Measuring Reflective Properties of Surfaces Using Reflectophotometer

Rudolf Bayer
Department of Electrical Power Engineering
Czech Technical University in Prague
Prague, Czech Republic
bayerrud@fel.cvut.cz

***Abstract*—Modern computer lighting design programs use for simplification reasons during calculations surfaces of purely diffuse reflection. For more accurate calculations it is necessary to use real reflective properties of surfaces that can be measured by a reflectophotometer. The reflectophotometer of the Department of Electrical Power Engineering, FEE CTU in Prague, allows measuring reflective properties of surface samples 2 by 2 cm. ReflectoSoft, an application designed especially for this reflectophotometer, enables measurements of BRDF in the Klems system of patches. The measured values can then be stored into a XML file containing the BRDF matrix of 145 × 145 elements. The results can be viewed using the software BSDFViewer.**

Keywords—reflectophotometer; OPTE-F3K; ReflectoSoft; BSDFViewer

I. Introduction

The human gets 80 to 90 % of information about the surroundings through the eyes. How objects affect luminous flux constitutes what we call the object's appearance. Most light-active surfaces around us are secondary light sources. Light emitted from primary light sources (sun, artificial light sources), hits a surface, changes its properties, is reflected and thus transmits information about the nature of the object's surface. The photometric properties of material surfaces are especially important in the design and construction of light-active surfaces in terms of reflected light flux spatial distribution, e. g. to reduce brightness in certain directions while maintaining maximum efficiency of the arrangement.

II. Reflectophotometer OPTE-F3K

Measuring reflective properties of surface materials can be carried out using the reflectometer OPTE-F3K of the Department of Electrical Power Engineering (Fig. 1). This device requires a Bruel & Kjaer Type 1100 luminance contrast meter [1] with an external optical sensor to measure reflective properties of material surfaces. The sensor is fixed in the reflectophotometer, its output connected to the contrast meter and the analog luminance voltage output fed back to the reflectophotometer.

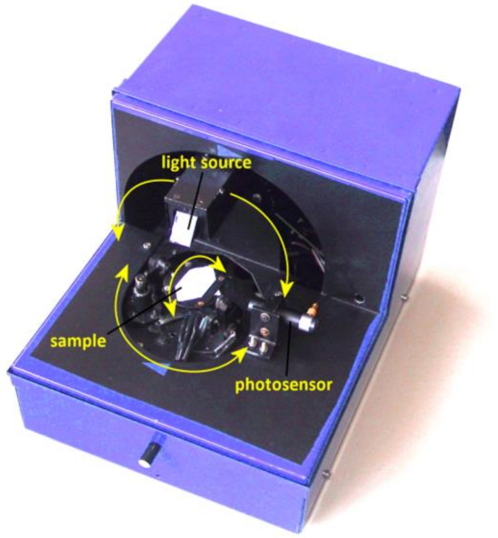

Fig. 1. Reflectophotometer OPTE-F3K without sample cover.

A. Mechanical properties

To measure luminance spatial distribution of a sample's surface for different incident light ray angles it is necessary to be able to change angles between the light source and sample's normal, the photosensor and the samples's normal and between planes defined by light source and sample's normal, photosensor and samples's normal. To make this movement possible, synchronous motors of type SMR 300-100 are used enabling rotation of the sample around two axes and rotation of the light source around a single axis. As seen in Fig. 4 gear trains had to be incorporated to provide speed and torque conversions. The actual angle arrangement can be found in Fig. 2 according to which the photosensor is stationary while the light source and sample are movable.

According to Fig. 2 the sample is placed on a pad with its normal *N* enabling rotation from $\gamma = 0°$ to $\gamma = 180°$. This pad can also be tilted from horizontal position $\beta = 0°$ to vertical

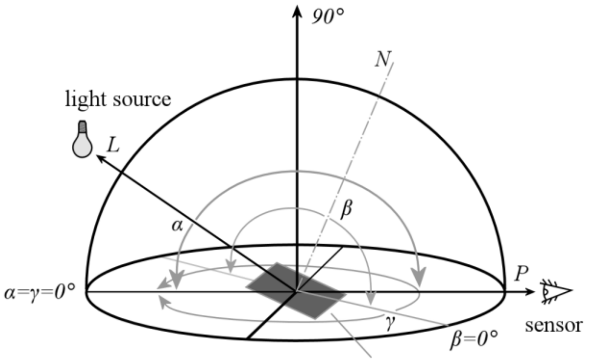

Fig. 2. Angle setup of the sample and light source used by OPTE-F3K.

position β = 90°. The reference light source can be rotated from range α = 0° to α = 150° due to mechanical limitations. Angles α, β and γ can be set with an accuracy of 0.5° [2].

The device is of relatively small dimensions (20 x 26 x 18 cm) implying the maximum size of the measured material samples to be 2 x 2 cm with thickness of 0.5 cm. Also samples with very rough surfaces can be measured, since the device illuminates only a small part of the sample's surface [2].

The mechanical design of the device makes it impossible to set all angle combinations of incident beam, sample and photosensor. This limits the measurable samples to those exhibiting isotropic reflective properties.

B. Upgraded Electronics

OPTE-F3K was originally designed to communicate with a computer via parallel port. Having only built-in amplifiers to drive its stepper motors using voltage levels of the parallel link there was no way to read motor positions or the luminance value. The measured data had to be collected manually.

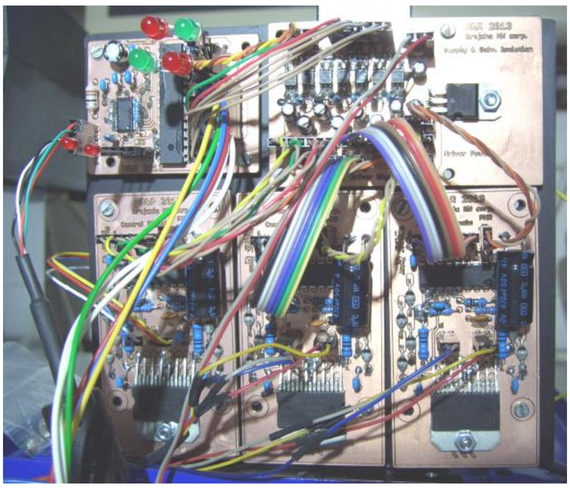

Fig. 3. A photograph of the upgraded back side of OPTE-F3K showing the μC and USB converter board (top left), source and optocoupler board (top right) and driver boards for all three stepper motors (bottom).

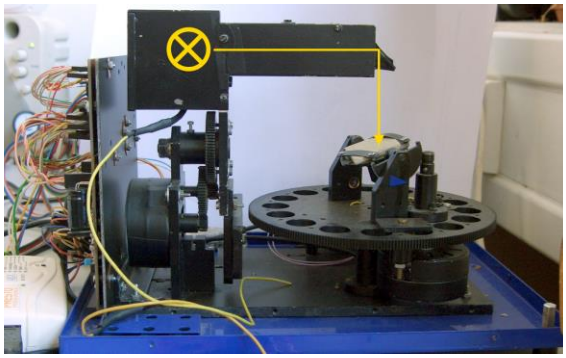

Fig. 4. Side view of OPTE-F3K with visible new electronics (left) and light source placement indicated. Gear trains are visible under the light source.

To enable automated measurements, the electronics of OPTE-F3K had to be redesigned (Fig. 3). The main requirements were to provide connection via USB and to digitize the measured luminance value.

The core of the new electronics is a microprocessor ATMega8L connected to an USB to RS-232 converter FT232RL. This enables the device to be connected to a modern computer and present itself as a virtual COM port enabling easy communication via a terminal or dedicated software.

Integrated circuits L297 and L298 have been used to drive the stepper motors powered by an external power supply connected to OPTE-F3K. Data lines connected to the computer are insulated by PC400T optocouplers to prevent damage by the external power source.

As seen in Fig. 4 the new electronics would not fit into the casing judging by the blue base. The whole board has been moved into a separate box attached to the rear side of OPTE-P3K.

C. Firmware

The firmware of ATMega8L has been programmed in C programming language using Atmel Studio. Only basic commands have been implemented leaving the "thinking" to the dedicated application ReflectoSoft.

A simplified HDLC protocol (High-Level Data Link Control) is used to communicate with a computer via virtual COM port. Using HDLC frames of constant width, commands with 2-byte data payload can be transmitted which is sufficient since the needed number of steps of each motor and the A/D converted luminance value do not exceed range of unsigned short integer 2^16 - 1. The address and checksum fields required by HDLC protocol have been omitted since address is not needed and noise should not occur on the connecting lines between FT232RL and ATMega8L UART pins.

The HDLC protocol uses frame delimiters and escape octets. Because data sent via serial port are transmitted as byte streams, delimiters come in handy when separating frames. Control escape octets are used to enable sending delimiters and escape octets inside frames.

III. REFLECTOSOFT

After upgrading the electronics of OPTE-F3K it has been enabled to set angles of all three built-in stepper motors (light source, sample rotation and tilt), turn motor power supply on and off, get position of motors and more via virtual USB serial port that has been chosen due to the lack of DE-9 connectors on most computers.

The Java application ReflectoSoft has been programmed making automated measurements of samples' reflective properties possible. After the reflectometer has been connected to a computer and an echo response has been received, automated measurements can be started.

Light source angle and sample tilt and rotation angles are chosen to conform to Klems patches in the course of automated measurements. Klems patches subdivide the hemisphere into 145 patches according to Fig. 5 and Tab. 1.

TABLE I. ANGLE RANGES AND NUMBER OF PATCHES FOR EACH SPHERICAL SEGMENT OF KLEMS PATCHES (FIG. 3).

Spherical segment angle range	***from***	0°	5°	15°	25°	35°	45°	55°	65°	75°
	to	5°	15°	25°	35°	45°	55°	65°	75°	90
Patch amount		1	8	16	20	24	24	24	16	12

Using Klems patches with angles from Tab. 1 makes it possible to export measured data into BSDFViewer XML format used by the BSDFViewer utility. Because OPTE-F3K is able to measure only isotropic reflecting sample surfaces, all missing data required by the BSDFViewer XML format have to be filled in, i.e. symmetric values have to be copied and rotation applied.

To avoid the need of interpolation during rotation, each spherical segment is subdivided into a constant number of patches being the least common multiplier of all spherical segments. From Tab. 1 deduced all spherical segments (Fig. 5) will be subdivided into 240 patches.

The BSDFViewer file format requires a square matrix of 145 x 145 values, i.e. for each incident patch (145 patches total) 145 sample luminance values. That makes a total of 21025 values. Applying rotational symmetry for isotropic reflecting samples, it is sufficient to take into account only a single incident patch per sphere segment, i.e. 9 incident patches, one per sphere segment. Because each sphere segment has been subdivided into 240 reflection patches (except the top patch) and mirror symmetry is applied, there are 121 reflection patches per sphere segment to be measured. For each incident patch there are in this case 969 output patches. Calculating all incident patches the total number of measured values will be 8712 ideally.

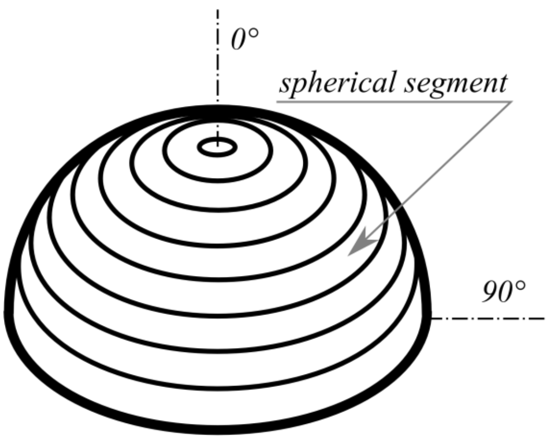

Fig. 5. A hemisphere subdivided into Klems patches.

Another decrease of the number of measured values is caused by the fact that mechanically it is impossible for the reflectometer to set light source and photosensor into the same position or near each other. This problem can be seen in Fig. 6. The unlit area of the reflection hemisphere on the right hand side could not be measured leaving the patches with zero luminance. After skipping all unavailable angle settings the number of measured angle combinations is 6490, taking about 3 hours for ReflectoSoft to complete a single sample measurement.

A. XML export

During the automated measurement quaternions of angles α, β, γ and luminance are stored to a text file chosen by the user in CSV format. To make visualization of the measured data possible using the application BSDFViewer, the measured data have to be exported into BSDFViewer XML file format.

The values contained in the XML file are the percent of luminance of the sample in the direction given by the outgoing patch relative to the luminance of the light source. For that purpose the luminance of the light source needs to be measured. To generate the output seen in Fig. 6 an inaccurate measurement has been done to roughly generate a sample output.

IV. CONCLUSIONS

By using the upgraded reflectophotometer OPTE-F3K, application ReflectoSoft and utility BSDFViewer it is possible to measure and view reflective properties of samples of sizes 2 by 2 cm (Fig. 6). Optically isotropic materials can only be measured due to the limitations of possible angle combinations of the light source and sample. The measuring process takes about 3 hours without the need of human interaction during that period. This time is affected insignificantly by the computer ReflectoSoft is running on.

For further utilization of the measured data it is necessary to minimize the size of the blind spot and/or to implement interpolation to calculate values of the skipped patches. Only then the output could be used by other simulation software. Furthermore the built-in light source's luminance needs to be measured precisely.

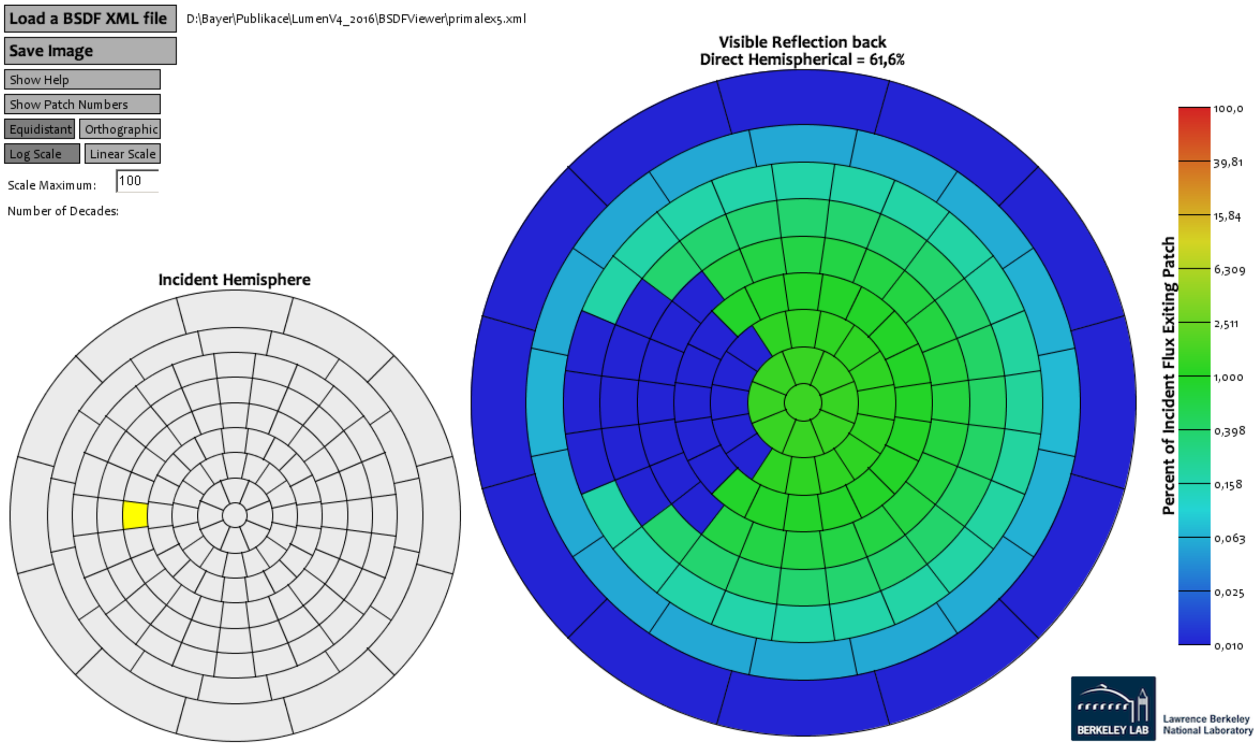

Fig. 6. BSDFViewer utility displaying ReflectoSoft export of a real sample measurement (Primalex painted wooden sample).

[1] Technical Review: Luminance contrast measurement [online]. Denmark, 1980, 1980(1) [cit. 2016-05-29]. ISSN 0007-2621. Dostupné z: http://www.bksv.com/doc/bn1681.pdf

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[3] M. Saxena, G. Ward, T. Perry, L. Heschong and R. Higa, “Predicting annual daylight with variable fenestration optics using BSDFs,” Fourth National Conference of IBPSA-USA, New York City, 2010.