Lightdrum – Surface Reflectance Measurement on Site

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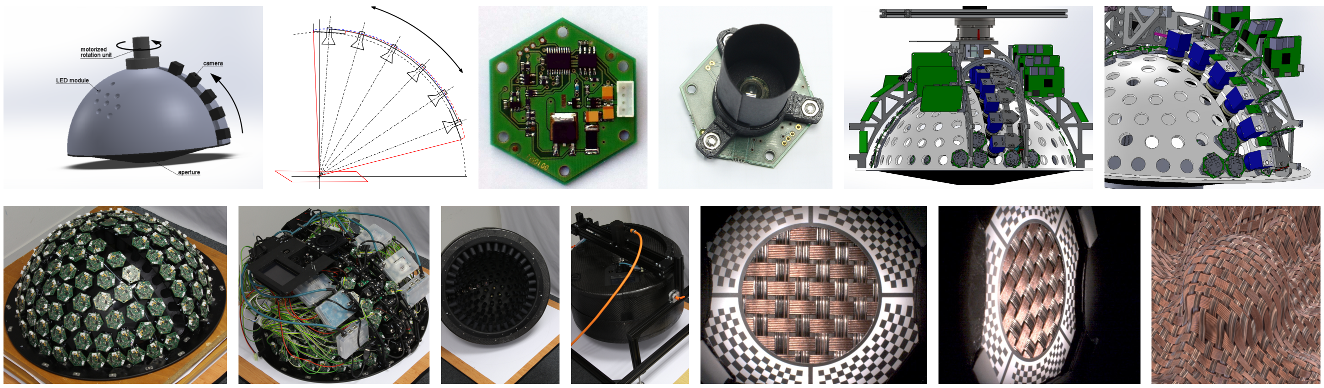

Figure 1: The pipeline of the Lightdrum project from measurement instrument design to a rendering of the measured sample.

ABSTRACT

We present a portable instrument for on site measuring of surface reflectance represented by the bidirectional texture function (BTF) and the bidirectional reflectance distribution function (BRDF). Our device allows for measurement application scenarios outside the laboratory without the necessity to extract the measured sample from its environment because the instrument is taken to the measured sample. The concept is a rotational lightweight light stage with a compact hemispherical dome and cameras along the meridian and light emitting diode (LED) modules illuminating the sample surface. The LED modules are fixed on the hemisphere and the six cameras can move along the arc in the range of the elevation angle from 0 to 75 degrees. By rotating the hemispherical dome along its axis we can set all possible camera directions to a measured sample. We use an auto-collimator to adjust the correct perpendicular direction of the instrument against the sample. The proposed instrument is portable and fast while maintaining a high degree of accuracy, achieving a quality similar to existing stationary BTF gantries that can be only used in a laboratory. The instrument design provides a good tradeoff between the accuracy of measurements and the practical applicability for measurement of locally flat samples. The instrument provides approximately 1000 HDR photographs in a minute that are necessary to capture spatially varying surface reflectance.

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CCS CONCEPTS

•Computing methodologies → Appearance and texture representations; Reflectance modeling; *Texturing;* **•Hardware →** Sensors and actuators;

KEYWORDS

surface reflectance, bidirectional texture function, surface reflectance measurement

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1 MOTIVATION

The measurement of surface reflectance is required for reproducing real world appearance in many scientific and industrial applications of computer graphics. In the movie and manufacturing industries with predictive rendering, the final appearance of the rendered image during design phase is of vital importance as it should match its real world counterpart. We can measure surface reflectance at a single point as a five dimensional BRDF (incoming light direction, outgoing light direction, wavelength). In an extended concept we can measure how the surface reflectance spatially varies over the surface. It is then represented by a seven dimensional BTF (position x, y, incoming light direction, outgoing light direction, wavelength). The BTF allows for capturing spatially varying fine surface appearance details caused by non-local effects such as subsurface scattering, masking, self-shadowing etc. A few commercially available setups e.g. REFLET180S (http://www.lighttec.fr) allow only for BRDF measurement (5D) but not for BTF measurement (7D) on site.

2 DESIGN

The design of our surface reflectance measurement instrument was motivated by several goals required by real world scenarios: (a) decreasing the time of measurement to the order of minutes, (b) allowing for true practical portability and on-site measurement, where no calibration is needed after the device is transported, (c) achieving high quality accurate data from the measurement that are useful for computer graphics, and (d) attaining the robustness needed for out of laboratory conditions including the proper aligning of the instrument towards a stationary measured sample. To attain the desired goals, a careful co-operative design dealing with several issues in software and hardware (mechanics, electronics and optics) had to be carried out.

We built a portable light stage equipped with six fast USB 3.0 cameras with Bayer filter. The cameras can move together along a meridian from the hemisphere pole ($\theta = 0^o$) towards the equator (maximum elevation angle $\theta = 75^o$). Small custom LED modules used for illumination are affixed to a plastic hemispherical dome that is mounted to an interior alloy frame with a camera subsystem. The interior alloy frame is mounted on a servo motor that rotates the dome with LED modules and cameras above the measured sample. The number of LED modules is 139 and 5 of them being located between the cameras. The cameras' elevation is set by a stepper motor moving the camera holder along a linear rail in the range of 12.5 degrees so that the angle of view of the neighboring cameras overlap in the end positions. The instrument axis is set perpendicularly to the sample by means of an auto-collimator that uses a laser and a small additional camera.

The cameras take HDR images of size 1040×776 pixels, each image being composed of four individual images of a different exposure. The cameras are connected to Hardkernel Odroid microcomputers that process the data from the cameras and composite high dynamic range (HDR) images from individual images. These six microcomputers are connected to a Raspberry Pi 2 control microcomputer that controls LED lighting and synchronizes the LED flashes with the camera data acquisition. The control microcomputer is connected to the camera for the auto-collimator, switches on/off the laser for the auto-collimator, and operates the steppermotor. It also displays the preview images needed for adjustment of the instrument on a touch display. All seven microcomputers are connected via an embedded network switch that also allows for data transfer from the instrument to external storage devices. The setup is connected by 3 cables to an external power box.

3 RESULTS

Our instrument is the first portable device for on site measurement where the viewing direction can be arbitrarily set with respect to a stationary sample. The limitation is that cameras move together along the meridian with the maximum elevation angle of 75 degrees. The measured area is a circle of diameter 51*mm* that can allow for a square sample 35×35*mm* corresponding to an image of 200×200 pixels for spatial resolution 150 DPI and 400×400 pixels for 300 DPI. As the number of viewing directions can be set arbitrarily, we must choose a particular measurement setting. For example: 20 rotations of the servo motor and two positions of the stepper motor give 120 different camera positions for the azimuth angle from 0^o to 360^o and the elevation angle from 4^o to 75^o. The camera field of view is 11.4^o, the incident light direction resolution is $11.1^o \pm 0.5^o$, the camera direction resolution is $10.1^o \pm 3.3^o$. For all 139 LED modules we get 16680 HDR images in Ward's HDR format that take 40 GBytes. The measurement time for this setting is 17 minutes. This measurement setting allows either for BTF measurement or for BRDF measurement with a high directional resolution.

Figure 2: Measurement on site (left) floor based holder for floor and wall close above the floor, (middle) tripod based holder for measuring on a wall and (right) for measuring on a ceiling.

For the rectification and alignment of the acquired images we created a marker sticker of size 85×85*mm* with a hole of diameter 51*mm* in the center. The marker sticker is made of aluminum foil and has a black-and-white radial checkerboard pattern used for an image alignment algorithm consisting of eight algorithmic steps. The sticker is glued onto the surface to be measured and the instrument is adjusted against the measured surface sample to be 1*mm* above the sticker. The example rendered image texturing a 3D object by the measured BTF is shown in Figure 1 (bottom right).

We use two frame holders to measure at four different situations encountered during on site measurement. The first one is a floor based holder for measuring a sample on the floor or on a vertical wall close to the floor. The second frame holder for wall and ceiling orientations of a sample is a simple U-shaped frame mounted on a heavy-duty tripod to achieve stability of the system during the rotational movement. Both holders allow us to adjust the position and tilt of the instrument over the sample to the required position given by the glued marker sticker by six degrees of freedom. The whole instrument including the frame holder weighs 15 kg. The instrument shape is a cylinder of diameter 600*mm* and height 330*mm*, prolonged to 520*mm* when we include the geared servo motor. The outer size of the whole instrument including the floor based frame holder is 820 × 660 × 520mm. The details of the proposed instrument called Lightdrum are given in [Havran et al. 2017; Hosek et al. 2017] and at the project webpage http://dcgi.fel.cvut.cz/projects/lightdrum/.

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