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Radiometric correction of hemispherical images

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Abstract

Light scattering in fore-optics of imaging radiometric instruments degrades images, the signal of dark pixels is enhanced and that of bright pixels is reduced. A procedure of restoring hemispherical images obtained with a hemispheric view CCD-radiometer is suggested. The circular hemispheric image is projected onto the sphere and Wiener filtering on the sphere is performed. For building the Wiener filter the point spread function of the instrument was measured in the laboratory, and test images of (partially) controlled radiance were measured. The procedure is applied for the correction of hemispherical radiometric images taken under forest canopy. In non-corrected near infrared images the signal of sky pixels in forest canopy gaps near zenith is enhanced 1.4–2.0 times. The applied correction reduces this error to the level of 1.1–1.2. In the red channel these figures are 0.8–0.9 and 0.97–0.99, respectively.

Keywords: Radiometry; Image restoration; Hemispherical image; Wiener filtering; Deconvolution on the sphere

1. Introduction

Hemispherical photography has been used for studying vegetation structure and radiation conditions in vegetation canopies since the fifties and sixties of the last century (Evans and Coombe, 1959; Anderson, 1964).

Studies where hemispherical images are used are published every year, especially popular are hemispherical images in the studies of forests (Madgwick and Bumfield, 1969; Bonhomme and Chartier, 1972; Lakso, 1976; Gemmel and Perttu, 1978; Wang and Miller, 1987; Chen et al., 1991). Special software, both commercial and freeware for the analysis of hemispherical images is available (WinSCANOPY, 2005; Baret and Weiss, 2004; HemiView, 1999; GLA, 1999, among others).

A recent review paper on hemispherical photography in leaf area index measurements is published by Jonckheere et al. (2004).

Attempts to use hemispherical photos for the estimation of radiation climate in forests were made in very early works (Evans and Coombe, 1959; Anderson, 1964; Madgwick and Bumfield, 1969), however the errors due to the photographic process, variations in exposure, development and printing of photos were the reason why in the following works the hemispherical photos were used mainly for cap fraction measurements.

The radiometric quality of digital consumer cameras which are most popular in vegetation studies is also low. They have a dynamic range of 8 bits (per colour), cameras use automatic exposure changing shutter speed or aperture, info about possible gamma corrections is not always available. Hemispherical images have been mainly used for cap fraction studies (Bonhomme and

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Chartier, 1972; Rich, 1990; Baret et al., 1993; Fournier et al., 1996; Frazer et al., 2001; Inoue et al., 2004; Ishida, 2004; Jonckheere et al., 2005; Nobis and Hunziker, 2005; Zhang et al., 2005). Some procedure of thresholding is applied for producing sky-foliage binary images. Every image is analysed independently, the thresholding level is determined using the histogram of pixel values.

Geometrical properties of hemispherical images have been studied rather carefully (Herbert, 1986, 1987; Frazer et al., 2001). Less attention is paid to the relation of pixel values and target radiance. General image processing methods of contrast enhancement, gamma correction, sharpening etc. are used in special software (HemiView, 1999; GLA, 1999; Baret and Weiss, 2004; WinSCANOPY, 2005). No attention is paid to the spray light in images. The scattering of light in the fore-optics of radiometric instruments is always present. The radiometric degradation of the hemispherical images is caused mainly by three effects. First, the point spread function (PSF) of the fore-optics is not a perfect delta-function due to the limits of (wide-angle) optics. Second, some dependence of neighbour cells of CCD-arrays on each other has been observed (Rieke, 2003). And third, some amount of light coming from the direction $r(\theta, \phi)$ is scattered to every pixel of the image due to possible contamination and mechanical damages of surfaces of lens and filters which are open to the environment. To keep the fore-optics of optical instruments perfectly clean in field conditions is practically impossible. This scattered light causes the PSF spreading over the whole image. Such dependence of neighbour pixels on each other in a digital image is discussed by Huang et al. (2002) and further studied by Du and Voss (2004). For the quantitative description of the effect the rotationally symmetrical point spread function is used. The instruments described by Huang et al. (2002) and Du and Voss (2004) had relatively narrow field of view. In this work the radiometric degradation of hemispherical images is studied and a correction procedure is suggested.

2. Background

2.1. The CCD-radiometer

In Tartu Observatory an imaging CCD-radiometer of hemispherical view was designed for the study of radiation fields in forests (Kuusk et al., 2002). An astronomical CCD-camera ST-8 (Santa Barbara Instrument Group, Santa Barbara, CA, U.S.A.) is equipped with fish-eye lens and filter box of two filters, so hemispherical 16-bit digital images in two spectral regions, red (675 nm) and near infrared (NIR, 800 nm) can be made. The fish-eye image is projected onto the CCD-array of 1500×1020 elements. The area of this circular image is about 870,000 pixels, the remaining area of the sensor array is not in use. The sensor of the camera ST-8 is cooled and thermostabilized, so the dark current is stable, and dark current and noise are of low value if compared to signal. CCD-arrays have highly linear radiometric response (Mullikin et al., 1994), so the imaging CCD-radiometer works as about 870,000 radiometers of very narrow field of view — about 0.2°, every radiometer looking in his own direction. For more details on the CCD-radiometer see the paper by Kuusk et al. (2002).

2.2. Image distortions

Radiometric measurements of high angular resolution in forests were planned with this radiometer. Measurements have been done in perfectly cloudless days in mature forests, the radiometer looking up in 1999, 2000 and 2002, and above a willow plantation, radiometer looking down in 2003.

A sample image made in a mature pine forest with NIR filter is shown in Fig. 1. The foliage (pine needles) is bright and clear sky in the background is very dark in the NIR spectral region. The measurement of the sky radiance in canopy gaps near zenith with the NIR filter shows the effect of spray light — the sky pixels in forest images are much brighter than in an image made in a clearing. Fig. 2 shows the measured sky radiance in digital counts (DC) close to the zenith during a series of measurements on 21 May 1999 in a pine forest. The series starts with a measurement in a clearing, then 20

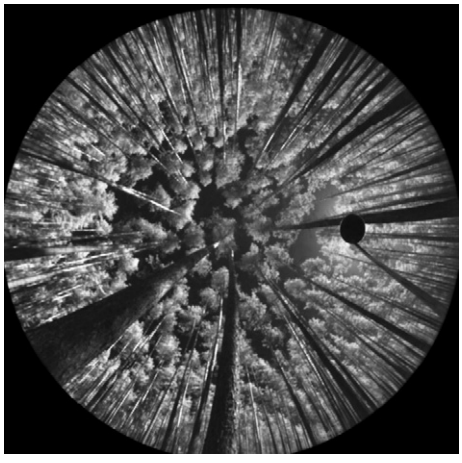

Fig. 1. Hemispherical NIR image of a pine forest.