[1]A New Dual Beam Technique for Precise Measurements of Spectral Reflectance in the Field

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Abstract - Field spectral measurements made using the single-beam method often include errors due to variation in illumination between measurement of the target and the reference (panel or cosine-corrected receptor). Although the dual-beam method avoids these errors, it introduces greater complexity due to the need to intercalibrate the two sensor heads used, and it is significantly more expensive. This paper describes an alternative dual-beam method which uses a neural network to estimate the complete irradiance spectrum from measurements made in 7 narrow bands. These narrow band measurements of irradiance may be made with a simple filter-based radiometer, thus avoiding the expense and complexity of a second spectroradiometer. The new technique has been tested using irradiance spectra from both continental and maritime locations.

INTRODUCTION

When making measurements of spectral reflectance in the field it is essential that the interval between the target measurement and that of the reference (panel or cosine-corrected receptor) is kept as short as possible, which is best achieved using two inter-calibrated spectroradiometers operating in dual-beam mode (Duggin and Philipson, 1982). However, this requires excellent inter-calibration between the two spectroradiometers, which is difficult to achieve and maintain under field conditions, and needs a second spectroradiometer, the cost of which is often prohibitive.

The alternative approach of using one spectroradiometer in single-beam mode avoids these problems but it is difficult to achieve the highest precision using this method because of the variability of global irradiance even over very short time scales, especially in a maritime region with a humid atmosphere. Although modern field spectroradiometers measure spectra very rapidly, there is often a significant delay (up to 30 seconds) between measurements of the target and the reference due to the need to optimise the gain of the instrument or to integrate over several analogue-to-digital conversion cycles in order to achieve a high signal-to-noise ratio in all parts of the spectrum.

In this paper it is argued that it is essential to sample the target radiance and the reference irradiance at exactly the same instant in time in order to minimise the unpredictable error introduced by sampling delay. Only in this way can any error from this source be eliminated. The aim of the technique described here is to avoid the use of an expensive second spectroradiometer and use a simple 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 calibrated neural network from which the complete irradiance spectrum at the time the target radiance was measured can be estimated.

PROOF-OF-CONCEPT

The proposed new technique was first tested using data collected in Colorado and Spain using an Analytical Spectral Devices FR spectroradiometer. Seven spectral bands were selected as the input data for a Multi-Layer Perceptron (MLP) network, and 61 output nodes representing the irradiance every 5nm from 700-1000nm were used. The network had a single hidden layer and was trained using stochastic back-propagation. The results were very encouraging as a proof-of-concept (Milton and Goetz, 1997), but were limited by the very clear sky conditions of the data available. It was felt necessary to test the technique under more challenging conditions for field spectrometry, so a second trial was conducted during summer 1999 in southern England.

SECOND FIELD TRIALS

For the UK field trials a Spectron SE590 spectroradiometer fitted with a cosine-corrected receptor was used. Once again, 7 spectral bands were chosen as the input data (425, 500, 780, 820, 830, 881 and 950nm), but this time 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.

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Network training

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 (Fig 1) and these were used to train the network. After training was completed the average unity scaled RMS error between input and output was 0.003. The large number of neurons allowed a small RMS error to be achieved but increased the time necessary to train the network (approximately 3 hours on a Pentium class computer).

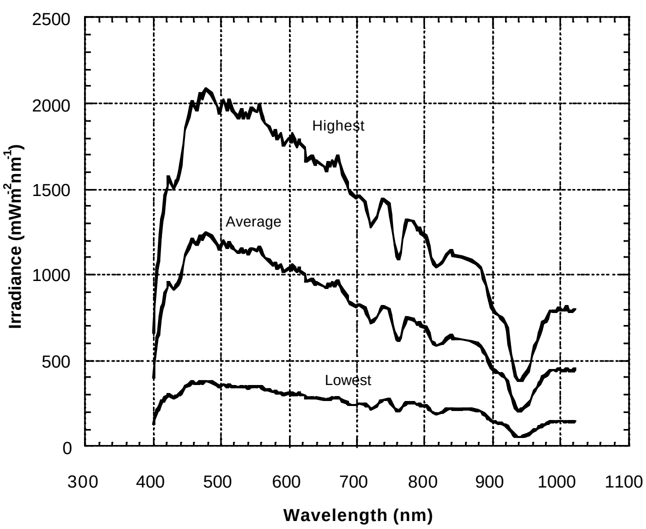

Fig 1. The range of irradiance spectra used to train the network.

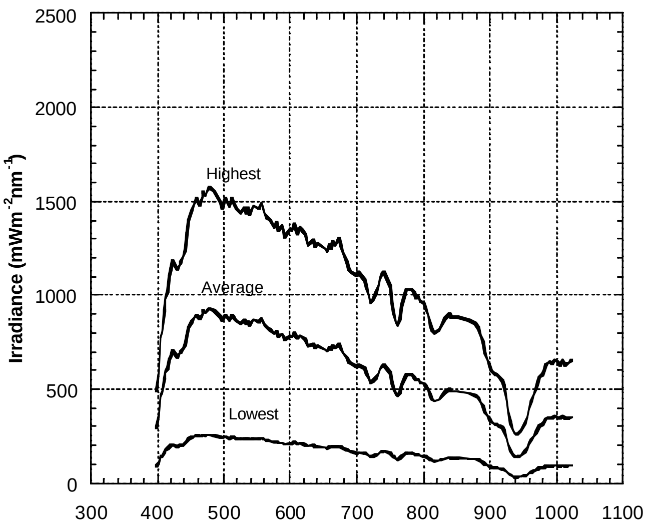

Fig 2. The range of irradiance spectra used to test the network.

Network testing

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 (Fig 2) 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.

RESULTS

The seven wavebands extracted from each of the 114 test spectra were presented to the network in turn and the predicted spectrum compared with that measured using the SE590 with cosine corrected receptor. The results are summarised in Figures 3 - 6. The sampled 163 wavebands accurately reproduced the major features of the spectral irradiance curve.

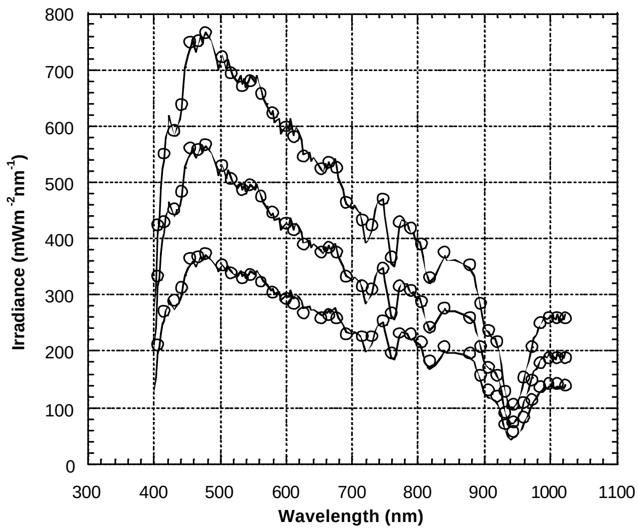

Fig 3. Measured irradiance (solid line) compared with three of the best results from the MLP (circles). Only every 4th MLP value plotted for clarity.

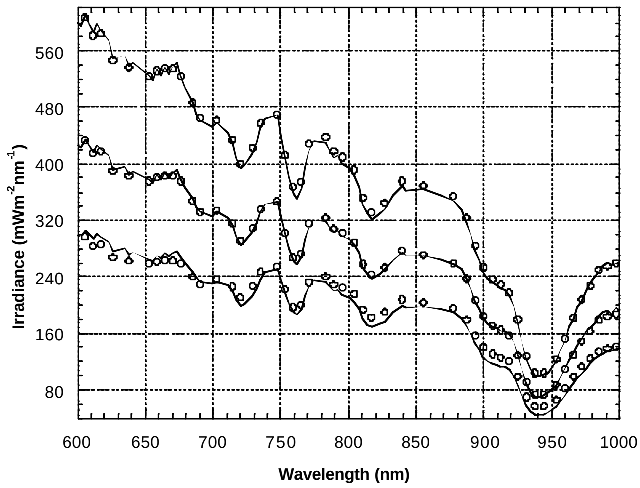

Fig 4. Measured irradiance over the region 600-1000nm (solid line) compared with three of the best results from the MLP (circles). Only every other MLP value plotted for clarity.

In particular detailed reconstruction was maintained of the absorption features at 720nm, 760nm, 820nm and 940nm. The results provided by the neural network compared favourably with the measured complete spectra. The neural network outputs were compared band by band to the recorded readings from their related spectrometer spectra.

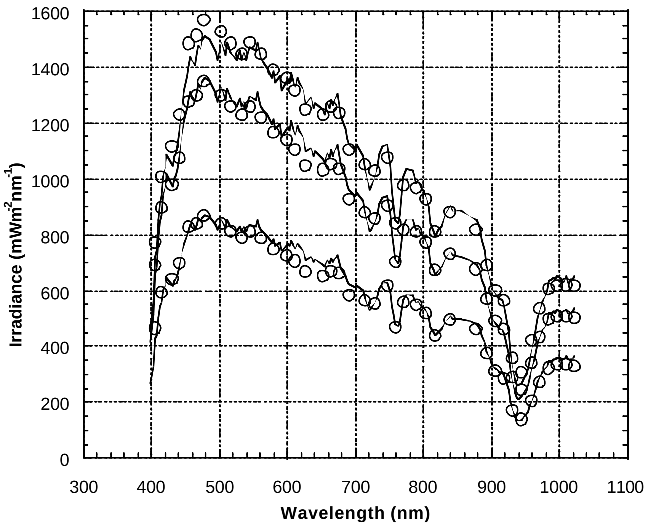

Fig 5. Measured irradiance (solid line) compared with three of the worst results from the MLP (circles). Only every 4th MLP value plotted for clarity.

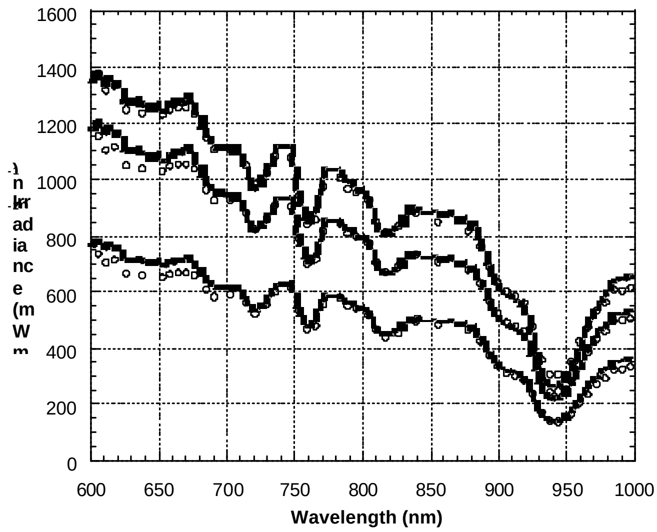

Fig 6. Measured irradiance over the region 600-1000nm (solid line) compared with three of the worst results from the MLP (circles). Only every over MLP value plotted for clarity.

The percentage difference between the recorded value from each waveband and the network output was then calculated. In general the greatest deviation between network output and spectrometer spectra was found in the regions of the 720nm and 940-950nm absorption features, although the exact form of this error varied considerably between individual recordings.

For each of the three testing data sets a band mean average of the difference between the observed and network response was calculated. The data from 11th August displayed the greatest deviation. A maximum mean difference of 9.8% was observed at 941nm with the standard deviation exceeding 10% at this wavelength. Other large mean percentage differences were observed at

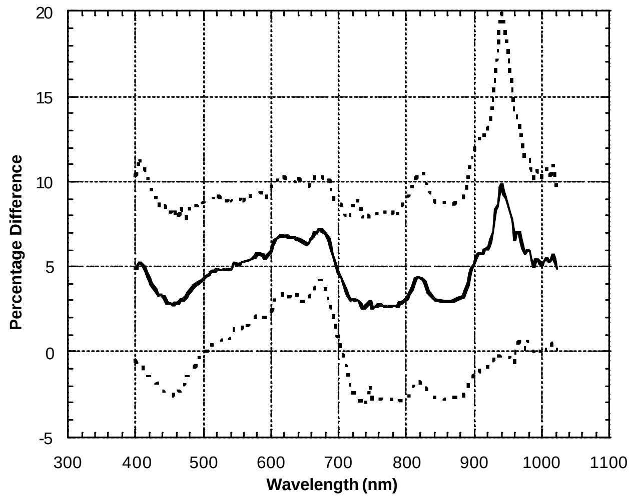

Fig 7. Performance of the neural network when applied to irradiance data collected during the partial solar eclipse on 11th August 1999. Mean percentage difference between measured data and those predicted by the network (solid line) shown together with the one standard deviation envelope (dotted lines).

673nm (7.2%) and 617nm (6.8%). The data collected on 11th August present an unusually challenging task for the neural network to cope with since they were collected during a partial solar eclipse (Sun 98% occluded). The aim of these measurements was to test how well the neural network dealt with an irradiance spectrum comprising skylight with very little direct solar irradiation. Unfortunately the sky conditions were cloudy at the time and the results from the neural network on this date are inconclusive.

The data from the other dates provided lower mean differences and significantly reduced standard deviations. The data from 12th August (Fig 8) shows just one area of large difference measuring 9.3% at 938nm and was probably caused by problems in reproducing the adjacent water absorption feature. The data from the 19th August (Fig 9) show differences between observed and network created spectra at 938nm (10.4%) and 676nm (6.1%). On both these days the predicted spectra had very low standard deviations (less than 4%), indicating that the network was performing consistently.

CONCLUSION

The irradiance spectra measured immediately prior to and after the partial solar eclipse were the most difficult to recreate. If these data are ignored then all of the remaining irradiance spectra were estimated within a maximum single band error (+/- 1 s.d.) of 13.4%, and for most wavelengths the error was much less than this. The ability of the neural network to accurately reconstruct complex irradiance spectra from seven carefully selected wavebands shows how few instrinsic dimensions irradiance spectra have and indicates the possibility that such a technique could be applied as a practical alternative to use of second inter-calibrated spectroradiometer. Despite the neural network being trained using spectra being collected a number of weeks prior to the test data, it has been shown that accurate reproduction of irradiance spectra remains achievable. The significant distance between the two locations has further displayed the robustness of a comprehensively trained network. The time taken to train the network was several hours, but this was a one-off procedure, since once established the weightings remained relevant so long as the sensor configuration was kept unchanged.

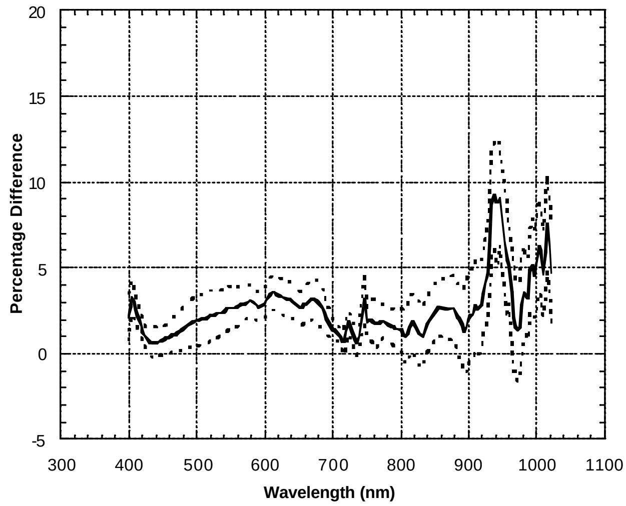

Fig 8. Performance of the neural network when applied to irradiance data collected on 12th August 1999. Mean percentage difference between measured data and those predicted by the network (solid line) shown together with the one standard deviation envelope (dotted lines).

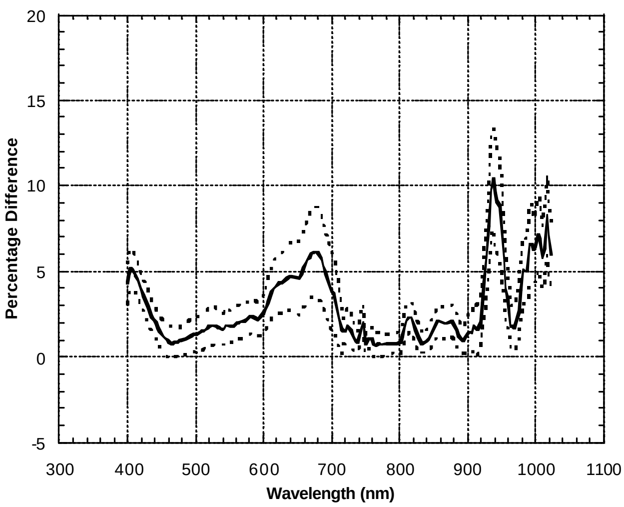

Fig 9. Performance of the neural network when applied to irradiance data collected on 19th August 1999. Mean percentage difference between measured data and those predicted by the network (solid line) shown together with the one standard deviation envelope (dotted lines).

The methods described during this study were applied to a single sensor, that is to say selected wavebands from the field spectroradiometer were used to mimic those provided by a multiband device. Future work is proposed to test this method through the application of a separate multiband device to work alongside the field spectrometer.

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