

## SEMIAUTOMATIC SURFACE REFLECTANCE MEASUREMENT FOR MONITORING OF MATERIAL WEATHERING

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**Summary:** *We present a device for measurement of surface reflectance in dependence on incidence angle and reflectance angle. This measurement enables us to quantitatively determine how much the surface is glossy or matt. The device is programmable, which enables us to choose non-equidistant steps of angles, and study special situations more in detail. It can be used for monitoring of material weathering or other types of degradation as weathering usually causes that the surface becomes more matt.*

**Keywords:** *surface, reflectance, photometry*

### 1 Motivation

A wealth of information is present in visual appearance of solid body surface. The surface appearance depends on the light (radiation) which illuminates the body: direction, wavelength, intensity, polarisation state etc and also on reflective properties of the surface itself. The change in the appearance of the surface indicates the acting processes. Investigation of the surface optical property can thus help in understanding of processes like gradual decrease of gloss and transparency of polymers, oxidation of metal surfaces, soiling of stones, etc. Precise knowledge of visual properties of surface is also important input parameter for other optical methods, like photometric stereo.

### 2 Optical Properties of Surfaces

For a given wavelength, surfaces of solid bodies can be divided into two groups: optically raw and optically smooth. These surfaces have the following properties:

optically smooth:  $h < \lambda/4$  and  $\Delta\varphi < \pi$ ;

optically raw:  $h > \lambda/2$  and  $\Delta\varphi > 2\pi$

where  $h$  is relief height,  $\lambda$  is wavelength and  $\Delta\varphi$  is phase variance in the resolution cell. Surfaces whose surface height  $h$  is bigger than  $\lambda/4$  and lower than  $\lambda/2$ , and whose phase variance is bigger than  $\pi$  and lower than  $2\pi$ , are transitional surfaces whose properties are common with the smooth or the raw surfaces in dependence on conditions.

In the world surrounding us, we deal mostly with raw surfaces. Light beam reflects from the raw surface not only to the direction defined by reflectance law ("reflected ray stays in the plane of the incidence, and size of the incidence angle is equal to size of reflectance angle"). The law is valid strictly only for optically smooth surface. The opposite of a smooth surface, is a perfect matt surface. We call idealised perfect matt surface as Lambertian surface (also called cosine surface). For Lambertian surface with constant reflectance

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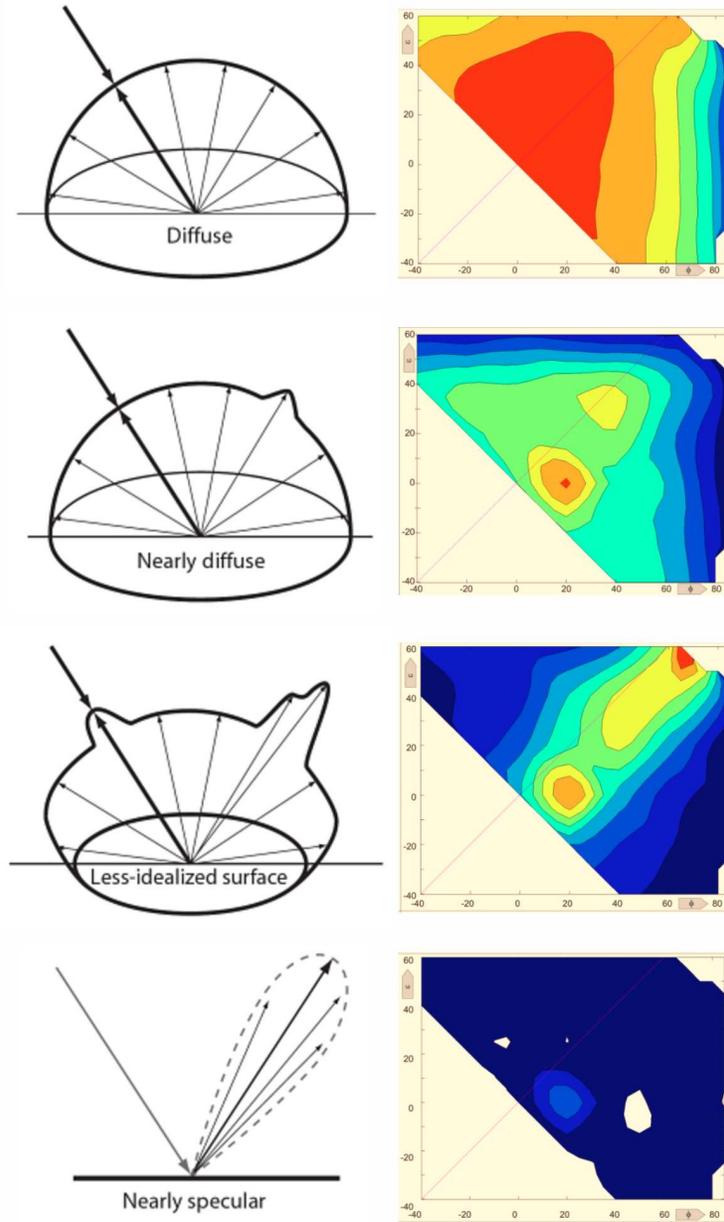


Figure 1: Types of surfaces (left column) taken from [4] and outputs of reflectometer for these surface types (right column).

coefficient  $\rho$  is valid: Reflectance  $R$  is directly proportional to cosine of incidence angle  $\varphi$  ( $R \sim \cos \varphi$ ). Reflectance  $R$  is independent on reflectance angle  $\varphi'$ . Reflectance connects with polarization too. By oblique incidence and reflectance of natural (i. e. unpolarized and time-incoherent) light from an object surface, also partial polarisation of reflected light occurs. We can divide unpolarized light to two plane-polarized light states. The states are named as  $s$  (also transversal electric,  $TE$ ) and  $p$  (also transversal magnetic,  $TM$ ). The  $s$  and  $p$  polarisation states (waves) are defined by geometry of incided and reflected ray and reflecting surface. Wave, whose electric intensity vector oscillates in ortogonal direction to incidence plane, is called  $s$ -wave. Wave, whose electric intensity vector oscillates in incidence plane, is called  $p$ -wave. The wave with  $s$ -polarisation reflects generally with other reflectance coefficient than  $p$ -polarized wave. If we measure

incidence angle  $\varphi$  from surface perpendicular, the  $s$ -wave reflectance  $R_s$  increases continually with  $\varphi$  from  $0^\circ$  to  $90^\circ$ . Dependence of  $p$ -wave reflectance  $R_p$  is more complicated.  $R_p$  decreases for  $p$ -wave from the value for perpendicular incidence to zero, and then it increases. Human eye same as photographic film, photoelectrical multiplier or a CCD camera are quadratic detectors: they register only amplitude, not phase of the optical wave, and they do not register polarisation. Different dependence of reflectance coefficient for  $s$ -wave and  $p$ -wave has influence to total intensity of reflected light, detected by a quadratic detector.

Universal description of reflectance on raw surface includes a possibility of reflection outside incidence plane. This is described with bidirectional reflectance distribution function (BRDF). However, such behaviour is present only by special types of surface (e. g. quartz penetrated with crocidolite fibers, yellow-brown colour, chatoyant glitter, etc.). Measurement in one plane is enough for investigation of most surfaces.

Results of measurement are summarized in Figure 1. The figure presents two columns of images. On the left, four cases of reflectance in 3D schematic plots of reflected light intensity from various types of surface are shown, the plots were taken from [4]. Right column then presents our measurement of the equivalent surface types in the form of two dimensional contour map encoding relative amount of light in particular configuration as a color (minimum (0) is dark blue, maximum (1) is red). In this reflectance diagrams: incidence angle  $\varphi$  is on horizontal axis, reflectance angle  $\varphi'$  is on vertical axis.

### 3 Current state of the development: Laboratory Device

We developed a device for measuring intensity of reflected light in dependence of incidence angle and reflectance angle in one plane. We call the device as "reflectometer". The device is enclosed in durable metal cabinet with an openable lid. In order to insure the controlled conditions, light absorbing fabrics, black velvet covers interior of the cabinet. The geometry of measurement and main components of device are shown in Figure 2. LED lamp is used as a light source (LED lamp) and DSLR camera (Canon EOS 600D) plays the role of detector. The rotational parts are driven by stepper motors.

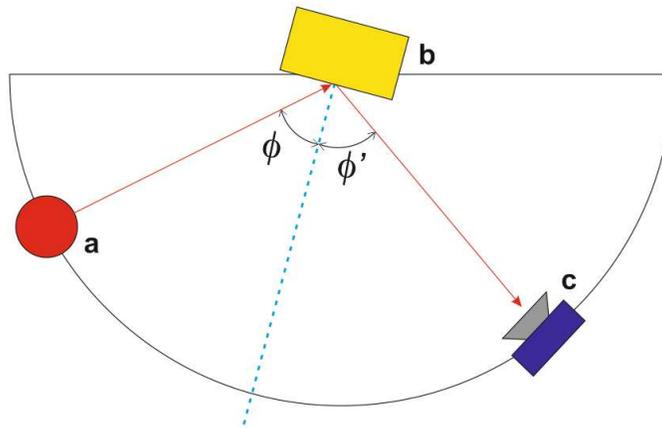


Figure 2: Schematics of reflectometer depicting the geometry of light source (a), surface of specimen (b) and detector (camera c).

Area of studied specimen surface is a square of about 1 cm side and is placed near to optical axis. High resolution of the image is not substantial; only photometry is important, therefore the DSLR is set so that measured signal is in its linearity interval. Exposure time has been chosen according to material reflectance. Snaps are saved in RAW format. Rotation stages are driven with step motors and gearing with reduction ratio 1 : 10. The step motors have 200 steps per revolution. We can control both rotational stages with precision of 2000 positions to the whole angle ( $360^\circ$ ). If we limit to full steps, "our angle unit" is  $0.18^\circ$  (five "units" = 1 grad, where 400 grads = full angle).

As shown on Figure 1, we measured several types of surface: a smooth polished metal, rough metal and oxidised metal (after polishing), and photometric standard Lambertian surface.

#### 4 Reflectivity measurement in infrared radiation

Experience gained in examination of relation between material's visual properties and its state of degradation led to a new direction of investigation focused on the surface properties studied also in a different range of electromagnetic (EM) radiation. The reason for this is, that the reflectivity measurement most sensitively depicts undergoing degradation processes during the transition from gloss to mat state. It can be easily explained with a reference to the above mentioned definition of optical roughness, the implication is the surface that appears rough (diffuse) in visible light, can be specular in longer wavelength of EM radiation.

In order to study feasibility of this approach we carried out a case study on a reflectivity of set of coins (Figure 3) in infrared radiation, more precisely in MWIR (middle wavelength infrared; 1500-5100 nm with maximum at 4000 nm). FLIR SC 7600 infrared camera was used as a detector, and an object kept at constant elevated temperature (100 °C was used as an infrared source, but in principle, the setting is the same as in the Figure 2. The preliminary investigation with IR imaging camera has demonstrated a possibility to



Figure 3: Coins with various degree of oxidization. The most oxidized coin (left) has the highest emmissivity.

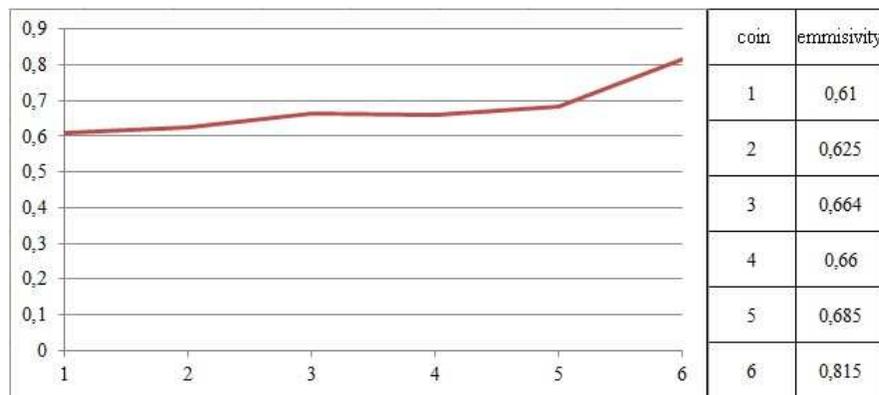


Figure 4: Emmissivity of coins: from the most specular (1) to the most matt (6).

determine reflectivity of surface also in MWIR range as shown in Figure 4. A possibility to incorporate this measurement directly in reflectometer, where light source would be replaced with a temperature controlled black body radiator, was also proved.

#### 5 Conclusions, Future Work, and Possible Applications

Degree of surface degradation can be measured through changes of its reflectance properties. Relatively simple equipment is sufficient to measure the reflectance properties in one plane, it means full investigation of

so called bidirectional reflectance function is not necessary like in the case of hemispherical reflection and fisheye objective proposed in [3].

It was shown that the reflectometer can be extended for measurement of reflectivity of material also in IR radiation. Another application of our reflectometer is possible: Coded photometry stereo needs a certain precondition of surface type, if we want so that this method works correctly. Usual precondition of Lambertian surface is not accomplished allways. Coded photometry stereo and its application is being studied in the ITAM mainly for purpose of documentation and study of cultural heritage objects like cuneiforms, seals, etc. but it can also be used for in-situ experiments in materials science field [2].

Determination of surface optical properties can greatly improve precision of 3D surface topography measurement carried out by photometry stereo method. This is especially true when surface topography of metallic specimens is to be studied. As the properties of metallic surface significantly differ from the Lambertian surface, which is usually assumed by PS method, considering true angular reflectance property of surface can improve detail and precision of 3D surface determination.

## 6 Acknowledgment

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