A NOVEL SCENE-RECORDING SPECTRORADIOMETER

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Abstract – *In this paper we describe an innovative approach to providing both a synthesised dual-beam capability and a permanent photographic record of the precise area sensed by a spectroradiometer. These advances have been achieved without modifying the spectroradiometer and may be used with a wide range of commercially-available spectroradiometers.*

1 INTRODUCTION

Developments in field spectroradiometers over the years have tended to focus upon improvements in data quality, achieved by faster scanning or better signal-to-noise ratio, or enhanced portability and ease of use, largely through advances in portable computer technology. Although these developments are important and to be welcomed, it is argued in this paper that virtually all exisiting field spectroradiometers are still deficient in several aspects that compromise their practical use in the field. The first of these aspects is the continued reliance upon single-beam instruments and therefore the introduction of errors due to the time delay between observation of the target and the reflectance panel. Dual-beam field spectroradiometers ***are*** commercially available but they are very expensive and we believe there is scope for more innovative approaches to addressing the problem of irradiance changes during measurements. The second deficiency of generally available field spectroradiometers concerns the precise identification of the area sampled, and once again, we believe there is scope for innovation, both in the capturing of these data in the field and in their subsequent processing to yield information about the spectral-spatial mosiac being measured.

In this paper we describe the prototype of an attachment which we have tested with six different commercially available single-beam field spectroradiometers and which provides both a synthetic dual-beam capability and a permanent visual record of the area sampled and its surroundings. These two improvements have been the subject of separate experiments but the intention is to combine both innovations in one new ‘Scene-Recording Spectroradiometer (SRR)’

2 REDUCTION OF ERRORS DUE TO IRRADIANCE CHANGES DURING MEASUREMENTS

The method we have developed to reduce the errors caused by irradiance changes between measurement of the target and the reflectance panel avoids the expense of a second spectroradiometer by using a low-cost multiband radiometer as the second sensor monitoring the spectral irradiance. The principle of the new technique is to measure the reference irradiance in a small number of carefully selected spectral bands and then use these data as inputs to a trained artifical neural network (ANN) from which the complete irradiance spectrum at the time the target radiance was measured can be estimated.

The technique was first developed using data collected in Colorado and Spain using an Analytical Spectral Devices FieldSpec FR™ spectroradiometer (Milton and Goetz, 1997) This paper presents the results of subsequent field trials using a Spectron SE590™ spectroradiometer fitted with a cosine-corrected receptor under the more challenging atmospheric conditions of southern England. Seven spectral bands were chosen as the input data (425, 500, 780, 820, 830, 881 and 950nm), and 163 output nodes were used, distributed over the range 399-1024nm so that a good reproduction of the complete irradiance spectrum could be achieved. The MLP had a single hidden layer containing 35 neurons and was trained using stochastic back-propagation.

A total of 593 irradiance spectra were collected at a coastal site in southern England on five different occasions between May and June 1999. Of these, 62 were selected to represent the range of variation in the data and these were used to train the network. The network was tested using 114 irradiance spectra collected on three separate occasions during August 1999 at a site approximately 50km distant from that where the training data were collected. The range of irradiance conditions covered by the testing data was less than that used to train the network, but still covered a wide range of sky conditions, ranging from clear skies to heavy cumulus cloud cover.

The seven wavebands extracted from each of the 114 test spectra were presented to the ANN in turn and the predicted spectrum compared with that measured using the SE590 with cosine corrected receptor. The results show excellent agreement between the measured irradiance and that predicted by the ANN. The percentage difference between the recorded value from each waveband and the ANN was generally largest in the regions of the 720nm and 940-950nm absorption features (Fig. 1). Further details of these UK field trials are provided by Milton *et al*. (2000).

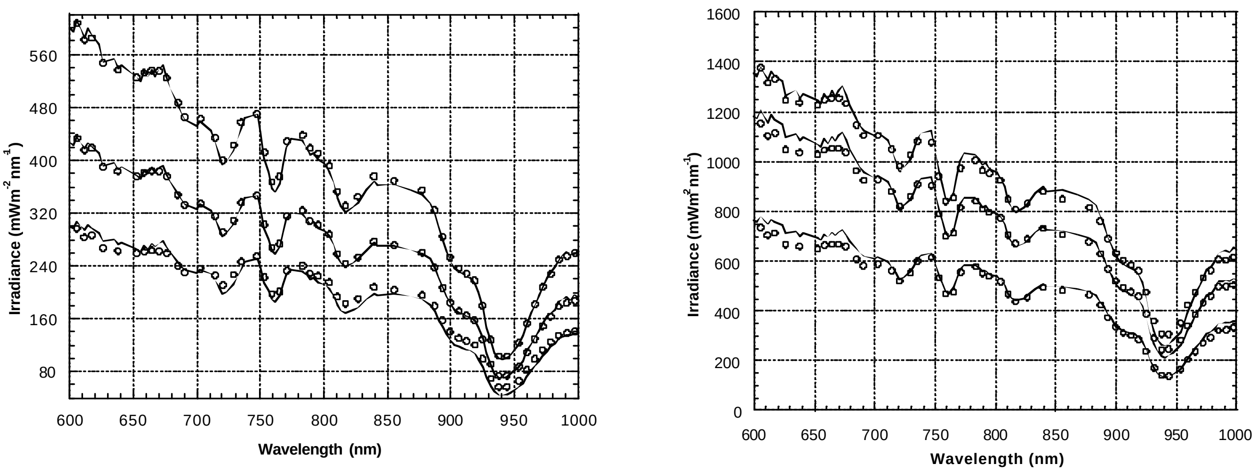

Fig. 1: Example irradiance spectra measured with a spectroradiometer (solid line) compared with the output from the ANN (circles)

3 IMPROVED VISUALIZATION OF THE AREA SAMPLED

The second innovation to be described addresses the need to identify very precisely the area on the ground sampled by the spectroradiometer. Commercial spectroradiometers are surprisingly deficient in this respect. Three approaches are common: first a manually operated reflex mirror may be provided (e.g. GER IRIS MkIV™), second a rifle sight may be offered (e.g. ASD FieldSpec FR) or third, a laser sighting spot may be used (e.g. GER 1500™ and 3700™). The first two approaches assume that the user will be in a location above or behind the spectroradiometer, which is often not the case as the spectroradiometer sensor head may be mounted on a mast or tower so as to elevate it above the surface being measured. The laser spot has the advantage that it illuminates the target but the small red dot is exceptionally difficult to see, especially when projected onto a dense vegetation canopy. None of these approaches provide a permanent record of the area sampled.

The approach we have adopted is a development of an instrument described by Berry *et al*. (1978), comprising a single lens reflex camera and a filter-wheel multiband radiometer. We have supplemented the film-based camera with a co-aligned digital camera, and have replaced the multiband radiometer by a spectroradiometer linked to the focusing screen with a fibre optic lead (Fig. 2).

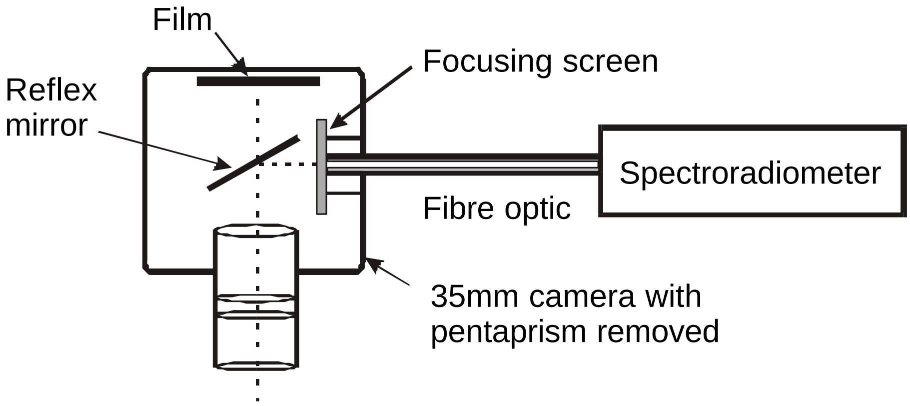

Fig. 2: Schematic diagram of the optical path through the combined SLR camera and spectroradiometer

This means that when the reflex mirror is 'down' the spectroradiometer views the central portion of the image in the camera viewfinder, and when the reflex mirror is 'up' a normal photograph of the scene can be taken by the film-based camera. A digital camera mounted adjacent to the film-based camera and can be triggered at the same instant that the spectroradiometer makes its measurement. Careful registration and calibration of the two cameras and the spectroradiometer allows the area measured to be outlined very precisely on both the photograph and the digital image.

The film-based camera is a conventional 35mm single-lens reflex (SLR) design (Miranda™), notable only in that it has a removable pentaprism and that the 50mm focal length lens has no anti-reflection coating. A mount was constructed to fit onto the focusing screen and provide a secure light-tight attachment for a fibre optic. The whole system has been used successfully with six different field spectroradiometers: Spectron SE590, ASD FSII™, GER1500, GER3700, ASD FieldSpec FR, and ASD FieldSpec Pro™. A digital camera (Kodak DC20™) is set up next to the SLR camera on a stable mount, so that the optical axes of both cameras are parallel to each other and their FOVs are overlapping for object distances of greater than 0.3 metres (see Fig. 3).

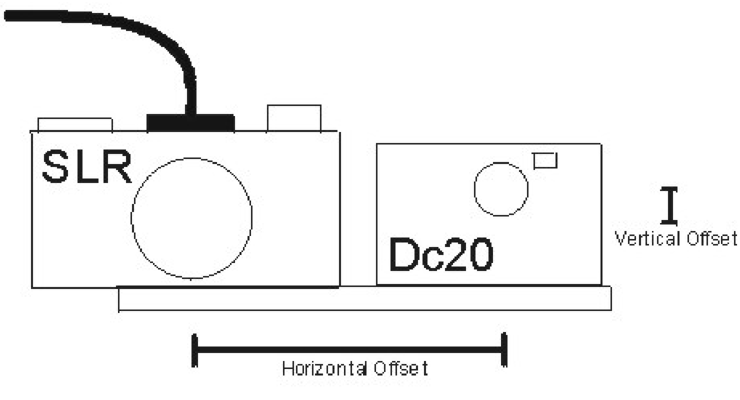

Fig. 3: Offset between the optical axes on the two cameras

When using the digital camera, the horizontal and vertical offset of the two camera lenses had to be taken into account. The distance between the cameras and the photographed object determines the position of the FOV of the spectroradiometer inside the FOV of the digital camera. The FOV of the spectroradiometer was photographed at distances from 0.3 to 1.9m in 20cm intervals and its centre was measured within the digital images. A fourth-order polynomial was fitted to the centre row and column position as a function of distance in order to calibrate the centre position of the FOV and an IDL routine was written to automatically inscribe a circle corresponding to the FOV of the spectroradiometer within the digital image.

4 TESTING THE FIELD-OF-VIEW

The field-of-view (FOV) of the new spectroradiometer is approximated by the FOV of the fibre-optic and this was defined by projecting a strong light source through the fibre and the camera optics onto a flat surface normal to the camera's optical axis. The circular FOV of the fibre was then delineated on a piece of paper fixed to the flat surface. In order to relate the FOV of the fibre to that of the camera, the piece of paper was photographed. The approximated FOV was tested by measuring the radiance from a circle of green leaves over a non-reflecting background. The radius of the circle was reduced successively in diameter until the FOV was completely covered with green leaves. Figure 4 shows the photographs taken with the SLR camera and the corresponding spectra recorded by the GER1500 spectroradiometer. The circle on the photographs depicts the calibrated FOV of the new spectroradiometer.

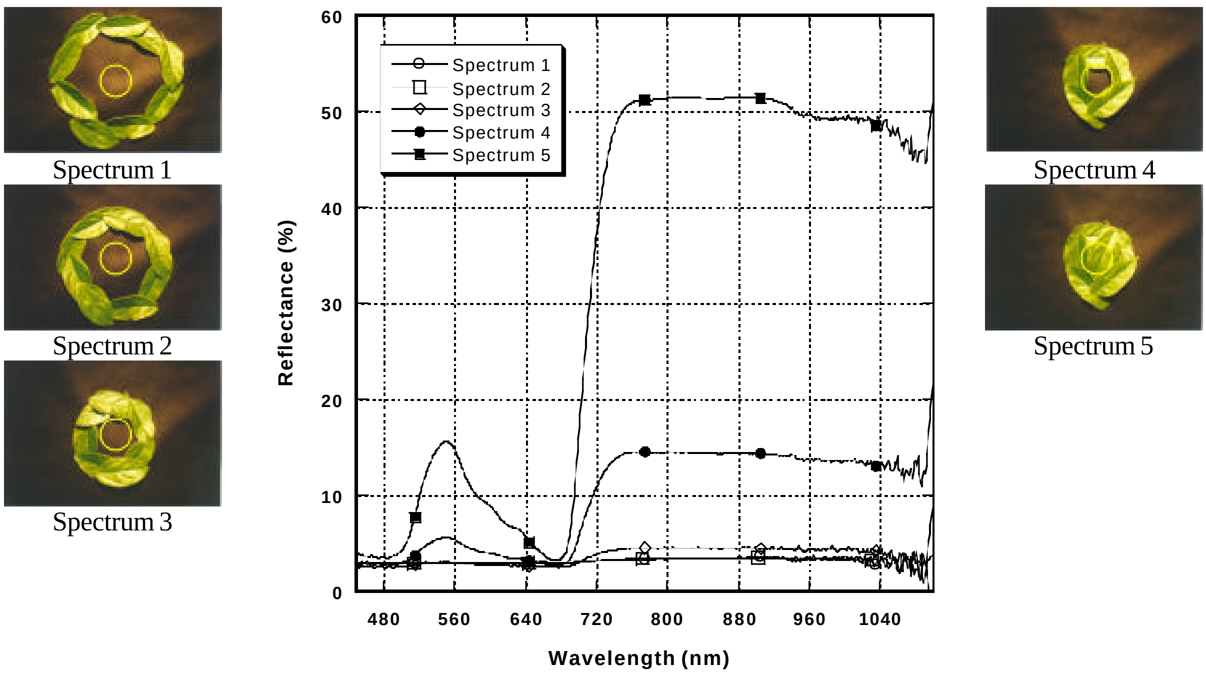

Fig. 4: The arrangement of leaves used in the laboratory to test the field-of-view of the new spectroradiometer

5 LABORATORY TESTS OF THE SCENE-RECORDING SPECTRORADIOMETER

The FOV determination described above was performed using a GER1500 spectroradiometer which is sensitive over the VNIR range. Further laboratory tests were undertaken using an ASD FieldSpec Pro spectroradiometer, which records data over the VNIR and SWIR (350 – 2500nm). Initial experiments focused on determining the reduction in signal-to-noise ratio expected with the new instrument due to the reduced signal level and the unknown transmission characteristics of the lenses in the SLR camera. The noise level of the new spectroradiometer was found to be about twice as high than that of the FieldSpec Pro between 350 and 1800nm. Measurements with the new spectroradiometer beyond 1800nm were unusable due to the poor transmission of the camera lens in the SWIR. The camera optics were found to attenuate the signal (higher standard deviation), but did not significantly change the mean spectrum between 400 and 1800nm.

6 FIELD MEASUREMENTS WITH THE SCENE-RECORDING SPECTRORADIOMETER

Scene variability over very short distances is a major problem when sampling semi-natural vegetation communities and the instrument described is ideal in such circumstances. Although it does not eliminate the need to sample the scene in a rigorous fashion, it provides a precise photographic record to accompany each spectrum. These photographs may be analysed further, either digitally or manually, and can help elucidate the spectral scene components present. In order to test the new instrument in the field it was used in November 2000 to measure a large number of spectra from an area of heathland in the New Forest, southern England. Figure 5 shows a series of digital images from the instrument with the sampling area of the spectroradiometer outlined automatically on each one. The target is a single *Calluna vulgaris* plant, comprising green leaves, brown leaves, shadow, twigs and dead flowers.

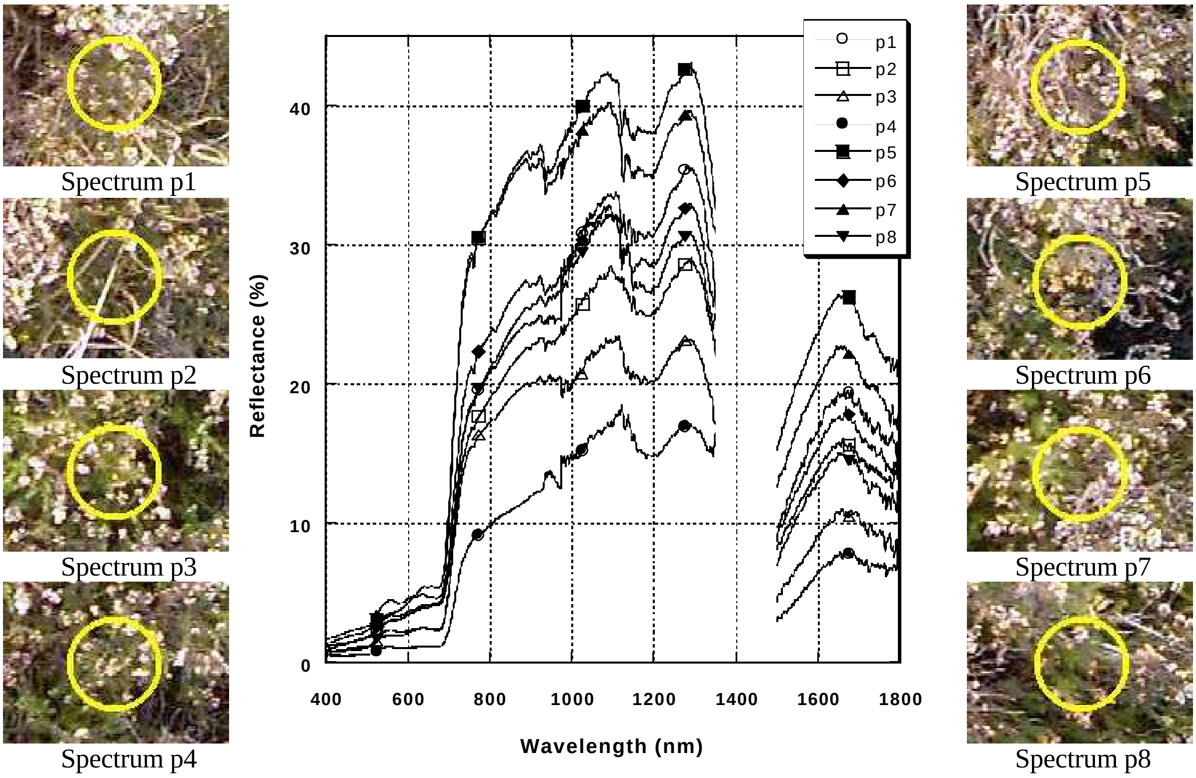

Fig. 5: Field reflectance spectra measured with the new spectroradiometer from different parts of a single *Calluna vulgaris* plant

The bidirectional reflectance of a vegetation canopy is generally assumed to be determined by the proportions of different scene components (sunlit leaves, shaded leaves, sunlit background, shaded background) presented to a sensor. The directional reflectance of individual leaves and the background may be measured, either in the field or the laboratory, but it is very difficult to characterise accurately the spatial assembledge of leaves, shadow and background that form the canopy. Conventional field spectroradiometers integrate the signal from an area of the canopy and provide no precise record of the area sensed, thus physical understanding of the interations and relationships between scene components is made more difficult, and validating canopy models at the scale of individual plants becomes almost impossible.

7 TOWARDS AN INTEGRATED SYSTEM

Following the success of these trials, an integrated version of the two innovations is being developed (Fig. 6). The ANN irradiance sensor is mounted on the top of a portable mast. It comprises a large diameter cosine-corrected receptor, behind which are seven silicon detectors fitted with interference filters to match the wavebands identified above. Data from the detectors are amplified and stored in a 12-bit data logger within the unit. The paired SLR/digital cameras are mounted together at the end of an offset arm, and the spectroradiometer is either housed in a backpack or fixed to the mast.

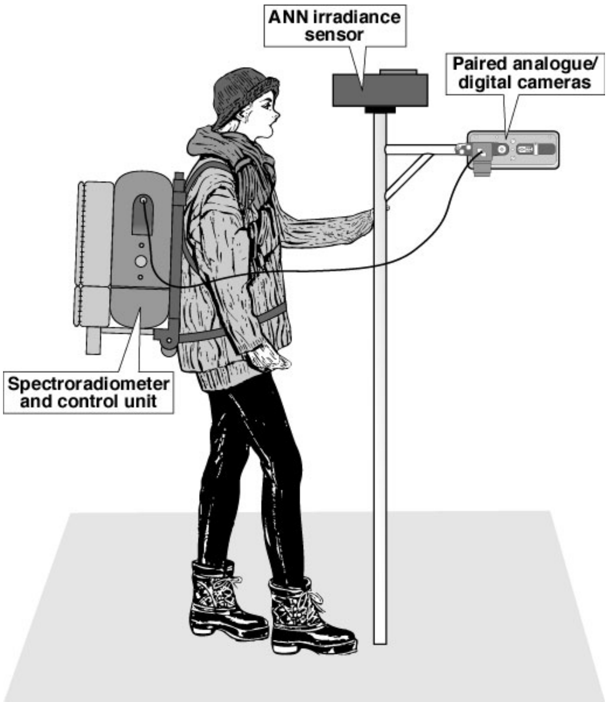

Fig. 6: The synthetic dual-beam Scene-Recording Spectroradiometer

8 CONCLUSION

Commercially-available field spectroradiometers are highly capable in many respects, but those who wish to use such instruments to measure accurate reflectance spectra from spatially heterogeneous targets in the natural environment often face major practical difficulties. The two innovations described in this paper are one approach to making high-performance field spectroradiometers more 'user friendly'. There is still some way to go, not least in reducing the size and complexity of the various components of the 'scene-recording spectroradiometer' described here, but we believe that this research highlights two important aspects of instrument design that have been overlooked in the continued quest for greater functionality, lower noise or finer spectral resolution.

9 ACKNOWLEDGEMENTS

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10 REFERENCES

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