Measuring Reflective Properties of Surfaces Using OPTE-F3K

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***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 OPTE-F3K 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 an XML file containing the BRDF matrix of 145 × 145 elements. The results can be viewed using the software BSDFViewer. The goal of this paper is to present the current state of the renovation of OPTE-F3K, which enables using measured reflective properties of real materials by ray tracing algorithms.**

Keywords—reflectophotometer; OPTE-F3K; ReflectoSoft; BSDFViewer

I. Introduction

The human receives 80 to 90 % of information about the surroundings through his 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) is reflected from surfaces, changing its properties and transmitting information about the nature of the 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 material surfaces can be carried out using the reflectophotometer 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 (measuring cell UA 601, acceptance angle ± 1,1°) 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 digitizing this value.

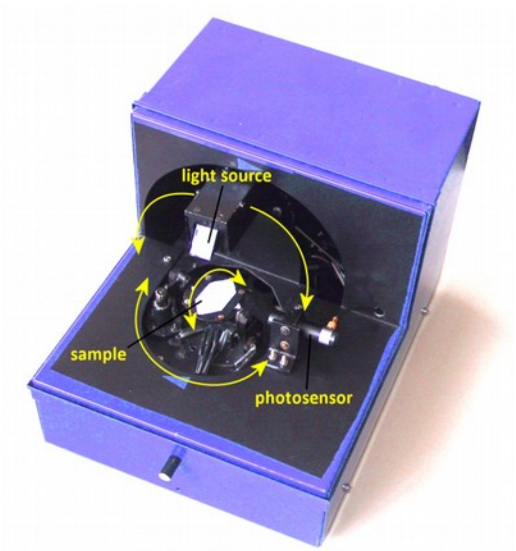

Fig. 1. Reflectophotometer OPTE-F3K

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 sample's normal and between planes defined by light source and sample's normal, photosensor and sample'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.

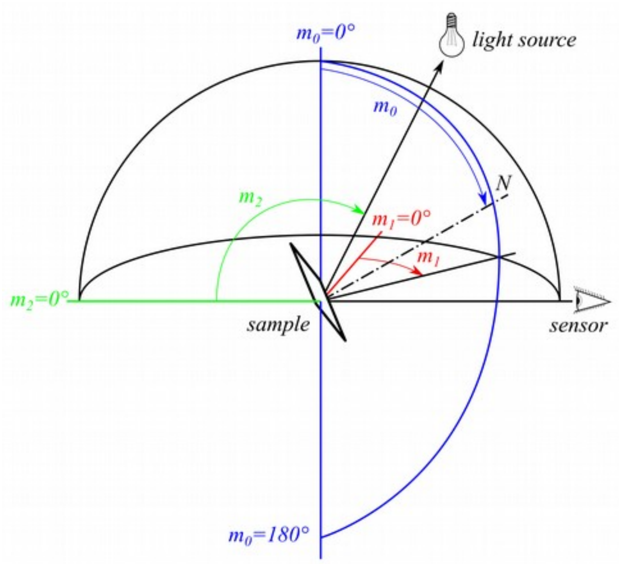

Fig. 2. Angle setup of the sample and light source used by OPTE-F3K.

According to Fig. 2 the sample is placed on a pad with its normal N enabling rotation from m1 = 0° to m1 = 90°. This pad can also be tilted from angle m0 = 0° (sample facing up) to m0 = 180° (sample facing down). The reference light source can be rotated from range m2 = 0° to m2 = 150° due to mechanical limitations. Angles m0, m1 and m2 can be set with an accuracy of 0.5° [2].The built-in light source is a halogen lamp powered by an external stabilized 12V DC power supply. The lamp's light flux is concentrated by an optical system into a small area on the sample's surface making only measurements of smooth sample surfaces possible.

The device is relatively small (20 x 26 x 18 cm) and only reflective properties of samples of dimensions 2 x 2 cm can be measured with thickness of 0.5 cm and less. The mechanical design of the device makes it impossible to set all angle combinations of incident beam, sample and photosensor. This limits the device enabling only measurements of optically isotropic materials.

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 read manually from the luminance meter's display.

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 design of the new electronics and its implementation has been carried out by the authors.

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.

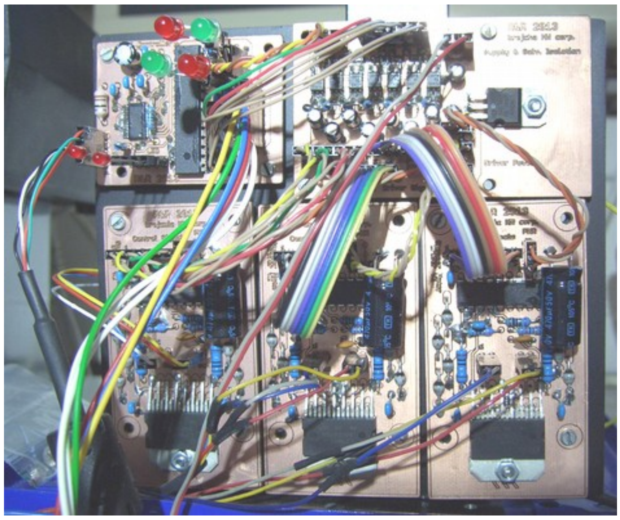
Fig. 3. A photograph of the upgraded back side of OPTE-F3K showing the µC and USB converter board (top left), source and optocoupler board (top right) and driver boards for all three stepper motors (bottom).

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.

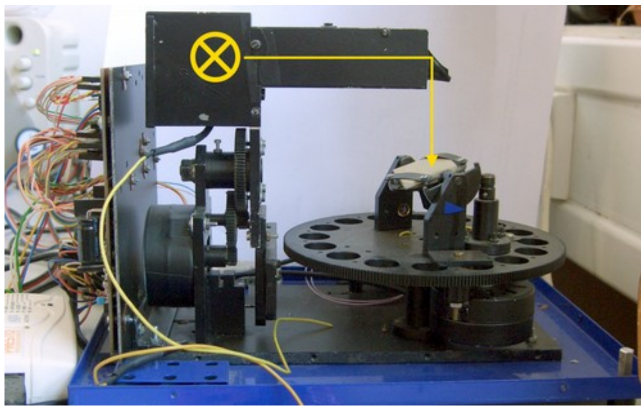
Fig. 4. Side view of the uncovered OPTE-F3K with visible new electronics (left) and light source placement indicated. Gear trains are visible under the light source.

C. Firmware

The firmware of ATMega8L has been programmed in C programming language using Atmel Studio by the authors. 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 are useful 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 by the authors 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	***fro m***	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

By using Klems patches with angles from Tab. 1 it is possible to export the measured data into BSDFViewer XML format used by the BSDFViewer utility. Because OPTE-F3K is able to measure only optically isotropic 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 (according to Tab. 1 spherical segments are divided into a different amount of patches), 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) there are 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 is 8712.

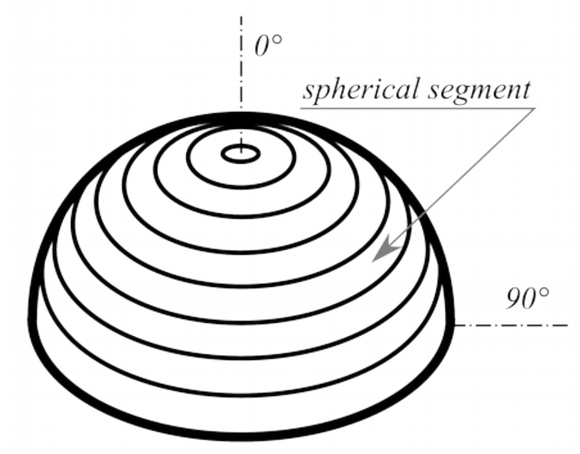

Fig. 5. A hemisphere subdivided into spherical segments with 240 patches per segment.

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 the output data displayed by BSDFViewer 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 automated measurements provided by the application ReflectoSoft, quaternions of angles α, β, γ (converted from angles m0, m1, m2 to conform to BSDFViewer angle convention) and luminance are composed, which can than be stored to a text file chosen by the user in CSV format, or, to make visualization of the measured data using the application BSDFViewer possible, to a BSDF LBNL XML file. The BRDF values, stored to this file format, are calculated by dividing the measured sample luminance for the given light incident angle and the given photosensor angle divided by the illuminance of the sample surface [4].

Due to the fact, that the projection of the lit sample surface is varying according to angles m0, m1 and m2 from the sensor's point of view, the measured luminances have to be corrected. A sample has been measured using both the photometric bench and reflectometer OPTE-F3K and correcting coefficients for all required angles have been acquired. For all following measurements those correction coefficients were applied.

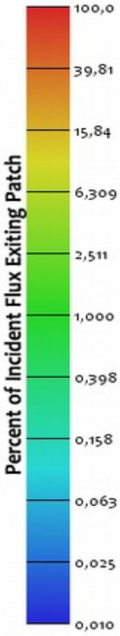

Fig. 6. Scale used for all following BSDFViewer outputs

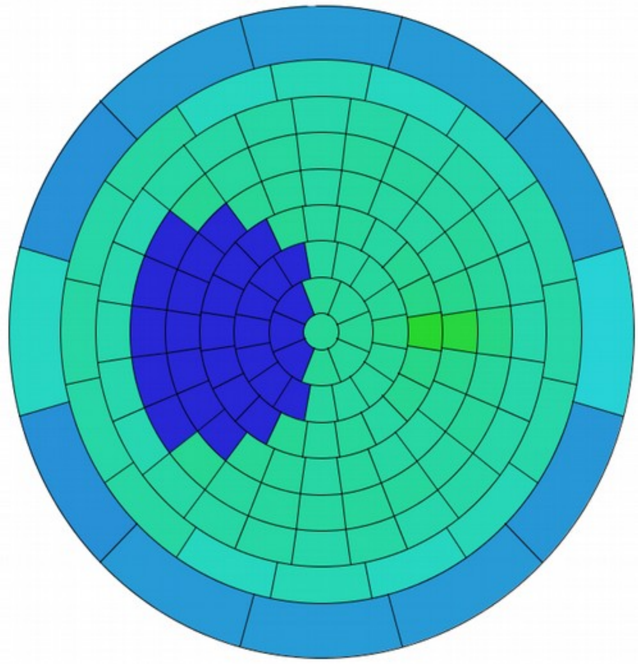

Fig. 8. BRDF values of light grey tile sample, light incident at angle 30° (from the left)

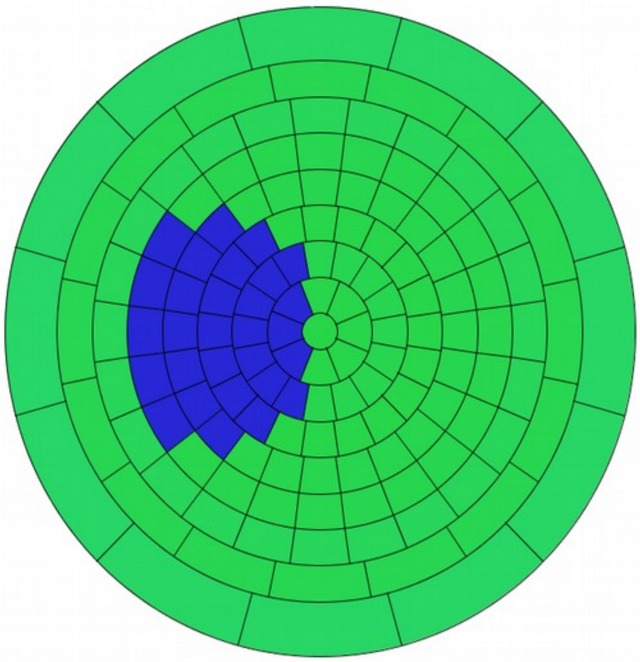

Fig. 7. BRDF values of white interior paint Primalex Polar sample, light incident at angle 30° (from the left)

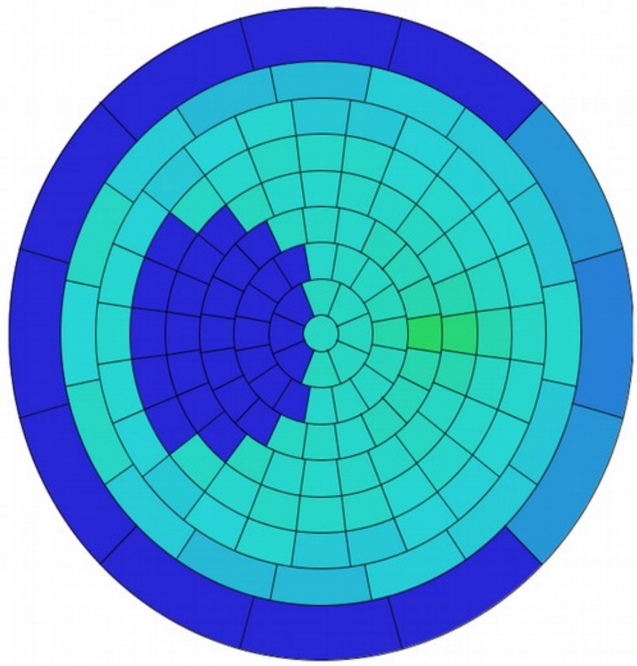

Fig. 9. BRDF values of pink tile sample, light incident at angle 30° (from the left)

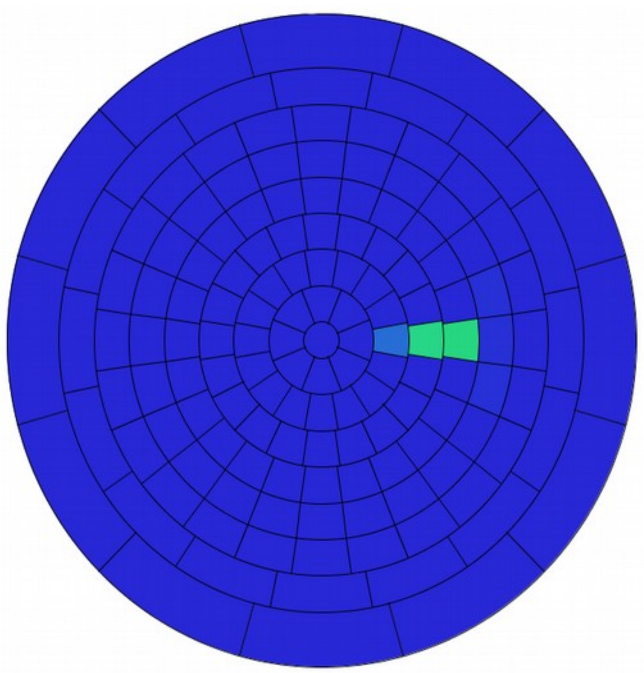

Fig. 10. BRDF values of black tile sample, light incident at angle 30° (from the left)

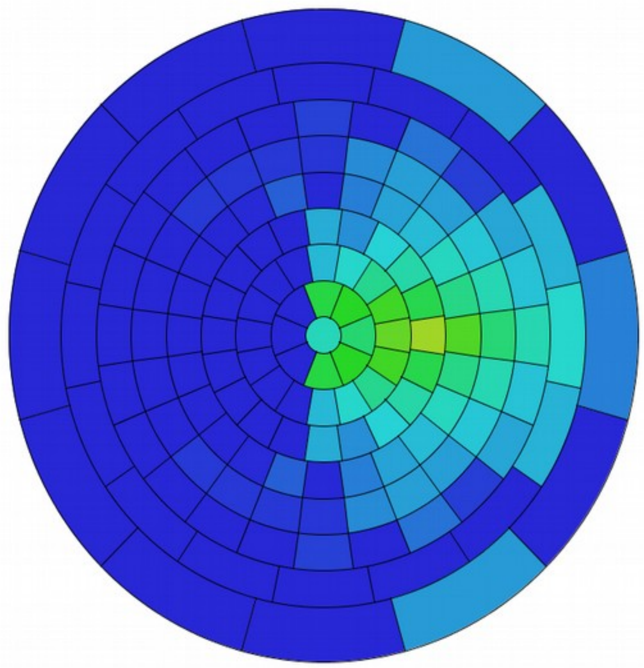

Fig. 11. BRDF values of sheet metal sample, light incident at angle 30° (from the left)

As seen in Fig. 7, the white interior paint Primalex Polar sample is a near diffuse reflecting surface, i.e. luminances, for a given angle of light incidence, are constant for all reflected directions. In Fig. 8, 9, 10 a specular reflection is visible. The light grey tile reflects the most light flux of the tile samples. The black tile sample reflects only the specular light flux. In Fig. 11 the BSDF for a sheet metal sample is shown. A specular reflection is also visible, but with a wider spread.

IV. Conclusions

By using the upgraded reflectophotometer OPTE-F3K, application ReflectoSoft and the utility BSDFViewer, it is possible to measure and view reflective properties of samples of sizes 2 by 2 cm. Optically isotropic materials can only be measured due to the limitations of possible angle combinations of the light source and sample tilt and rotation. OPTE-F3K is only experimental, uncertainties have not been evaluated. The measuring process takes about 3 hours without the need of human interaction during that period. This time is affected insignificantly by the performance of 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. The acquired BRDF data can than be used by ray tracing algorithms to calculate photometric values in a system of nondiffuse surfaces taking multiple reflections into account.

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