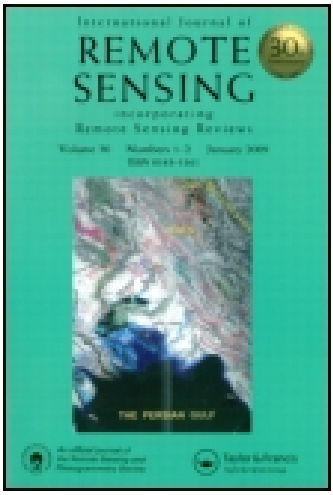
This article was downloaded by: [Erciyes University]
On: 22 December 2014, At: 17:31
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



International Journal of Remote Sensing

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tres20

Technical note A new technique for interpolating the reflectance red edge position

T. P. Dawson & P. J. Curran

Published online: 25 Nov 2010.

To cite this article: T. P. Dawson & P. J. Curran (1998) Technical note A new technique for interpolating the reflectance red edge position, International Journal of Remote Sensing, 19:11, 2133-2139, DOI: 10.1080/014311698214910

To link to this article: http://dx.doi.org/10.1080/014311698214910

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any

form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

Downloaded by [Erciyes University] at 17:31 22 December 2014

INT. J. REMOTE SENSING, 1998, VOL. 19, NO. 11, 2133–2139

Technical note

A new technique for interpolating the reflectance red edge position

T. P. DAWSON

Environmental Change Unit, University of Oxford, 5 South Parks Road, Oxford, OX1 3UB, England, UK

P. J. CURRAN

Department of Geography, University of Southampton, Highfield, Southampton, SO17 1BJ, England, UK

(*Received 17 July 1997; in final form 10 December 1997*)

Abstract. The point of maximum slope on the reflectance spectrum of vegetation between red and near-infrared wavelengths, termed the red edge position (REP), is correlated strongly with foliar chlorophyll content and provides a very sensitive indicator of, among other things, vegetation stress. The high spectral resolution of airborne imaging spectrometers now offers the potential for determining the REP of vegetation canopies at regional scales. However, the accurate estimation of the REP is dependent upon sensor band positions and widths. Various techniques have been developed to minimize the error in estimating the REP, such as linear interpolation or inverted Gaussian curve fitting in the region of the red edge which requires an *a priori* knowledge of the spectrum under investigation. This technical note presents a simple technique known as Lagrangian interpolation which is applied to the first-derivative transformation of the reflectance spectrum. The technique fits a second-order polynomial curve to three bands, which need not be equally spaced, centred around the maximum slope position. A second derivative is then performed on the Lagrangian equation to determine the maximum slope position.

Downloaded by [Erciyes University] at 17:31 22 December 2014

1. Introduction

The 'red edge' is the name given to the abrupt reflectance change in the 680–740 nm region of vegetation spectra that is caused by the combined effects of strong chlorophyll absorption and leaf internal scattering. Increases in the amount of chlorophyll visible to the sensor, either through an increase in leaf chlorophyll content, or Leaf Area Index (LAI), result in a broadening of a major chlorophyll absorption feature centred around 680 nm. The effect is to cause a movement of the point of maximum slope, termed the red edge position (REP). The position of the red edge has been used as an indicator of stress and senescence of vegetation (Collins 1978, Horler *et al.* 1983, Rock *et al.* 1988, Boochs *et al.* 1990, Jago and Curran 1995).

Three techniques have been used to locate the REP. First, linear interpolation assumes the reflectance red edge can be simplified to a straight line centred around a midpoint between the *shoulder* reflectance maximum, R_s, usually at about 780 nm and the reflectance minimum, R_0, of the chlorophyll absorption feature usually at about 670 nm. The REP is then estimated by a simple linear equation using the slope of the line (Guyot *et al.* 1992, Danson and Plummer 1995). Second, the inverted

0143–1161/98 $12.00 © 1998 Taylor & Francis Ltd

Gaussian technique (Bonham-Carter 1988, Miller *et al.* 1990) employs a least-squares procedure to fit a normal curve to the reflectance red edge (Lucas *et al.* 1995, Cutler and Curran 1996). The estimated REP is then the midpoint of the ascending edge of the normal curve. Whilst the red edge of a vegetation canopy spectra is primarily a function of leaf optical properties, it is also convoluted by shadow and soil or understorey spectra which may affect the REP. These effects, coupled with the need to pre-determine two or more *anchor* points, such as R_s and R_0, weaken the argument for using the linear and inverted Gaussian curve fitting techniques. A third technique locates the REP as the maximum first derivative of the reflectance spectrum in the region of the red edge using a range of high-order curve fitting techniques (cubic spline and high-order polynomial) to fit a continuous function to the derivative spectrum (Savitsky and Golay 1964, Horler *et al.* 1983, Demetriades-Shah *et al.* 1990, Railyan and Korobov 1993, Chen and Elvidge 1993). The use of derivative spectrometry is commonly employed to resolve or enhance absorption features that might be masked by interfering background absorption (Curran *et al.* 1990, Filella and Peñuelas 1994). Spectral derivatives also aid in suppressing the continuum caused by other leaf biochemicals (such as lignin and secondary pigments) and canopy background effects (Elvidge 1990, Curran *et al.* 1991). However, the existing curve fitting techniques are quite complex and, together with the Gaussian method, computationally demanding. A summary of the attributes of the three methods is presented in table 1.

The method of calculating the first derivative is reviewed here as it forms part of the technique to estimate the REP proposed in this technical note. A first-difference transformation of the reflectance spectrum calculates the slope values from the reflectance and can be derived from:

$$D_{\lambda(i)} = (R_{\lambda(j+1)} - R_{\lambda(j)})/\Delta\lambda \quad (1)$$

where $D_{\lambda(i)}$ is the first-difference transformation at a wavelength i midpoint between wavebands j and $j+1$. $R_{\lambda(j)}$ is the reflectance at the j waveband, $R_{\lambda(j+1)}$ is the reflectance at the $j+1$ waveband and $\Delta\lambda$ is the difference in wavelengths between j and $j+1$. Although the first derivative transformation will highlight the maximum slope position, the accuracy of the REP is limited to the continuity and spectral resolution of the reflectance spectrum. For example, the Airborne Visible/Infra Red Imaging Spectrometer (AVIRIS) provides continuous spectra with a 10 nm channel separation and the Medium Resolution Imaging Spectrometer (MERIS), proposed for launch on board Envisat in 1999, will have five discontinuous spectral bands (located at 665 nm, 681·25 nm, 705 nm, 753·75 nm and 760 nm) with bandwidths of

Table 1. A summary of the advantages and attributes of four interpolation techniques for determining the red edge position.

Technique	Application to reflectance or derivative spectra	Complexity	Suitability for canopy spectra	Suitability for discontinuous spectra
Linear	Reflectance	Low	No	No
Gaussian	Reflectance	High	No	Yes
High-order curve fitting techniques	Derivative	High	Yes	Yes
Lagrangian	Derivative	Low	Yes	Yes

Downloaded by [Erciyes University] at 17:31 22 December 2014

2·5 nm (1), 7·5 nm (2) and 10 nm (2) in the region of the red edge (Perry 1995). The subtle shifts of the REP may not be detected by either sensor because the underlying spectrum is sampled at a limited number of points. Differentiation of the reflectance spectra will reduce the signal-to-noise ratio (SNR) and some form of smoothing prior to the derivative analysis may be required. The optimum differentiating interval necessitates a compromise between noise levels in the data and bandwidth of the signal (Demetriades-Shah *et al.* 1990). A technique for locating the REP accurately in spectra that have been sampled coarsely is presented here. The technique is based upon the three-point Lagrangian interpolation technique (Jeffrey 1985). The technique uses a second-order polynomial fitting procedure which is applied directly to the first-order derivative spectrum.

Downloaded by [Erciyes University] at 17:31 22 December 2014

2. Lagrangian technique

The value of the first derivative of the reflectance red edge at any wavelength λ will be D_λ. The Lagrangian interpolation technique for three known bands is given by

$$D_\lambda = \frac{(\lambda-\lambda_i)(\lambda-\lambda_{i+1})}{(\lambda_{i-1}-\lambda_i)(\lambda_{i-1}-\lambda_{i+1})}D_{\lambda(i-1)} + \frac{(\lambda-\lambda_{i-1})(\lambda-\lambda_{i+1})}{(\lambda_i-\lambda_{i-1})(\lambda_i-\lambda_{i+1})}D_{\lambda(i)} + \frac{(\lambda-\lambda_{i-1})(\lambda-\lambda_i)}{(\lambda_{i+1}-\lambda_{i-1})(\lambda_{i+1}-\lambda_i)}D_{\lambda(i+1)} \quad (2)$$

In this case, the band having the maximum first derivative will be λ_i with λ_{i-1} and λ_{i+1} representing the two bands on either side of the maximum derivative. $D_{\lambda(i)}$, $D_{\lambda(i-1)}$ and $D_{\lambda(i+1)}$ will be the first-derivative values. Approximate values of D_λ can then be determined for any theoretical band position (figure 1). To determine the wavelength of the position of maximum slope, we perform a second derivation on equation (2) and resolve for when the second derivative is zero, i.e.

$$\mathrm{REP} = \frac{A(\lambda_i+\lambda_{i+1}) + B(\lambda_{i-1}+\lambda_{i+1}) + C(\lambda_{i-1}+\lambda_i)}{2(A+B+C)} \quad (3)$$

where

$$A = \frac{D_{\lambda(i-1)}}{(\lambda_{i-1}-\lambda_i)(\lambda_{i-1}-\lambda_{i+1})},\ B = \frac{D_{\lambda(i)}}{(\lambda_i-\lambda_{i-1})(\lambda_i-\lambda_{i+1})}, \text{ and}$$

$$\mathrm{C} = \frac{\mathrm{D}_{\lambda(i+1)}}{(\lambda_{i+1}-\lambda_{i-1})(\lambda_{i+1}-\lambda_i)} \quad (4)$$

The Lagrangian technique has the property of forcing the interpolating curve through the given points and so takes into account the curvature of the function. It is also useful because the three band positions λ_i, λ_{i-1} and λ_{i+1} need not be equally spaced. In addition, by applying it as a final procedure to the first-derivative spectrum, we can also ensure that the error due to the interpolation is minimized.

3. Comparison of the Lagrangian technique with the linear and inverted Gaussian methods

Unlike other more advanced methods of interpolation, there is no error estimate available for the Lagrangian interpolation technique but the emphasis here is on the location of the REP rather than the theoretical value of the first derivative.

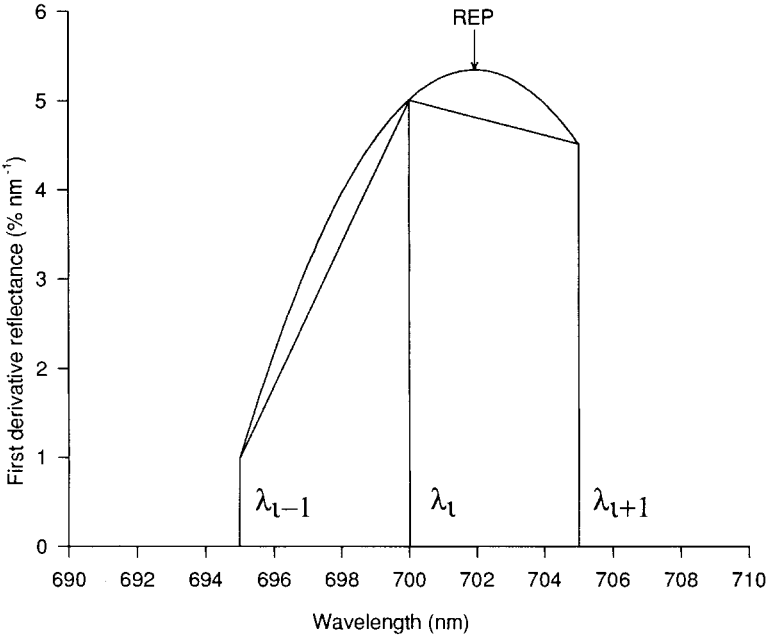


Figure 1. The three-point Lagrangian interpolation technique to determine the red edge position.

Downloaded by [Erciyes University] at 17:31 22 December 2014

The three-point Lagrangian technique, representing one of the simplest of the derivative-based curve fitting techniques, was compared to the linear method and an inverted Gaussian fitting procedure using model-generated pure leaf spectra. The comparison study was not to highlight differences between the techniques but rather to establish their similarity in detecting the subtle movement in the REP as a consequence of variation in leaf chlorophyll content.

The linear method, as interpreted by Clevers (1994), uses four wavebands and the REP is determined using the following equations:

$$R_{\text{red edge}} = (R_{670} + R_{780})/2 \tag{5}$$

$$\text{REP} = 700 + 40\left[\frac{R_{\text{red edge}} - R_{700}}{R_{740} - R_{700}}\right] \tag{6}$$

The inverted Gaussian method used a nonlinear iterative solution which applies a least-squares fitting of the reflectance spectrum in the 670–800 nm wavelengths to the following equation (Bonham-Carter 1988):

$$R_\lambda = R_s - (R_s - R_0)\exp - \left[\frac{(\lambda - \lambda_0)^2}{2k^2}\right] \tag{7}$$

where k is the Gaussian shape parameter, measured in nanometres, such that $\text{REP} = \lambda_0 + k$. By setting λ_0 to 670 nm, the values of R_0, R_s and k were variable, determined by the fitting procedure.

The LIBERTY leaf model (Dawson *et al.* 1998) was used to simulate leaf reflectance spectra corresponding to a theoretical leaf chlorophyll content (per unit leaf area) of between 50–550 mg m^{-2}. A reflectance spectrum was produced for each

level of chlorophyll. The REP was then determined using each of the three methods (figure 2).

Although the linear method has the advantage of rapidity, it overestimates the REP by approximately 10 nm when compared to the other two methods. However, for both the linear and Lagrangian techniques, a similar logarithmic relationship between chlorophyll concentration and REP was observed, whilst a quadratic model best fits the data generated by the inverse Gaussian method. The coefficient of determination R^2 was greater than 0·99 for all three methods.

The Lagrangian interpolation equation can be generalized to fit a higher-order polynomial curve using four or more wavebands, in common with other high-order curve fitting techniques, but this study has demonstrated that the three-waveband equation is adequate for accurately locating the REP for a wide range of foliar chlorophyll contents.

Downloaded by [Erciyes University] at 17:31 22 December 2014

4. Conclusion

A fast technique for locating the position of the red edge has been presented, based upon Lagrangian interpolation. The technique, using three wavebands centred around the maximum first derivative of a vegetation reflectance red edge, fits a parabola through the first-derivative values. A second derivative is then performed upon the Lagrangian equation to determine the REP at the local maximum. It assumes no *a priori* knowledge of the spectrum and its simplicity, coupled with the flexibility that results from the fact that the wavebands need not be equally spaced, makes it very useful for observing red edge shifts using the latest generation of airborne and spaceborne imaging spectrometers.

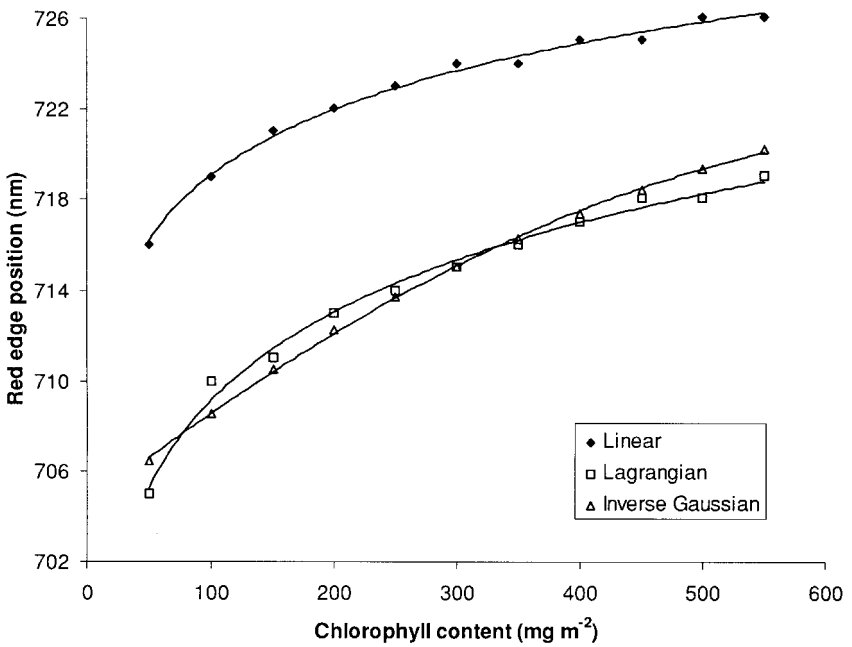


Figure 2. The relationship between chlorophyll content and red edge position for three interpolation methods.

Acknowledgments

This research was funded by the Natural Environment Research Council (GT4/94/407/L to TPD) and the British National Space Centre. The authors are indebted to Ted Milton, Rosemary Jago and Mark Cutler (University of Southampton) for their assistance and advice, and to the anonymous referees for their helpful comments.

References

Bonham-Carter, G. F., 1988, Numerical procedures and computer program for fitting an inverted Gaussian model to vegetation reflectance data. *Computers and Geosciences*, **14,** 339–356.

Boochs, F. Kupfer, G., Dockter, K., and Kuhbauch, W., 1990, Shape of the red edge as vitality indicator for plants. *International Journal of Remote Sensing*, **11,** 1741–1753.

Chen, Z., and Elvidge, C. D., 1993, Description of derivative-based high spectral-resolution (AVIRIS) green vegetation index. *Proceedings of the SPIE: Imaging Spectrometry of the Terrestrial Environment*, **1937,** 43–54.

Clevers, J. G. P. W., 1994, Imaging spectrometry in agriculture—plant vitality and yield indicators. In *Imaging Spectrometry—A Tool for Environmental Observations*, edited by J. Hill and J. Mégier (Dordrecht: Kluwer Academic), pp. 193–219.

Collins, W., 1978, Remote sensing of crop type and maturity. *Photogrammetric Engineering and Remote Sensing*, **44,** 43–55.

Curran, P. J., Dungan, J. L., and Gholz, H. L., 1990, Exploring the relationship between reflectance red edge and chlorophyll content in slash pine. *Tree Physiology*, **7,** 33–48.

Curran, P. J., Dungan, J. L., Macler, B. A., and Plummer, S. E., 1991, The effect of a red leaf pigment on the relationship between red edge and chlorophyll concentration. *Remote Sensing of Environment*, **35,** 69–76.

Cutler, M. E. J., and Curran, P. J., 1996, An observation of shifts in the position of the red edge at different spatial resolutions. *RSS96: Remote Sensing Science and Industry* (Nottingham: Remote Sensing Society), pp. 290–297.

Danson, F. M., and Plummer, S. E., 1995, Red edge response to forest leaf area index. *International Journal of Remote Sensing*, **16,** 183–188.

Dawson, T. P., Curran, P. J., and Plummer, S. E., 1998, LIBERTY—modelling the effects of leaf biochemistry on reflectance spectra. *Remote Sensing of Environment*, **65,** 50–60.

Demetriades-Shah, T. H., Steven, M. D., and Clark, J. A., 1990, High resolution derivative spectra in remote sensing. *Remote Sensing of Environment*, **33,** 55–64.

Elvidge, C. D., 1990, Visible and near infrared reflectance characteristics of dry plant materials. *International Journal of Remote Sensing*, **11,** 1775–1795.

Filella, I., and Peñuelas, J., 1994, The red edge position and shape as indicators of plant chlorophyll content, biomass and hydric status. *International Journal of Remote Sensing*, **15,** 1459–1470.

Guyot, G., Baret, F., and Jacquemoud, S., 1992, Imaging spectroscopy for vegetation studies. In *Imaging Spectrometry: Fundamentals and Prospective Applications*, edited by F. Toselli and J. Bodechtel (Dordrecht: Kluwer Academic), pp. 145–165.

Horler, D. N. H., Dockray, M., and Barber, J., 1983, The red edge of plant leaf reflectance. *International Journal of Remote Sensing*, **4,** 273–288.

Jago, R. A., and Curran, P. J., 1995, The effect of land contamination on the relationship between the red edge and chlorophyll concentration of a grassland canopy. *RSS95: Remote Sensing in Action* (Nottingham: Remote Sensing Society), pp. 442–449.

Jeffrey, A., 1985, *Mathematics for Engineers and Scientists* (Wokingham, UK: Van Nostrand Reinhold), pp. 708–709.

Lucas, N. S., Plummer, S. E., Danson, F. M., and Curran, P. J., 1995, Coupling a forest ecosystem model with remotely sensed data. *Proceedings 'MAC Europe 91' Workshop*, ESA WPP-88 (Paris: European Space Agency), pp. 187–193.

Miller, J. R., Hare, E. W., and Wu, J., 1990, Quantitative characterisation of the vegetation red edge reflectance I. An inverted-Gaussian reflectance model. *International Journal of Remote Sensing*, **11,** 1755–1773.

Perry, M. (editor), 1995, *The Medium Resolution Imaging Spectrometer: Report of the MERIS*

Downloaded by [Erciyes University] at 17:31 22 December 2014

Scientific Advisory Group, March 1995, ESA SP-1184 (Noordwijk: European Space Agency), pp. 1–62.

RAILYAN, V. Y., and KOROBOV, R. M., 1993, Red edge structure of canopy reflectance spectra of *triticale*. *Remote Sensing of Environment*, **46,** 173–182.

ROCK, B. N., HOSHIZAKI, T., and MILLER, J. R., 1988, Comparison of *in situ* and airborne spectral measurements of the blue shift associated with forest decline. *Remote Sensing of Environment*, **24,** 109–127.

SAVITSKY, A., and GOLAY, M. J. E., 1964, Smoothing and differentiation of data by simplified least squares procedures. *Analytical Chemistry*, **36,** 1627.

Downloaded by [Erciyes University] at 17:31 22 December 2014