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Modeling the Directional Reflectance (BRDF) of a Corrugated Roof and Experimental Verification

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ABSTRACT

Remotely sensed images with a pixel size of about 1 m can nowadays be acquired by airborne scanners and in the near future also by high resolution satellites. With such a high spatial resolution, remotely sensed data of urban areas can resolve structures like a roof into the different surface segments with different inclinations, e.g. in the case of a gabled roof. We have measured the BRDF (Bidirectional Reflectance Distribution Function) effects thoroughly on a roof covered with corrugated (sinusoidally shaped) roof tiles and on a sample of flat roof tiles. We modeled the shape of the corrugated tiles by a cosine function and assumed that every infinitesimal surface patch of the roof tile has a BRDF proportional to the BRDF of the flat roof tile. Model results and measurements agree well. The most critical parameters are the ratio height over wavelength of the sinusoidal roof tiles and the intensity of the specular peak of the surface patch. It is possible to retrieve these parameters from the measurements.

INTRODUCTION

The intensity of the radiance reflected from a surface depends on the illumination and viewing geometry. It is described by the Bidirectional Reflectance Distribution Function (BRDF) as defined by [1] as the ratio of the radiance reflected into viewing direction and the incoming irradiance from one direction. So far, most of the publications about BRDF concentrated on vegetation canopy or soil. The availability of high spatial resolution (less than 1 m) data by new satellites will make detailed studies of urban areas possible. Structures like roofs can be resolved into the different roof segments. Segments of different inclination will receive different irradiances and reflect the light differently due to their intrinsic BRDF properties. In this study, we present a BRDF model for a corrugated roof and the experimental verification. Our goal is to improve multispectral image classification and change detection procedures.

BRDF OF THE FLAT ROOF TILES

The BRDF of the flat roof tile was measured from a sample of size 30 cm × 30 cm, the actual field of view had an area of only about 3 cm × 3 cm for nadir viewing. We used a sensor called OVID [1] (Optical Visible and near Infrared Detector) from the Max-Planck-Institute for Meteorology, Hamburg, Germany, in the spectral range from 600 to 900 nm with 61 channels (for more details on the sensor see [2]). We fitted an empirical function to the measured BRDF values. The model was proposed by [3], modified by [4] to take into account the reciprocity principle, and extended by [5] by a specular peak, see [6] for a detailed explanation of the specular term. The model passed a statistical χ^2-test, it describes the BRDF of the flat roof tile very well [5].

BRDF MEASUREMENTS OF THE CORRUGATED ROOF

The BRDF of the corrugated roof tiles was measured from the roof terrace of a 18 story building, pointing the sensor down to the surfaces of the investigated roof. The distance sensor-target was about 70 m, the field of view about 30 cm × 30 cm. We measured 9 different points on the roof, see fig. 1. Assuming that each point has the same BRDF, we obtain BRDF-measurements at 9 different angles of reflection for the surface type 'corrugated roof' (for exact angles see captions on the plots in fig. 3, where the data is shown as a function of the relative azmimuth angle). The angles of incidence varied with the course of the sun, altogether we gathered data at 124 different combinations of angles. Skylight effects were taken into account by subtracting a measurement of the roof being in shadow interpolated to the time of measurement (for a detailed explanation of the measurements see [7], [8]). This time we used the spectrometer OVID in the spectral range from 610 to 1600 nm. Fitting the modified Walthall BRDF model mentioned above to the data results in an average deviation of 15 to 20 % (depending on wavelength), the χ^2- test clearly failed.

COSINE-BRDF MODEL

We modeled the shape of the corrugated roof surface by a cosine function. Our cosine-BRDF model can be understood as a ray-tracing model for a surface of one-dimensional roughness where the slope at each surface patch is known. It is computationally very fast, but the results are only numerically and not of an analytical form. It is exact re-

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garding single scattering, masking and shadowing. The twice scattered component is only approximated, but in our case (the albedo of the roof is about 0.1) this component is negligible (less than 2 % on average). The model obeys Helmholtz's theorem of reciprocity (interchanging the angles of incidence and reflection does not change the BRDF value), often called reciprocity principle. It is possible to assign any analytical BRDF to the surface patches.

FITTING RESULTS AND DISCUSSION

Assuming a BRDF proportional to the previously measured BRDF of the flat roof tile for each infinitesimal surface patch in our cosine model and fitting with one free parameter (for the brightness) considerably improves the χ^2- test. For 124 measurements, one free parameter and a confidence value of $1-\alpha = 0.99$ the limit is $\chi^2_{1-\alpha} = 162.4$ (the assumption is reasonable since the material of the flat tiles is similar to the material of the corrugated tiles, although the coloring of the flat tile is much brighter (factor of about 3), the free parameter for the brightness is therefore absolutely necessary). The fit passes the χ^2- test up to a wavelength of 1400 nm and rises to a maximum of $\chi^2 \approx 250$ at 1600 nm (remember that the BRDF of the flat tile was only measured for the wavelength range 600 to 900 nm).

It is obvious from the data that the specular peak rises for higher wavelengths (see [7], [8]). We therefore tested another BRDF model for the surface patches: we assumed a Lambertian component a_0 plus a specular peak with the same shape as the specular peak of the flat roof tile, but varying intensity a_1: $BRDF = a_0 + a_1 \times \mathit{Shape}_{\mathit{Specular}}$ (see [6] for a discussion on the specular peak). This yields two free parameters, a_0 and a_1. Results from the fits are shown in fig. 2. The χ^2 values are comparable to the results using the BRDF of the flat tile. They pass the χ^2- test up to a wavelength of 1400 nm, but rise to only $\chi^2 \approx 200$ at 1600 nm. The ratio a_1/a_0 stays almost constant from 610 to 900 nm, but rises linearly for higher wavelengths, at 1600 nm reaching four times its value of 900 nm. This explains why χ^2 for this model is lower than using the BRDF of the flat roof tile, where the ratio a_1/a_0 is fixed to its value at 900 nm, suppressing the relative increase of the specular peak.

We conclude that for our case, the shape of the non-specular BRDF of the flat tile is not really important, it is sufficient to assume a Lambertian component plus a specular peak of the form described in [6].

PARAMETER RETRIEVAL BY BRDF MEASUREMENTS

The value of χ^2 is determined by substracting the predicted values from the measurements, dividing by the error and summing over all measurements: $\chi^2 = \sum_i(\mathrm{BRDF}_i^{\mathrm{measured}} - \mathrm{BRDF}_i^{\mathrm{modeled}})^2/\mathrm{Error}_i{}^2$. We computed this value using different cosine amplitudes A in our cosine model, see fig. 4. The strong and continuous rise of χ^2 for wrong values of A makes the inversion of this parameter easy. The smallest value for χ^2 was obtained (using the BRDF determined from the flat tile) for $A = 0.87$, the true value being $A = 0.91$. The deviation of 4 % is remarkably small for shape determination from BRDF measurements (the average error for each measured BRDF value is about 10 %). But it must be noted that this is a very special case, because a lot of prior knowledge was used: BRDF of the flat tile, orientation and inclination of the roof, cosine shape of the roofing tiles. The value of A obtained by inversion varies only a few percent with wavelength, see fig. 5.

CONCLUSIONS AND OUTLOOK

We have shown that the models presented above are capable of predicting accurately the BRDF of typical roofs, provided the type of roof and its surface orientation are known. The critical parameters of the model are the cosine amplitude of the corrugated roof and the intensity of the specular peak of the flat roof tile.

In August 1997, we acquired multispectral imagery from the city of Nuremberg, Germany, with an airborne scanner. The flight paths were chosen in a way to obtain several view angles for each pixel. We are planning to apply the model presented above to this data.

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Fig.1: Investigated roof with measured points, picture taken from sensor position. The inclination of the roof surface normal to nadir is $15°$.

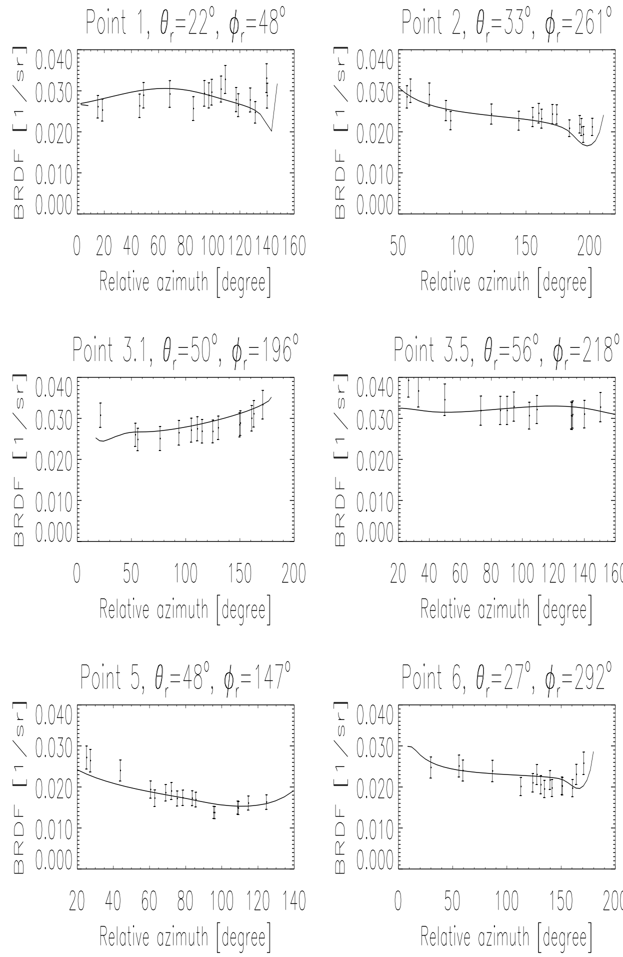

Fig. 3: Measured data (with error bars) of the BRDF from the roof in fig. 1 and fitted model (solid line) at a wavelength of 900 nm as a function of relative azimut angle. Note that the incident zenith angle is NOT constant in these plots. θ_r *= zenith angle of reflection,* ϕ_r *= azimuth angle of reflection,* $\phi_r = 0°$ *or* $\phi_r = 180°$ *are 'parallel to the cosine crest' (no masking from the cosine shape for these angles).*

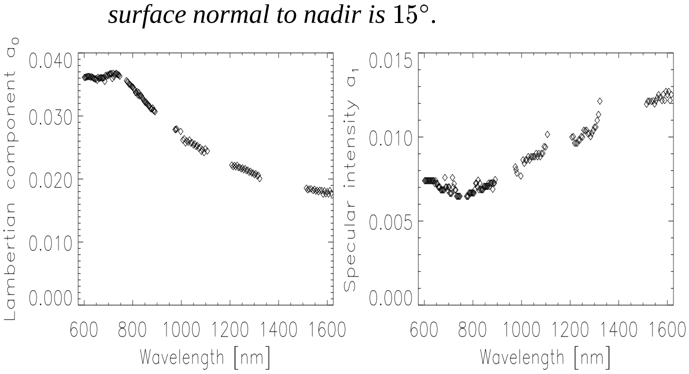

Fig. 2: Fitting $a_0 + a_1 \times$ *Shape*$_{Specular}$ *as BRDF of the surface patches yields the above coefficients.* a_0 *(plot on the left) drops by half from 610 to 1600 nm,* a_1 *(plot on the right) doubles from 610 to 1600 nm. Wavelengths of high atmospheric absorption are not shown.*

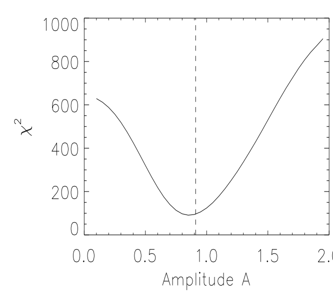

Fig. 4: χ^2 *as a function of the cosine amplitude* A *for 900 nm, using the BRDF of the flat roof tile, dashed line=true value of* A.

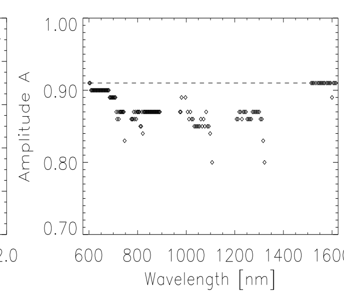

Fig. 5: The retrieved cosine amplitude A *(using the BRDF of the flat tile at 900 nm) as a function of wavelength, dashed line=true value of* A.