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Short communication

Potential applications of near infra-red hemispherical imagery in forest environments

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Abstract

Hemispherical photography is commonly used in studies investigating the light environment beneath the forest canopy. This paper documents a methodology to adapt a standard digital camera to take hemispherical images in the near infra-red. These images can then be post processed to calculate sky-view factors, branch/bole-view factors and foliage-view factors. The further potential of the instrument is then demonstrated by combining the near infra-red images with standard visible images to produce a hemispherical NDVI image. Further discussion is also given to the potential applicability of the techniques above the forest canopy.

Keywords: Hemispherical fisheye; Near infra-red; NDVI; View factors

1. Introduction

The light environment beneath forest canopies plays a role in a number of ecological processes (Hale and Edwards, 2002). Hemispherical photographs are commonly used to assess the light environment and numerous studies are evident in the scientific literature (e.g. Anderson, 1981; Rich, 1990; Frazer et al., 2001). Hemispherical photographs show the intrusion of the forest canopy into the sky hemisphere (Fig. 1a) and are acquired by using a camera equipped with a 180° field of view fish-eye lens. From such images, gap fraction data can be derived for the assessment of parameters such as the sky-view factor, leaf area, clumping and foliage inclination angles (e.g. Rich, 1990; Frazer et al., 2000; Walter et al., 2003).

Early studies relied on images being collected on film which led to delays in processing as the images needed to be developed and scanned. The use of digital cameras has overcome this limitation, allowing images to be assessed and retaken in the field if necessary (Hale and Edwards, 2002). However, as demonstrated by Milton (2002), a further advantage of some digital cameras is that they can be easily adapted to take pictures in near infra-red (NIR). NIR is a wavelength commonly used in forest meteorology due to the spectral properties of vegetation (Fig. 1); light is absorbed for photosynthesis in the visible spectrum (VIS) where as light is transmitted and reflected in NIR. Traditionally, NIR images were taken using 35 mm infra-red film but these were expensive, unreliable and required specialist processing (Milton, 2002). Hence, despite the abundance of studies using visible hemispherical photography for forestry research, there are presently no studies using hemispherical photographs collected in NIR. This paper presents a methodology to obtain NIR hemispherical images by adapting an inexpensive digital camera. Some of the potential applications of the apparatus are then discussed.

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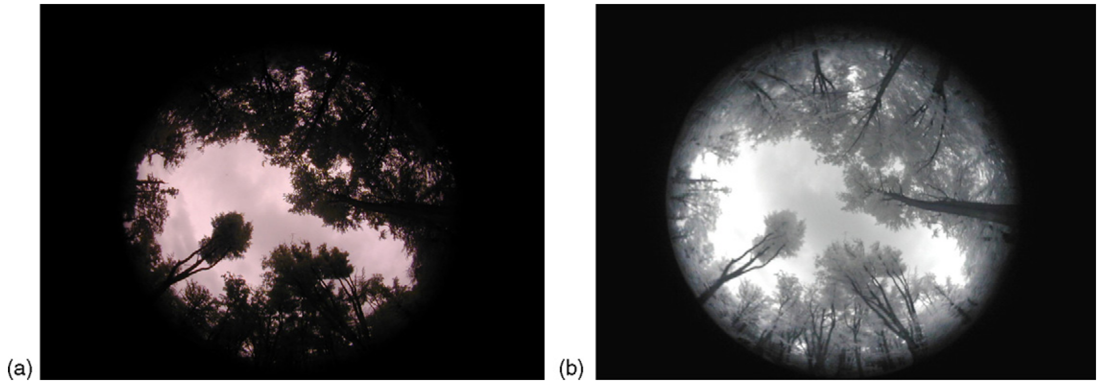

Fig. 1. (a) Fisheye image of a forest clearing and (b) NIR fisheye image of the same site.

2. Camera adaptation

Charge couple devices (CCD) are light-sensitive integrated circuits located at the focal plane of many modern digital cameras (Leblanc et al., 2005). These produce different results from ordinary film-based cameras as CCD matrices are often sensitive to NIR radiation beyond the visible spectrum. The standard test to determine whether a camera can sense NIR is to investigate whether the camera can 'see' the beams emitted from a TV remote control. The brighter the beam, the more sensitive the camera is to NIR. Fortunately, the Nikon cameras often used to collect hemispherical images are very sensitive and can be easily adapted to take images in NIR. Although the sensitivity of Nikon cameras to NIR has decreased in later models, Coolpix models prior to the 990 have a strong sensitivity to infra-red light. For the purpose of this investigation, a standard Nikon Coolpix 950 equipped with a FC-E8 fisheye lens was adapted.

Manufacturers reduce the sensitivity of the camera to NIR by attaching an infra-red blocking filter (hot mirror) to the CCD matrix. A Unicam UV500 spectrophotometer was used to conduct a spectral sensitivity analysis of the filter between 300 and 900 nm (Fig. 2). The impact of the infra-red blocking filter can be clearly seen by restricting transmittance to below approximately 750 nm. However, as the 'remote control test' confirms, not all NIR wavelengths are completely blocked out. Therefore, the first step in adapting a camera is to remove the infra-red blocking filter from its rubber mount, before replacing it with a clear piece of glass of exactly the same shape and size (Fig. 3a and b). The effect of this change on the camera is shown in Fig. 2 which clearly shows the increased sensitivity of the camera above 600 nm. Next, the visible light needs to be blocked out and this can be achieved by using an inexpensive screw-on cold mirror filter (Fig. 2 and Fig. 3c). Indeed, there is no reason why the hot mirror could not be directly replaced by the cold mirror, thus removing the need for the replacement glass, but the materials proved too difficult to source for this investigation. Once the adaptations are made, the digital camera is capable of capturing images in NIR (Fig. 1b). The camera can still be used as a standard digital camera (albeit more sensitive to NIR) by using a simple clear filter of the same thickness of the cold mirror filter (Fig. 3c). This ensures that the optics remain correct and is particularly important when using additional lenses such as a fisheye (Fig. 1a).

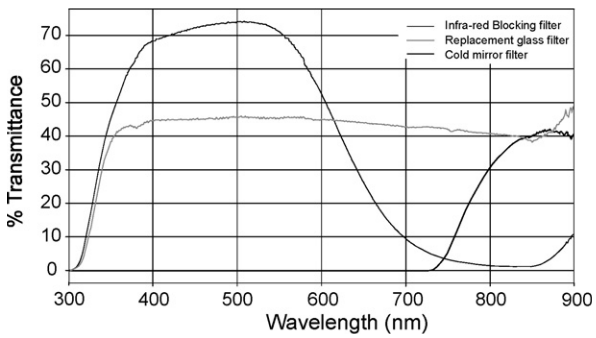

Fig. 2. Spectral sensitivity analysis of the Nikon 950 infra-red blocking filter, replacement glass filter and cold mirror filter between 300 and 900 nm. No information is available on the upper response of the CCD, but is likely to exceed the 900 nm used in the diagram due to the spectral characteristics of silicon.

3. Foliage-view factors

One advantage of using NIR hemispherical imagery instead of VIS is that due to the spectral properties of vegetation, additional information can be derived from the image. For example, the increased contrast evident in the NIR image means that it should be much easier to separate bole/branch-view factors from foliage-view factors. To test the utility of the adapted camera for

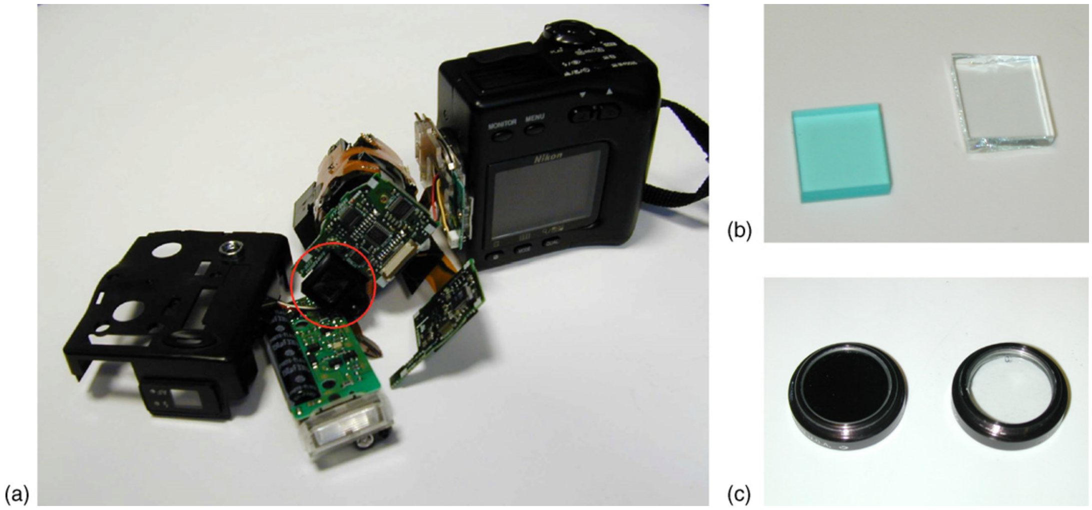

Fig. 3. (a) Internal view of the Nikon Coolpix 950 showing the location of the infra-red blocking filter (circled red), (b) the infra-red blocking filter and replacement glass filter and (c) cold mirror filter and plain clear glass filter.

calculating foliage-view factors, imagery was taken at 20 sites (10 deciduous, 10 coniferous). All images were collected under homogenous cloudy conditions to ensure luminance remained consistent across the sky hemisphere. The camera was mounted and levelled using a tripod at a height of 1 m above the ground.

Segmentation of the images can be easily done manually, which is an adequate approach for a small

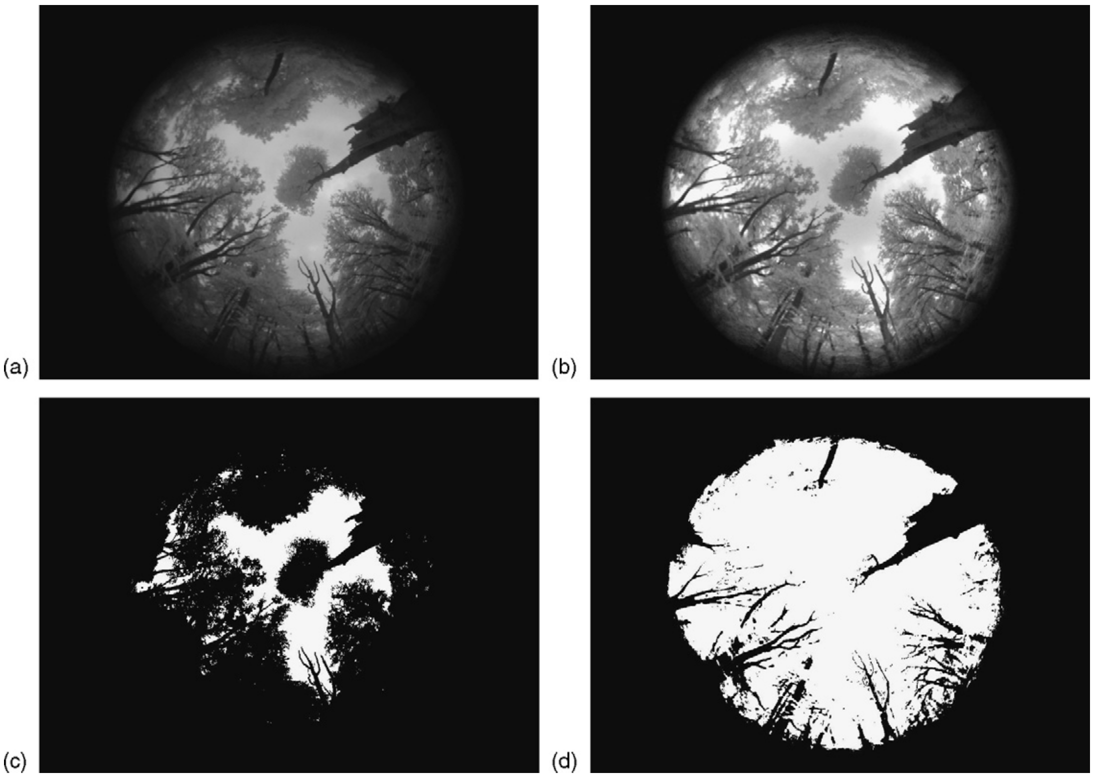

Fig. 4. (a) Unprocessed NIR fisheye image, (b) the same image after vignetting removal, (c) segmented NIR fisheye image showing the sky-view factor including foliage and (d) excluding foliage.

number of images. However, should the scale of the study increase, then this becomes an onerous task which requires automation using threshold techniques. Indeed, the selection of a correct brightness threshold in order to segment sky pixels from canopy pixels is one of the main difficulties when using hemispherical photography (Jonckheere et al., 2004). Distortion in fisheye optics cause a reduction in luminance (brightness) in the image periphery when compared to the centre pixels (Fig. 4a). This effect is called vignetting and means that a single threshold is often insufficient to segment an entire image (Wagner, 2001). Although sophisticated automated threshold techniques have been achieved using edge detection (Nobis and Hunziker, 2005), simple vignetting removal algorithms, which are available in many paint package software programs, can greatly improve image contrast (Fig. 4b). Additional techniques can also be applied in the event of sky luminance heterogeneity (see Wagner, 2001), although this was not considered essential in this study. After image processing, a single threshold can be easily applied to segment canopy pixels (Fig. 4c) and branch/bole pixels (Fig. 4d). Images can still be manually edited if required.

Once segmented, view factors can be readily calculated from the images by using any standard sky-view factor calculation algorithm. In this study, the sky-view factor and bole-view factor were calculated for each segmented image by using the approach of Chapman et al. (2001). This technique calculates view factors (shown to be accurate to within ±0.02) from a segmented binary image by means of an annular template. Foliage-view factors could then be readily calculated by subtracting the sky-view factor from the branch/bole-view factor (Table 1).

Using a threshold to automate the binary segmentation of the canopy for the calculation of sky-view factors proved to be straightforward, however the automated segmentation of the branch/bole-view factor was more difficult and often required manual intervention, particularly for coniferous vegetation. The thresholds used for each image are also shown in Table 1 and vary from image to image in line with the luminance at the time the image was taken. Interestingly, the thresholds used for the bole/branch view factors are roughly half of that used for sky-view factors. This would suggest that there is some potential in producing a fully automated algorithm to segment all view factors if light levels are simultaneously recorded at site (e.g. Ishida, 2004; Wagner, 2001).

4. Ground based NDVI

The Normalised Difference Vegetation Index (NDVI) exploits the spectral behaviour of vegetation:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{VIS}}{\mathrm{NIR} + \mathrm{VIS}} \tag{1}$$

NDVI is typically used for large-scale vegetation monitoring from satellites and is commonly obtained by the combinations of channels 1 (VIS) and 2 (NIR) of AVHRR. (e.g. Lim, 2002; Sellers et al., 1994; Quarmby et al., 1993). However, ground based NDVI measurement techniques also exist. For example, Pontailler et al. (2003) measured NDVI in situ by using a laboratory-made sensor. In situ measurements of NDVI are not new (e.g. Pearson et al., 1976) but have not been widely used to date. Pontailler et al. (2003) believe that this could be due to the lack of a simple portable instrument. However, by exploiting the techniques so far explained

Table 1
Foliage-view factors for 10 deciduous clearings and 10 coniferous clearings

Site	Deciduous					Coniferous				
	Sky-view factor threshold	Branch/bole-view factor threshold	Sky-view factor	Branch/bole-view factor	Foliage-view factor	Sky-view factor threshold	Branch/bole-view factor threshold	Sky-view factor	Branch/bole-view factor	Foliage-view factor
1	188	92	0.091	0.769	0.678	154	90	0.269	0.748	0.479
2	160	61	0.301	0.878	0.577	177	72	0.215	0.829	0.614
3	226	100	0.048	0.920	0.872	197	87	0.194	0.872	0.678
4	156	69	0.285	0.793	0.508	142	71	0.634	0.865	0.231
5	119	48	0.527	0.922	0.395	185	75	0.119	0.860	0.741
6	181	86	0.122	0.906	0.784	203	61	0.164	0.897	0.733
7	210	79	0.037	0.898	0.861	187	48	0.28	0.812	0.532
8	205	75	0.027	0.886	0.859	208	61	0.151	0.822	0.671
9	115	48	0.477	0.867	0.390	228	80	0.076	0.918	0.842
10	168	57	0.207	0.878	0.671	165	87	0.305	0.908	0.603

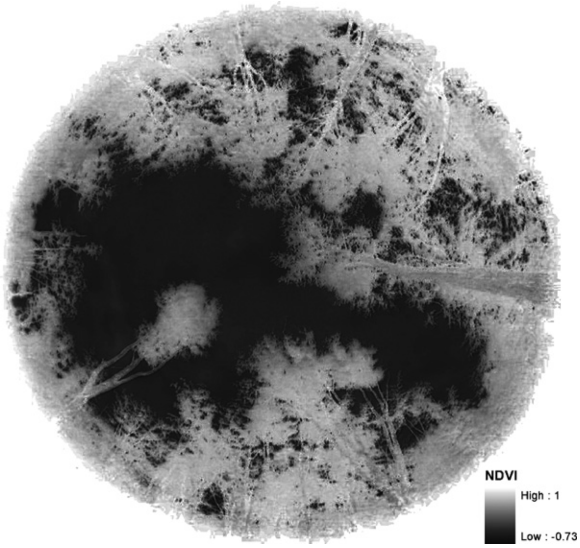

Fig. 5. Hemispherical NDVI calculated from the imagery shown in Fig. 1.

in this paper, it is now possible to make inexpensive ground based NDVI measurements quickly and easily. Fig. 5 shows a hemispherical NDVI calculated from (1) and using the two images shown in Fig. 1.

However, a major difference between ground based NDVI and satellite based techniques are that the measurements are no longer based on solar radiation reflected from vegetation, but instead from diffuse and transmitted radiation. Hence, the camera may actually have greater utility above the canopy without the fisheye lens (Fig. 6). The high spatial resolution and definition provided by a digital camera could prove useful in assessing the small scale variability (even leaf scale) of NDVI. If it is possible that NDVI could be calculated from the same wavelengths for both ground and satellite data, the camera could be used for ground-truthing exercises. There are many problems which exist with satellite estimates of NDVI, including sub-pixel reflectance (mixed pixels) as well as gap and shadow effects. Hence, results using this apparatus on a tower could be used to improve the weighted and soil adjusted vegetation indices specifically developed to help overcome these limitations (e.g. Clevers, 1999; Qi et al., 1994). An alternative application would be to use a pair of cameras to collect stereo imagery from which an estimate of the leaf area density profile could be obtained.

Fig. 6. Ground based NDVI estimates from 1 m above the ground.

5. Conclusions

This paper has outlined a simple methodology to adapt a standard Nikon 950 digital camera to take images in NIR. The methodology should be applicable to other NIR sensitive makes and models of camera, although the possibility of removing the infra-red blocking filter (without internal damage) needs to be checked, as does the availability of a suitable cold mirror filter. A number of potential applications for forestry meteorology have been discussed including the calculation of foliage view-factors and ground based hemispherical NDVI images. Indeed, the equipment has the potential to make NDVI measurements at a scale previously not possible without the use of expensive hyperspectral imaging techniques. Although considerable refinement of the techniques is still required, the low cost of both the camera and adaptation should enable the increased use of NIR imagery in a number of light environment studies.

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