CAPTURING MATERIAL VISUALIZATION DATA USING GONIOMETERS

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Abstract

Reproduction of the appearance of real-world materials in virtual environments has been one of the ultimate challenges of computer graphics. The required material representations depend on the complexity of the material's appearance. They start with a bidirectional reflectance distribution function (BRDF) describing distribution of energy reflected in the viewing direction when illuminated from a specific direction. As the BRDF cannot capture a material's spatial structure, it has been extended to a more general bidirectional texture function (BTF) capturing non-local effects in rough material structures, such as occlusions, masking, sub-surface scattering, or inter-reflections. A monospectral BTF is a six-dimensional function representing the material appearance at each surface point for variable illumination and view directions, parameterized by elevation and azimuthal angles. This paper describes application of gonioreflectometrs for capturing BTF for material visualization purposes. It starts with the reference measurement setup and continue with introduction of portable measurement approaches to capturing approximate BTF. Finally, we discuss future challenges in material acquisition.

Keywords: BTF, texture, material appearance, measurement setup, portable

1 Introduction

Bidirectional texture function (BTF) is capable to introduce photorealistic material appearance into computer graphics visualizations. A mono-spectral BTF is a six-dimensional function representing the appearance of a material sample $BTF(x,y,\theta_i,\varphi_i,\theta_v,\varphi_v)$ at a surface point with coordinates (x,y) for variable illumination $\mathbf{I}(\theta_i,\varphi_i)$ and view $\mathbf{V}(\theta_v,\varphi_v)$ directions, where θ and φ are elevation and azimuthal angles, respectively, as shown in Figure 1.

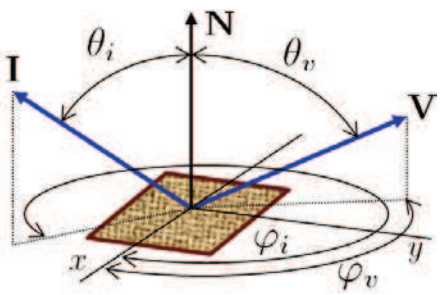

Figure 1 – A BTF parameterization over material surface

In practice the BTF is obtained as a collection of thousands of material surface images for variable illumination and viewing directions. As the BTF data achieve photo-realistic visualization of material appearance it has high application potential mainly in areas requiring physically correct visualizations ranging from computer-aided interior design, visual safety simulations and medical visualizations in dermatology, to digitization of cultural heritage objects. The measurement of BTF is, due to its high dimensionality, very time- and storage-space-demanding. A majority of the current BTF acquisition setups are based on either expensive hardware or specialized equipment demanding laboratory assembly and calibration. As such setups are usually composed of research and custom build devices, the limited availability of resulting measured data reflect their high development and acquisition costs. This consequently limits the number of publicly available BTF samples as well as their usage in real applications.

2 Related work

In field of computer graphics and image processing several approaches to capturing BTF were applied. Majority of setups was based on gonioreflectometers realizing the required four mechanical degrees of freedom (DOF) of camera/light/sample movement, e.g., (Dana, 1999), (Koudelka, 2003), (Sattler, 2003), (Holroyd, 2010). Because the measurement times were too long (often over 10 hours), other setups were used to reduce the required number of DOF using parabolic mirrors (Dana, 2004), or a kaleidoscope (Han 2003). They allowed the capture of many viewing directions simultaneously, but at the cost of a limited range of surface height or elevation angles. The measurement time can also be reduced to approximately two hours by simultaneously using multiple lights and sensors (Mueller, 2005), at a high financial cost of such a setup.

This article briefly overviews the gonioreflectometer-based setups at our institute, shows achieved results, and concludes with challenges for material acquisition devices.

3 Reference Device

To evaluate any novel BTF measurement approaches, we need a reference device. For this purpose we use UTIA gonioreflectometer (Filip, 2013). This state-of-the-art setup consists of the measured sample held by a rotating stage and two independently controlled arms with camera (one axis) and light (two axes) as shown in Figure 2.

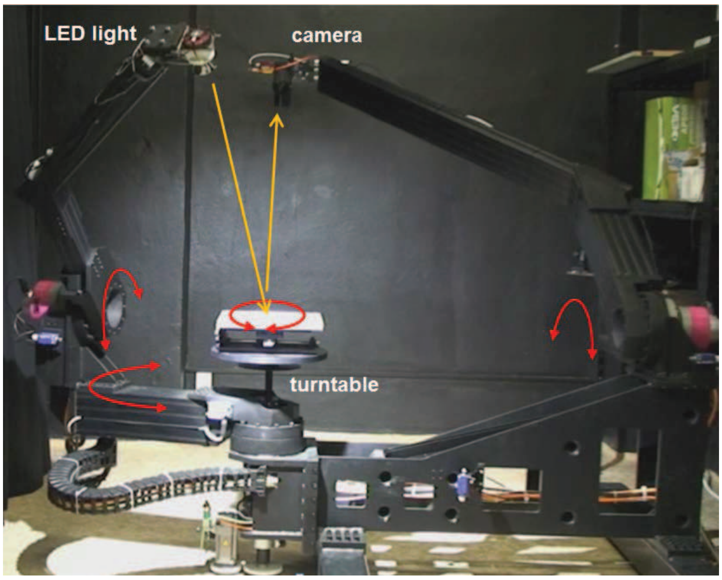

Figure 2 – UTIA gonioreflectometer for reference BTF measurements

It allows for flexible and adaptive measurements of nearly arbitrary combinations of illumination and viewing directions. Although camera view occlusion by arm with light may occur, it can be analytically detected, and in most cases alternative positioning is possible. Verified illumination and camera arms positioning angular accuracy across all axes is 0.03 degree. The inner arm holds LED light source 1.1m from sample producing a narrow and uniform beam of light. The outer arm holds an industrial full-frame 16Mpix RGB camera AVT Pike 1600C. The sensor's distance from the sample is 2m. Using different optics we can achieve spatial resolution up to 1071 DPI (i.e., 24μm/pixel), which constrained maximal sample's size to 44x44 mm. Samples of size up to 139x139 mm can be measured in resolution 350 DPI. A typical uniform measurement procedure captures material surface in 81 illumination and 81 viewing directions over hemisphere resulting in 6561 HDR images. Although this reference setup allows very accurate positioning and high-resolution data capture its main limitation is that mechanical positioning, exposure, and data transfer of 6561 measurements typically take around 20 hours. Figure 3 shows four materials captured by the reference goniometer using 6561 images.

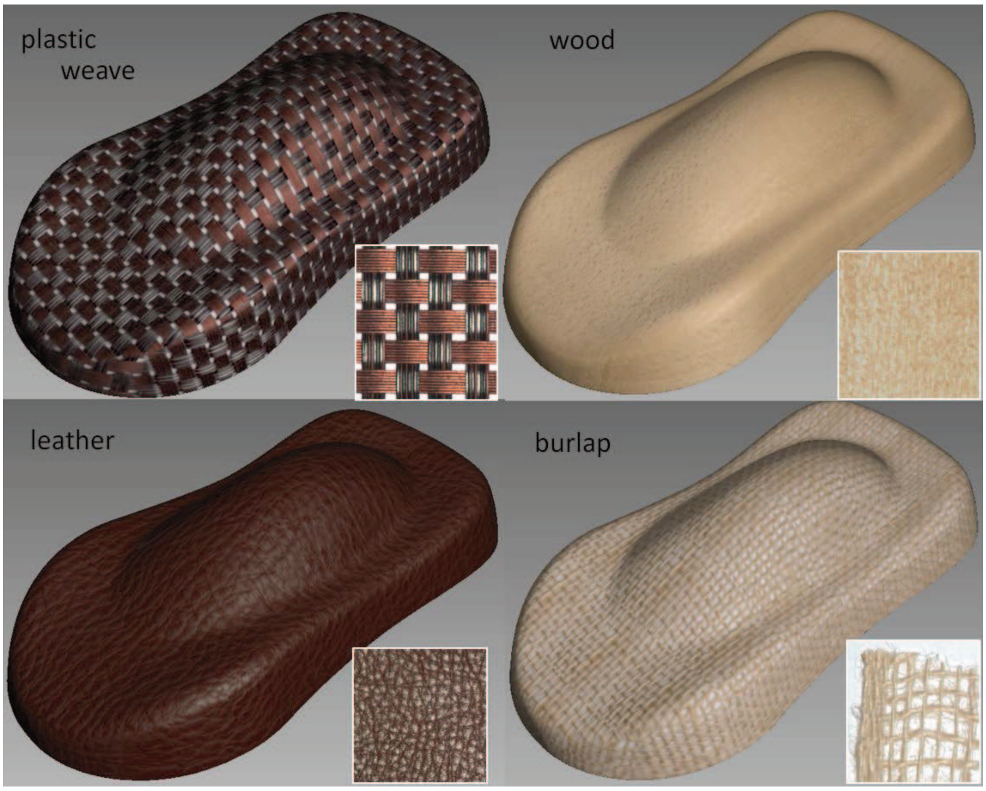

Figure 3 – Examples of measured materials: plastic, wood, leather, fabric

4 Portable Devices

Due to excessively long measurement process using the reference goniometer, we look for faster and more flexible measurement solutions for less demanding applications. One of them relies on sparse capturing of images of material surface for fixed elevation angles and variable azimuthal angles. One set of images is measured using rotation of the mutually fixed light and sensor around the sample, while the other set is obtained by mutually opposite movements of the light and sensor with respect to the sample. In both cases, the camera and light travel full circle around the sample and return to their initial positions.

4.1 Proof-of-concept device

First, we developed a proof of concept device (Filip, 2014) consisting of a mechanical gantry holding two arms rotating synchronously in either the same or opposite direction. The gantry was built using a toy construction set as is shown in Figure 4. We used a single DC motor run at a constant speed and manually switchable gears. One of the arms holds two LED Cree XM-L with 20 degree optics. The second arm has two positions for attachment of a Panasonic FT3 compact camera. Elevations of the LEDs and camera in both positions are fixed at 30 and 65 degrees. The setup's dimensions are 0.6x0.6x0.4m, and weight of 6kg. The measurement process takes 5 minutes. However, as only a subset of BTF was captured using 200 images the remaining data were linearly interpolated. The measurement method is based on two perpendicular so called slices in angular BTF space (Filip, 2014) measured across azimuthal angles for fixed light and camera elevations. As the slices are perpendicular to anisotropic and specular highlights they bear enough information to approximate azimuthally-dependent behavior of the BTF.

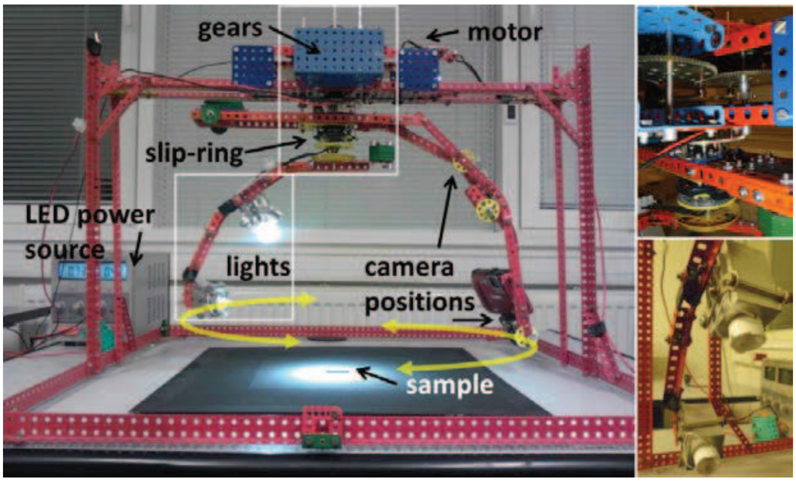

Figure 4 – Proof-of-concept of fast and portable BTF measurement device

In total, image registration and interpolation takes around 20 minutes. Figure 5 show four materials captured using the device.

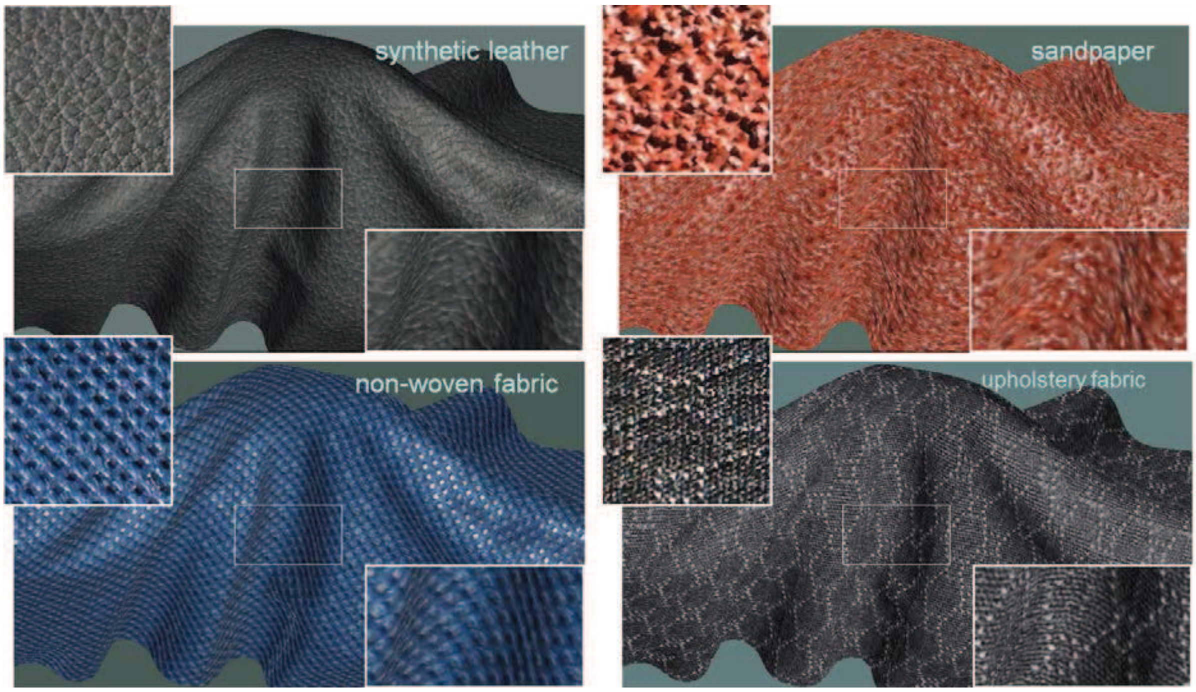

Figure 5 – Materials captured by the portable BTF measurement device: leather, sandpaper, fabric

4.2 Portable prototype

The promising results of this setup resulted in building an automatic BTF capturing device (Figure 6) based on similar concept. Its current configuration uses two independent arms holding four LED lights (Cree XM-L, optics 20^{o}) and two global shutter USB cameras of resolution 1.3Mpix. Similarly to the initial setup, it captures sample of size up to 3x3cm with resolution 400DPI. Setup's automatic calibration, movement of the arms, and capturing of images is controlled remotely from PC and the measurement time is 20 minutes. In contrast to the initial setup, we do not capture video sequence but individual photos of the surface for variable exposures allowing us to capture BTF data in high dynamic range (HDR). This results in much sharper recorded images and sub-pixel registration accuracy. The setup is portable of weight 20kg and thus can be used for field measurements. Due to a modular concept of the device, one can use up to six lights and cameras and thus adapt the speed of measurement procedure and captured data fidelity to application needs (Filip, 2014).

Figure 6 – A prototype of portable BTF capturing device

We compared performance of these setups with the reference one on a set of materials ranging from leather, fabrics to sandpaper. We rendered the measured BTF on a 3D object as shown in Figure 7. The images in the left column yield from 6561 images taken by the reference goniometer in 20 hours, while the images in the right column are results of reconstruction from less than 200 images taken using the portable device in 5 minutes. To objectively evaluate our results we ran a psychophysical study on eight naive subjects comparing the measured specimen with the rendered data. In a user study we found that the average subject was able to recognize differences between complete and sparse measurements as well as distinction between data from reference and proposed setups. However, high standard deviations in both experiments suggest that feedback significantly depends on personal preference. We assume, that even though the BTF reconstruction from sparse samples is not always physically accurate, the performed perceptual study confirmed our setup captures the overall look-and-feel of a given material's appearance.

5 Future Challenges

Although our measurements already cover a wide spectrum of real-world materials, the novel printing and coating technologies introduced several types of visually attractive materials that, among others, represent a challenge for current measurement approaches.

One example of them is a group of highly anisotropic materials exhibiting multimodal anisotropy (Figure 8 left). Such behaviour is typical for brushed and fabric materials and is due to an azimuthally non-uniform structure elements distribution. The anisotropy is even more challenging when the material is highly specular. Another challenge is a measurement highly reflective, spatially non-homogeneous material, e.g. paints (Figure 8 right), whose correct capturing and visualization is difficult due to a combination of its high dynamic range and high frequency nature of pigment flakes. For the mentioned materials the sampling using 81x81 samples was insufficient and our future work should resort to adaptive sampling strategies.

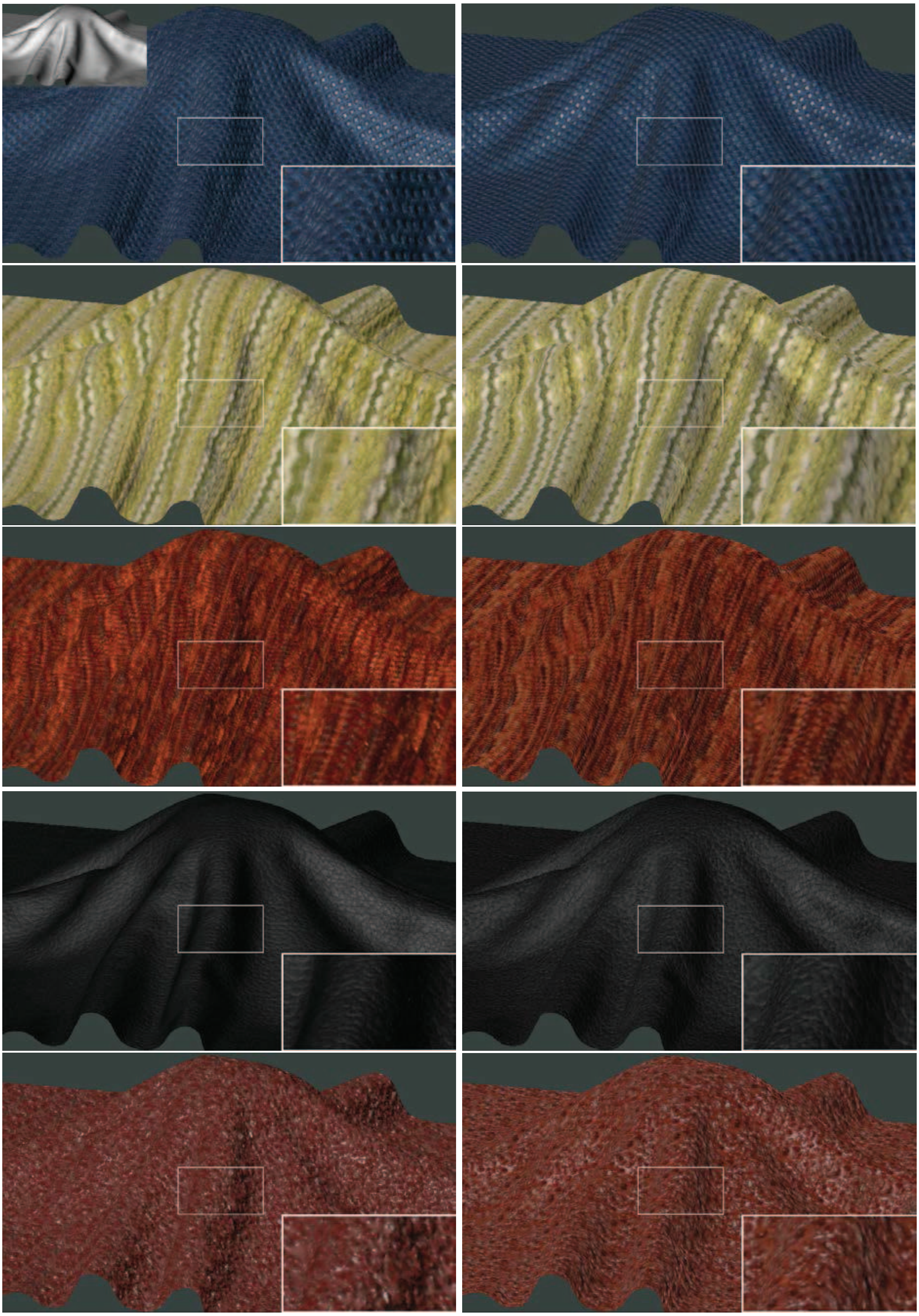

Figure 7 – A comparison of BTF captured by the reference goniometer in 20 hours (left), and using the portable device in 5 minutes (right)

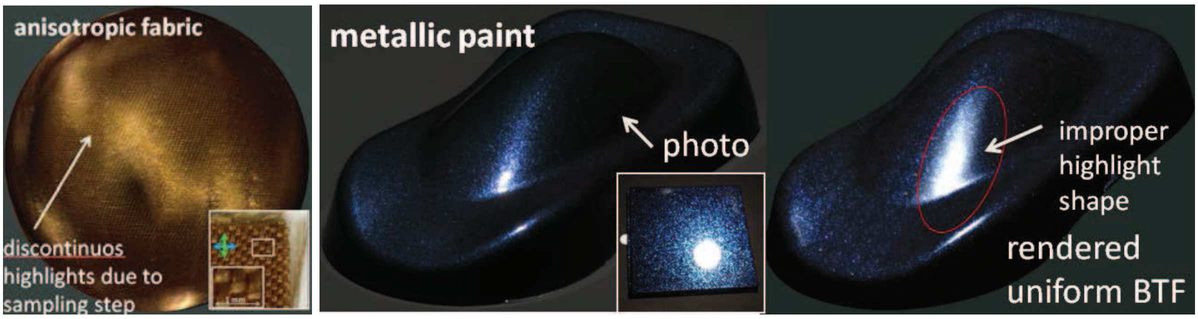

Figure 8 – Highly anisotropic and specular material measurement challenges

Another even more specific group of materials are holographic and lenticular materials (Figure 9). The holographic materials exhibiting intrigue light diffraction behaviour (light diffraction on grating, e.g. decorative wrapping foils). On the other hand, lenticular materials are based on translucent surface with optical profile defining spatially varying light refraction and interaction with background surface exhibiting angularly dependent image changes. Also this group of materials cannot be reliably captured by standard uniform angular sampling.

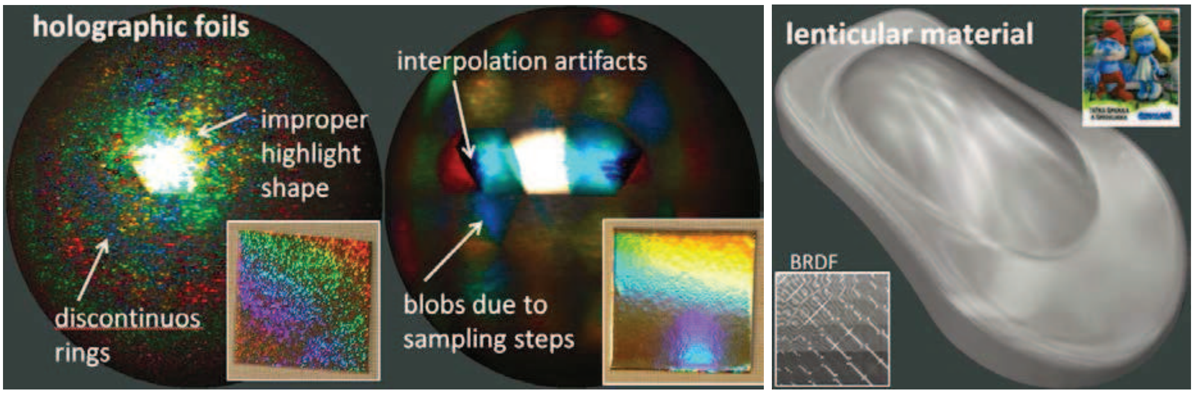

Figure 9 – Holographic and lenticular materials measurement challenges

6 Conclusions

In this paper we overviewed goniometric devices used for capturing of material appearance data at UTIA. They range from highly accurate reference goniometer to portable devices for approximate BTF measurement using sparse data slice. Although we accuracy of the reference device is necessary for other setups validation, we consider that speed and simplicity of the presented portable devices will make these approximate BTF measurements accessible even to such applications for which the standard BTF acquisition methods are time-consuming and difficult to afford.

7 Acknowledgements

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