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Practical Experiences with Using Autocollimator for Surface Reflectance Measurement

V. Havran

Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic

Abstract

We present our experiences with using an autocollimator to set up the surface reflectance measurement for both BRDF and BTF. Assuming the measured material appearance is put on a locally flat surface, the autocollimator allows us to set the perpendicularity of the measured sample in stationary measurement setups. The principle works also vice versa, we can align the measurement setup against a stationary sample for on-site measurements. The autocollimator requires to use a collimated beam of light, a mirror, a beam splitter, and a detector. We describe the autocollimator principle, problems, and the issues involved when using an autocollimator for surface reflectance measurement setups.

Categories and Subject Descriptors (according to ACM CCS): I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Color, shading, shadowing, and texture I.4.1 [Image Processing and Computer Vision]: Digitization and Image Capture—Reflectance

1. Introduction

The measurement of surface reflectance in visible spectrum was addressed within last decades intensively as the problem is inherently difficult due to the dimensionality of the measured function. For a *bidirectional distribution reflectance function* (BRDF) [NRH*77] representing the reflectance over a point we need 4 dimensions. Two of them are used to represent the incident light direction and the other two for outgoing light direction. Considering the dependence on wavelength when measuring a full visible spectrum, the BRDF then can be understood as a 5 dimensional function. Once we extend it by two more dimensions as the surface reflectance can vary over the measured surface, we get 6-dimensional (or 7-dimensional) function. This extension that parameterizes the position of a point x, y makes the measurement time and the output data size even more demanding. One of the extensions introduced by Dana et al. [DVGNK99] is called *bidirectional texture function* (BTF). BTF measurement gantries were surveyed recently by Schwartz et al. [SSW*14].

As the amount of data measured is enormous, the measurement can be time consuming. It is then really important to carry out the measurement only once. The range of BRDF values has several order of magnitudes, in particular for highly specular surfaces such as polished metals. The absolute error of measurements depends on the mutual positioning of the measurement device and the measured sample. Small angle deviations during the measurement can change the measurement values significantly for non-diffuse surfaces. For this reason the visual appearance can be also significant for a single rendered image, if it contains specular highlights. The difference in rendered animation will not be that perceptually noticeable as the highlights changes quickly. However, we still want to get as accurate surface reflectance measurements as possible. This requires to align the local coordinate system of the measured sample and local coordinate system of the measurement gantry. While there are algorithms partially compensating for the uncertainty of the normal orientation of measured surface [VF12], they are time consuming. It is more convenient to orientate the sample against the measurement gantry as accurately as possible and then provide only small software compensation, if needed. In particularly, for glossy surfaces.

Below we describe the principle and the use of an *autocollimator*, a device that was designed and used for alignment purposes in optics. Unfortunately, this alignment is mostly overlooked in computer graphics research dealing with sur-

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face reflectance measurement, including BRDF, SVBRDF, and BTF measurement setups.

2. Autocollimator

In optics there are different types of autocollimators [Goo89] that can be used for different purposes, including the quality tests of optical components. Such applications can be found for example in [MW13]. However, we are interested in the alignment of the measured sample at the right position in the surface reflectance measurement setup.

The principle of a simplified autocollimator is depicted in Fig. 1. The autocollimator [MW13] uses a beam of collimated light (i.e. parallel rays of light focused to infinity). The beam is split into two mutually perpendicular beams at a (half-reflecting) beam splitter. The first beam (reference beam, in blue color in Fig. 1) passes directly through the splitter and is back-reflected at the output face of the cube. The second beam (object beam, in red color) is reflected at the splitter and propagates to the sample measured. A *flat mirror* must be placed on the surface. Here the beam is reflected back (in green color) to the splitter. These two back-reflected beams are recombined at the beam splitter and propagate toward a *detector*, forming two spots. This detector can be implemented for simplicity as a CCD/CMOS chip. The reference spot is fixed and its position on the detector depends on the mutual position of the laser LED module and the beam splitter. The distance between the reference and object spots determines the angular misalignment of the sample. If the sample is perfectly perpendicular to the laser beam, the two spots overlap.

Traditional design of an autocollimator is more complicated, see for example [Goo89]. There is an illuminated crosshair placed in the front focal plane of a collimating lens. This lens projects the crosshair to infinity. After being reflected at the measured surface, the beam travels back through the lens to a beam splitter. An image of the crosshair formed by the lens overlays a scale placed behind the splitter. This image is observed through an eyepiece or by a camera. However, the above described simplified principle uses a laser LED module, equipped by its own optics (lens and aperture). That module implements the collimator. The construction with a laser LED module is simpler and cheaper, but the achievable accuracy and discernibility is lower than that of the traditional design.

Knowing the distance to the mirror, the deviation angle of a mirror δ is computed as: $\delta = \frac{1}{2}\arctan(x/l)$. The size of detector pixel and the distance between the mirror and the detector gives the discernibility of the collimator in terms of the minimum deviation angle δ that can be recognized. For example, for a large scale gonioreflectometer with the distance $l = 1000$ mm, the pixel size of 7μm, we can get the discernibility $\delta = 1/2\arctan(0.007/1000.0) = 0.0004^o = 1.44$ *arcsec*. However, this value is rather hypothetical, as we cannot distinguish the distance of a single pixel between two spots. If the image on a detector is observed by a human, the practically achievable discernibility is at least by one order of magnitude worse.

The size of the detector (and the beam splitter in front of the detector) gives also the range of δ that can be measured. So for the example above with the detector chip size $d = 7.2$ *mm* (1024 pixels $\times 7\mu m$) the range of deviation angle from the center is then: $\delta_{max} = 1/4\arctan(7.2/1000) = \pm 0.102^o$. Obviously, in such a configuration of the autocollimator this is rather a small angle that requires a surface to be relatively accurately perpendicularly set so the beam gets back to the autocollimator. We have identified three ways to enlarge the angle range δ_{max}. First, we can increase the size of detector chip. Nowadays, we are limited to the chip size of roughly 36×24 mm and this solution is expensive. Second, we can replace a chip by a larger matte screen and observe the screen by a closely located digital camera (as shown in Fig. 2). This is much less expensive. Third method is to position a small flat screen in front of the beam splitter output. This additional screen must have in the middle a hole for the beam splitter. The beam is incident for larger δ onto the flat screen instead to the beam splitter. We can watch the reflected beam spot on the screen during rough adjustment of the perpendicularity. Optionally, we can use another small camera watching this additional flat screen from a distance.

3. Results

We have tested three devices equipped with an autocollimator. Initially, we have tested the autocollimator used in the BRDF reflectance device from Light Tec company, model REFLET-90. This is a stationary gonioreflectometer for spectral reflectance measurement of isotropic BRDFs. The source of light is a divergent light beam of an angle $\pm 0.09^o$, $\pm 0.18^o$, $\pm 0.35^o$, and $\pm 0.5^o$. The sample of a measured material is put onto a tip and tilt stage. A small circular high quality flat mirror is then put onto the measured sample positioned horizontally. The tip and tilt stage with the sample is then adjusted so that the reflected beam and incoming light beam are parallel, which can be visible on the output beam flat mount. After the coarse adjustment the light gets back to the high dynamic range detector, the tilt can be adjusted finely by finding the maximum amplitude of the reflected illumination.

We have also tested two autocollimators constructed with laser LED modules. They use a standard beam splitter (Edmund Optics), a matte screen (Edmund Optics), and a camera. We have observed that the laser (with a beam diameter of $\approx$ 3mm) forms a spot on the screen of roughly 5% of the screen size. When the reference and object spots get to the same place on the screen, the sample orientation is right. Obviously, the resolution of the autocollimator is not then given by the size of a pixel, but by the discernibility of the

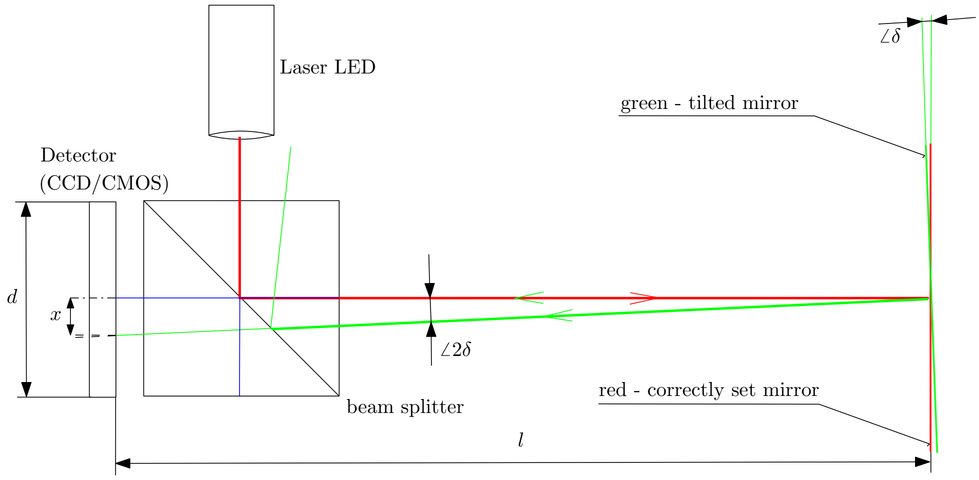

Figure 1: *The principle of autocollimator with a laser LED module. It consists of a collimated beam light source, a beam splitter, a detector and a flat mirror put on the measured surface sample that we want to orientate perpendicularly to the beam.*

two spots. Fortunately, both spots have different intensities and diameters so they are easy to distuinguish.

4. Limitations

Obviously, it is necessary to fulfill some conditions to use the autocollimator. We need to fit it inside of the measurement setup as it has some physical size. It is possible to buy an autocollimator module from the companies producing optical devices, where the detector chip is subdivided into 4 parts and in case of the ideal setting of the autocollimator and the mirror, each of the four chips gets the same energy from the back reflected beam. Some manufactured autocollimators have an output aperture, where it is possible to mount its own camera or other optical parts.

Second, it is necessary to have the locally flat surface of a measured sample. Third, it is necessary to fix the mirror onto the sample. Some BRDF/BTF measurement setups however mount the measured sample on a robotic arm, so it is necessary to find an appropriate mounting technique how to temporarily fix a flat mirror onto the measured sample. For other stationary setups that have a fixed or only rotated sample located horizontally to the ground such as Light Tec company REFLET-90, the BTF measurement setups Dome 1 and Dome 2 [MMS*05, SSW*14], gravity is sufficient means for mounting the mirror onto the measured sample.

For on-site measurements, where we position and adjust the measurement gantries against a sample that is fixed in space, the adjustment with an autocollimator becomes more tricky. First, we need to find locally flat sample to measure. Second, we need to mount the mirror onto the sample tightly so that the mirror is parallel to the measured sample. However, we also must be able to dismount the mirror fast and easily. The surface reflectance gantry for on-site measurement has to be equipped with a field stop. Through the field stop a sample illumination, measurement, and protection of the measured sample from disturbing environmental lighting can be implemented. After the gantry position and orientation is adjusted, the mirror has to be removed before the measurement takes place. In principle, this requires a thin mirror or a slot where the mirror does not touch the measurement gantry. This enables an independent move of the gantry without touching the mirror. We have tested a plausible solution by producing a thin yet relatively rigid mirror by polishing stainless steal plates.

5. Conclusion

We have presented a description of an autocollimator, a device used to set up and measure angular deviations, traditionally used in optics. We discussed selected issues with using the autocollimator for setting up the surface reflectance measurement to get the sample orientation appropriate. We hope that the autocollimator will become more widespread in the surface reflectance measurement setups in computer graphics and computer vision communities.

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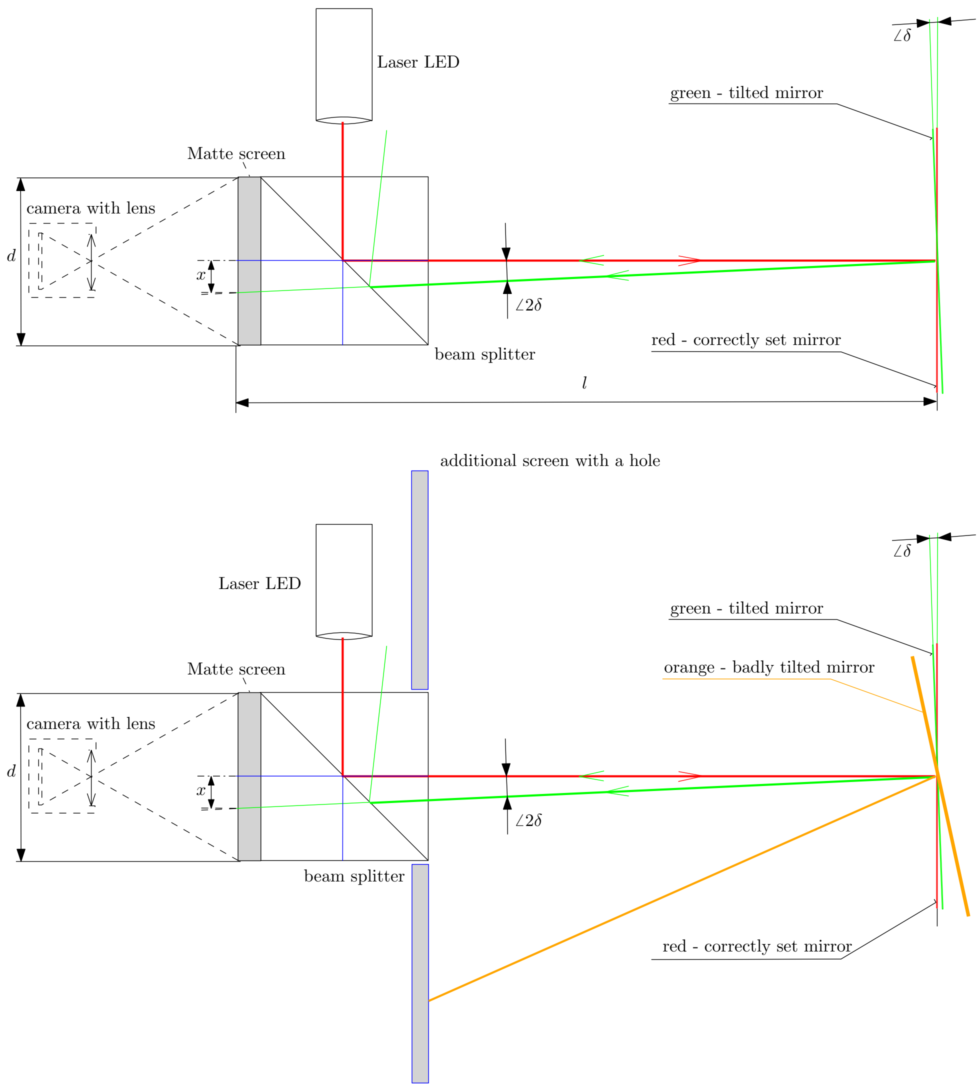

Figure 2: *(Top) The autocollimator with a laser LED module and the matte screen observed by a camera. (Bottom) The autocolimator with a laser LED module, the matte screen observed by a camera, and the additional screen in front of a beam splitter.*

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