors. By using additional filters in the peripheral field of view the spectral focus can be altered.

4 Light distribution optimization

With a microcontroller in the luminaire the dosimeter's data can be evaluated. The dosimeter's position and viewing direction can be estimated by edge comparement of a low-res image of the dosimeter with the room geometry. For the transmission of the collected dosimeter data to the luminaire, an appropriate data protocol must be implemented.

To determine the optimized luminous distribution curve of the luminaire(s) for a desired light stimulus from the participant's point of view, a backwards simulation of the light distribution in the room geometry in dependency of the reflection values of the enclosing room surfaces is planned. This will be achieved with an adapted spectral radiosity simulation tool developed in 2018 during a diploma thesis [9]. With additional cameras in the luminaire –analogue to the dosimeter– the room geometry and the reflectance values for the five action spectra can be estimated by an evaluation of the camera HDR images.

The spectral simulation program persists of a simple mesh algorithm and the calculation of the radiation exchange between the mesh patches. The program was developed for daylight distribution calculations of spectral sky data in interiors. The program will be extended to handle artificial lighting and objects in the room geometry. Figures 3 to 5 show a simple room geometry mesh, a colour rendering of the final simulation and the radiance and irradiance distribution of an exemplary mesh patch.

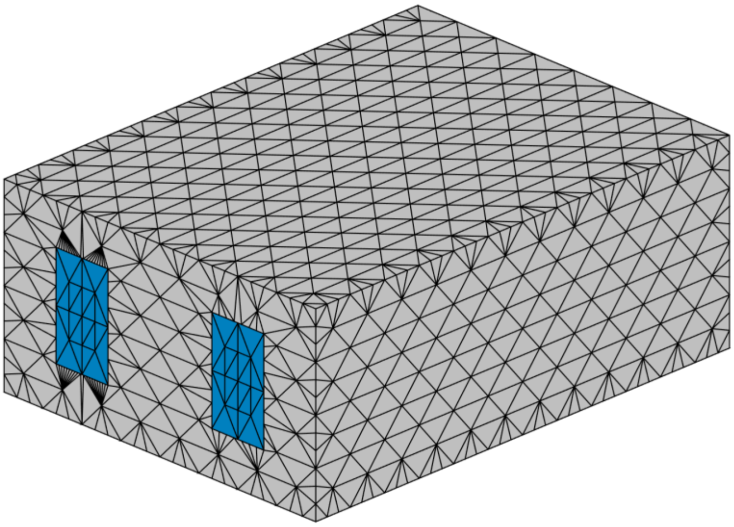

Figure 3: Mesh of a simple room geometry [9]

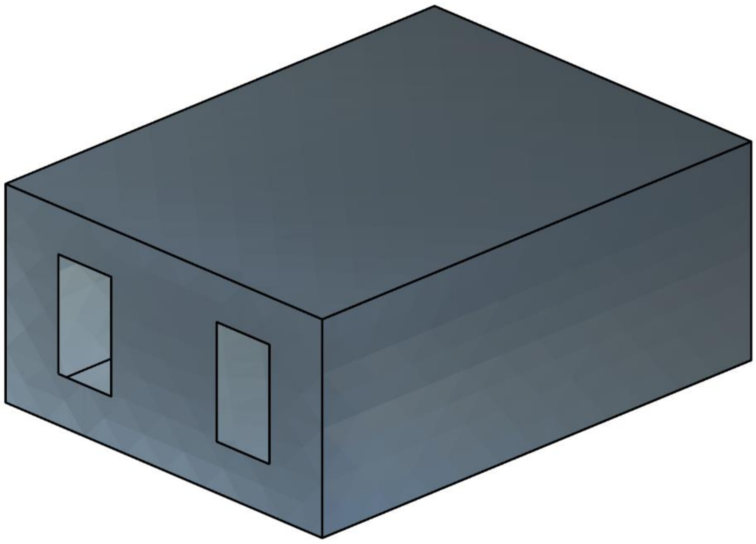

Figure 4: Colour rendering of a simple room geometry simulation [9]

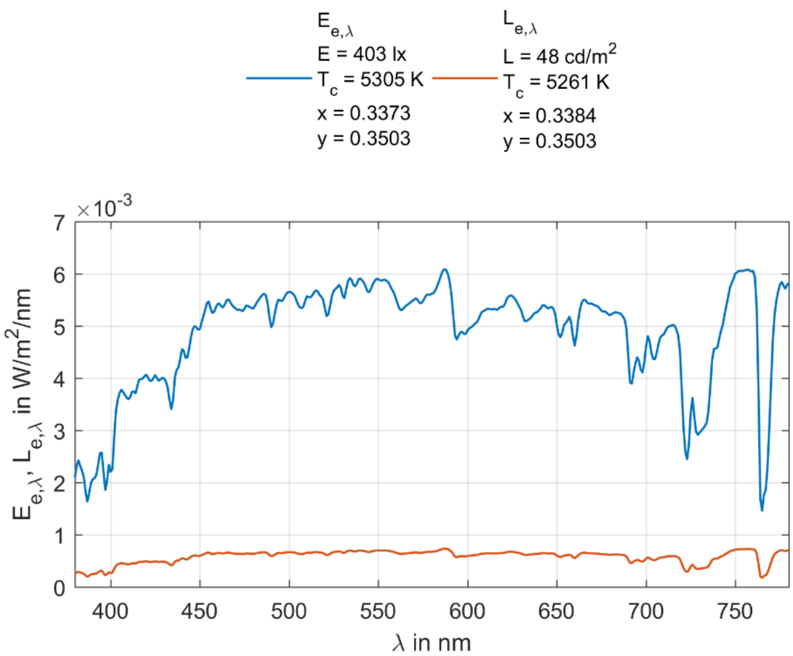

Figure 5: Exemplary spectral radiance and irradiance simulation of an exemplary mesh patch [9]

5 Luminaire

To enable personal lighting, the luminaire must be able to emit light in different directions depending on the viewing direction of the individual. This allows for the utilization of the light incidence, which is believed to have influence on the IIL effect size [5]. The luminaire should also be able to emit different spectra with adaptable intensity.

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