Measurement of the light vector and the illumination-distribution solid using Raspberry Pi

Jan Krüger
Department of Lighting and Multimedia
TÜV SÜD Product Service GmbH
Garching, Germany
jan.krueger@tuvsud.com

***Abstract*—Currently, measuring devices for the detection of light direction and directionality of light are rarely available. On the other hand, light direction and shadow characteristics are important quality criteria in the field of lighting. Against this background an open-source measurement device will be presented which can measure the light vector and illumination-distribution solid [1] at a fixed point in space. Furthermore, evaluations of diffuseness and directionality can be derived from the measured data. In this paper an old concept from 1885 is taken up and brought to present time as an open-source project.**

Keywords—light vector, light direction, illumination-distribution solid, Raspberry Pi

I. Introduction

Current metrics for the description of directionality, diffuseness and shadow characteristics do not suit the complexity this topic e.g., vertical and cylindrical illuminance [2] or cubic illumination [3]. Furthermore, measurement devices for the description of light in space rarely exist. By contrast light direction and shadow characteristics (e.g., shading and cast shadows) are important quality criteria in lighting design. Directionality and diffuseness are important determinants of human perception. It is well-known that they influence edge perception, shape perception of objects, modelling of faces, perception of roughness of surfaces, visuo-motor performance, color recognition, room appearance and visual comfort [4].

With the help of the light vector and the illumination-distribution solid a more detailed description of such mechanisms is possible. Furthermore, a three-dimensional representation of light in space can be derived from the measured data if illumination distribution solids are determined in a 3D-grid-system of evaluation points in space.

II. Theory of the Illumination-Distribution Solid

The concept of the illumination-distribution solid was introduced firstly by Lehonard Weber [1]. In his original paper Weber called the concept brightness solid (German: “Helligkeitskörper”). From a photometric point of view, this name is quite misleading for this reason, it will be referred to as the illumination-distribution solid in this paper as it was also called by Gershun [5]. Weber derived his concepts from daylight observations and described even already a measurement apparatus by Schmidt and Haensch at this time. Weber's concepts were revived in a publication by Lingenfelser [6], he made the concepts available to illumination engineers. Apart from the description of the theoretical concept Lingenfelser does not give detailed information about measurement devices or on the way how the illumination-distribution solid can be measured.

A theoretical description of a measurement apparatus can be found in Gershun’s “the light field” [5]. Gershun describes a device with a two-sided photoelement which is capable to measure the “light vector”. Furthermore, Gershun refers to the existence of a measurement instrument called “the vectorscope” which originates from M. M. Gurevitch from the Optical Institute. According to Gershun the light field at a fixed point in space can be described by a combination of a scalar and a vectorial approach.

The spherical illumination is direction independent and can be measured with an opal glass sphere with a photometer inside. With the help of such a setup the incident light from all directions is integrated to one scalar illuminance value.

The vectorial approach is described by Gershun in the following way: “The luminous flux through a surface may be considered as the flux of a vector point-function, the projection of this vector on a given direction being proportional to the difference in illumination of the two sides of a plane element which is normal to that direction.” (p. 90) [5].

Some years after Lingenfelser and Gershun the idea of a light vector was taken up by Cuttle, who published a circuit diagram of two subtracting measuring photometers. Besides, Haeger presents an apparatus for the measurement of the light vector which was already equipped with a motor control unit for adjustment of the orientation of the photometers [7].

The light vector was even integrated into the lighting standard DIN 5031-3 [2] where it is dated back to a publication from Hellwig [8].

In the recent past, two dissertations by Liedtke [9] and Krüger [4] dealt with the measurement, quantification and evaluation of light direction and light distribution in space.

The literature in the previous section exemplifies that the existing devices for measurement of the light vector and illumination-distribution solid originate from a time when computers, data processing and automatization were not applied in light measurement. Further on, it becomes clear, that a commercially available device did not existed at no time. Only research institutes developed prototypes for own projects. Against this background an open-source device was developed with the following characteristics:

- Miniaturization of the measurement principle in the form of a handheld meter for tripod
- Automatization of the measurement procedure
- Digital evaluation and graphical representation of measurement results
- Open-source code and hardware with individual adjustment possibilities

III. Description of the Device

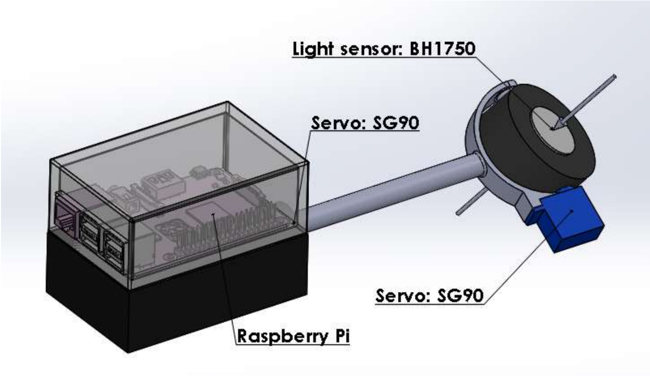

Fig. 1. Description of measurement device

The measuring device is based on a Raspberry Pi [10], which is a credit card-sized, full general-purpose computer with USB ports, an HDMI port, a jack for audio, and an Ethernet port for network connection. Further, the device (figure 1) consists of a photometer unit with two back-mounted photometers for measurement of illuminance in opposite directions (digital light sensor BH1750FVI [11]). The light sensors are connected to a Raspberry Pi 3 Model B+ [10] by General Purpose Input Output Pins (GPIOs). Two I2C busses (Inter-Integrated Circuit) at GPIOs 2+3 and GPIOs 23+24 were activated for the light sensors. Both sensors are powered by 3,3V provided by Pins 1 and 17. With the help of a servo unit (Tower Pro SG90 [12]) the photometer unit can automatically be rotated in any direction at a fixed point. The adjustment of angles is triggered via pulse width modulation from GPIOs 18+12. The motors are powered by 5V from Pins 2 and 4.

To maintain the fixed point in space the device can be mounted on a tripod. The servo unit allows the rotation around two axes. Simultaneously with the rotation, the illuminances in several spatial directions are determined. The illuminances and rotation angles are transmitted to the Raspberry Pi. From these values the light vector for every direction in space can be calculated. Vectors are characterized by direction and value. The direction of the vector is calculated from the rotation angels of the axes, the illuminance value is calculated from the subtraction of the illuminance readings from opposing orientations. Through the measurement of an appropriate number of vectors in different directions the illumination-distribution solid can be calculated. From the illumination-distribution solid the directional composition can be depicted [6].

For a better understanding, the result of a measurement with a sideward light incidence from a single light source is illustrated in figure 2. The vectorial graph was automatically calculated from double-sided illuminance measurements in 122 directions in space. For the representation, a coordinate transformation was calculated. The data were converted from Spherical coordinates (two rotation angles of the servo motors, and two-sided illuminance) to Cartesian coordinates. A surface interpolation over the vector tips would lead to the illumination-distribution solid.

Besides the graphical representation, the device saves the illuminance values together with the angles to a csv-file. It also provides an immediate feedback to the user after completion of the measurement by turning the photometer unit into the dominant light direction.

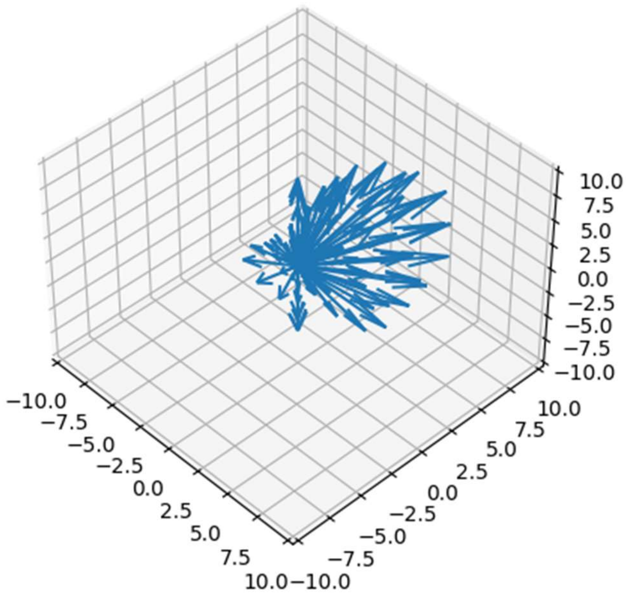

Fig. 2. Quiver-plot of light vectors

IV. Limitations

In this section some limitations will be highlighted, that should be considered during use. It should be noted that the device does not measure the luminous flux through a fixed evaluation point in space. A surface integration over the tips of the light vectors will not lead to the total luminous flux like it is known from measurements of luminaires with a goniophotometer. During each measurement one light sensor captures the cos-corrected light incidence from a solid angle of 180 degrees. To obtain the luminous flux, the light sensor has to be equipped with a tube, which restricts the solid angle. Further on, the step width of the servo motors must be adjusted to the solid angle of the tube. In this phase of development these extensions were waived specifically. Nevertheless, these adjustments are possible with very little effort.

Further limitations arise from the utilization of a low-cost light sensor. The datasheet [11] shows that the spectral adjustment in the range around 550nm deviates significantly from the V(Lambda)-function. Nevertheless, the manufacturer assures a good adjustment. For level control the operator can choose from three different integration times. The manufacturer specifies a measurement range from 1lx to 65535lx. It should be noted that these limitations could be bypassed the application of a more precise sensor. In principle the Raspberry Pi allows the operation of analog light sensors, but in this case an analog to digital converter is required. E.g., the MCP3008 which is a low cost 8-channel 10-bit analog to digital converter. Nevertheless, for this project, it was specifically planned to avoid expensive hardware.

Last, but not least, it is worth mentioning that parts of the housing could cast shadows onto the sensor and affect the test results. From figure 1 it becomes clear, that it is not possible to scan a solid angle of 360 degrees without passing an area that is obstructed by housing components. These influences can be minimized by appropriate positioning.

V. Application Areas

Primarily this device is meant to be used in lighting design and lighting research. It aims to develop a better understanding of complex lighting situations when measured in a 3D-grid of evaluation points. Of course, lighting scenes can be simulated in programs like DIALux and Relux but in the case of overlapping luminous intensity distributions from multiple luminaires with daylight incidence in combination with ambiguous reflective properties of the environment, measurements in the real scene could be a good supplement. Apart from this scope an application in the field of photography or computer vision could be beneficial to determine light direction and light composition in a scene to extract shading and cast shadows from the image information.

The python code provided together with this paper (supplementary material) constitutes the basis for a variety of use cases and is open to modifications. E.g., range and step size of sensor movement, integration time or output format can be customized for specific tasks.

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