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Bathymetry calculations with Landsat 4 TM imagery under a generalized ratio assumption

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Remotely sensed bathymetry from multispectral imagery generally is based on a simple reflectance model[1]; the radiance in wavelength band i at water depth Z is given by the equation

$$L_i = L_{i\infty} + c_i \cdot R_{ai} \cdot \exp(-2k_i \cdot Z),$$

where L_i is the radiance value in band i, $L_{i\infty}$ is the average signal over deep water, c_i is a constant that is a function of several optical parameters, R_{ai} is the bottom reflectance in band i over bottom type a, and k_i is the diffuse attenuation coefficient.

Solving for Z, one obtains the formula

$$Z = LN(c_i \cdot R_{ai})/2k_i - X_i/2k_i,$$

where we have adopted the convention that $X_i = LN(L_i - L_{i\infty})$. This single-band reflectance model assumes that the bottom reflectance is constant over the bottom type, that the atmosphere and the sea state are uniform, and that other background optical effects are either uniform or constant throughout the image.

To reduce errors due to the variation of the bottom reflectances, a two-band ratio method (or dual-band method) was devised.[2,3] In this algorithm, the depth is given by the equation

$$Z = [{}^1\!/_2 \cdot (k_1 - k_2)] \cdot [LN(c_1 \cdot R_{a1}/c_2 \cdot R_{a2}) + X_1 - X_2],$$

where the subscripts 1 and 2 indicate different bands. In this method, the assumption is that changes in the bottom reflectances occur so that the ratio $c_1 \cdot R_{a1}/c_2 \cdot R_{a2}$ remains constant.

Another method, which we call the linear multiband method, gives the depth by

$$Z = \Sigma\omega_i \cdot ({}^1\!/_2 k_i) \cdot [LN(c_i \cdot R_{ai}) - X_i],$$

where the sum is taken over several bands and the weights ω_i satisfy the constraint that $\Sigma\omega_i = 1$. Paredes and Spero,[4] generalizing the assumption that the ratio $c_1 \cdot R_{a1}/c_2 \cdot R_{a2}$ remains constant, assume there are constants ζ_i and α, independent of bottom type a, so that

$$(c_1 \cdot R_{a1})\zeta_1 \cdot (c_2 \cdot R_{a2})\zeta_2 \cdot (c_3 \cdot R_{a3})\zeta_3 \ldots = \alpha.$$

With this assumption, they show that certain weights ω_i can be found so that, when used in the above multiband linear depth equation, produce an equation for Z independent of the bottom reflectance and depend only on the values ζ_i:

$$Z = ({}^1\!/_2 \cdot \Sigma\zeta_i \cdot k_i) \cdot (1 - \zeta_1 \cdot X_1 - \zeta_2 \cdot X_2 \ldots).$$

Alternatively, this equation may be written

$$Z = A_0 + A_1 \cdot X_1 + A_2 \cdot X_2 + \ldots + A_n \cdot X_n$$

where the coefficients $A_0, A_1, \ldots, A_n$ are constants independent of the bottom type at which the depth is being calculated (see Ref. 4 for more details).

It has been suggested that when the assumption underlying the two-band ratio method is not satisfied, the linear multiband algorithm may be more accurate given more bands than bottom classes. This method has been applied to two channels of multispectral data using an airborne sensor.[5] In this paper we use the linear multiband algorithm on two channels of a Landsat 4 TM scene and demonstrate its improved performance over the two-band ratio method.

The Landsat scene (scene 5032614162 taken 21 Jan. 1985) contains Isla de Vieques, an island off the southeast coast of Puerto Rico in the Carribean Sea. The water clarity in this area is extremely good, and bottom reflectances in the blue and green channels (TM bands one and two) are detectable for depths up to 25 m. Bottom reflectances in the red channel (TM band three) are detectable for depths up to ~6

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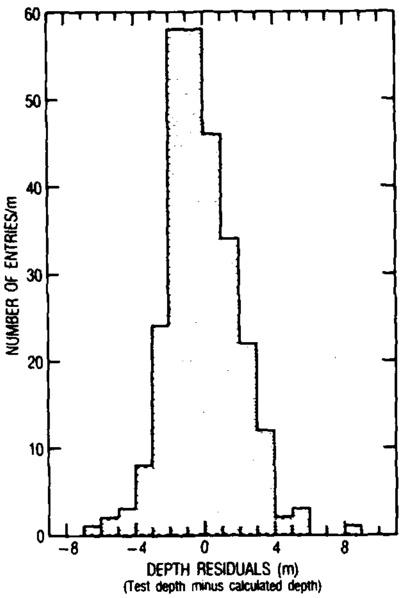

Fig. 1. Depth residuals resulting from the linear multiband model. The residuals were calculated using the second set of calibration points which were not used in the original regression. A Gaussian distribution fit to this histogram yielded a mean of −0.13 m and a σ = 1.86 m.

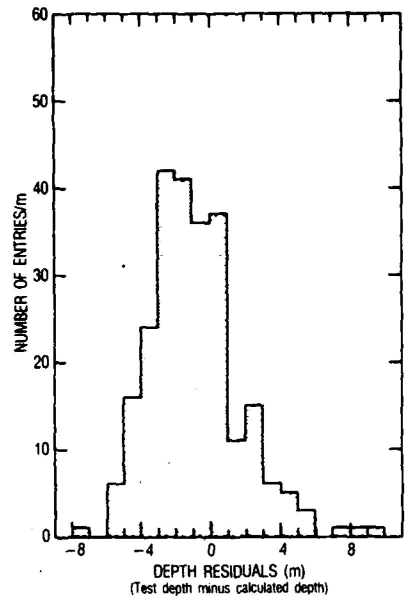

Fig. 2. Depth residuals resulting from the two-band ratio algorithm calculated using the second set of calibration points. The residual mean is 0.093 m, and the rms is 2.66 m.

m; sensor noise (striping) over the water renders this band useless at deeper depths.

The general procedure for this comparison was to first convert a NASA/GSFC CCT to an image data file and to georeference this data file against a Defense Mapping Agency 1:25000 combat chart. This combat chart contains not only bathymetric soundings but also land feature identifications that aid in the georeferencing process. A set of ~600 calibration points was then selected by recording depths from the chart; about 300 of the points were used in our regression fit, and the remaining 300 used as a test set to check the calculated depth against the actual depth.

The average deep water signal for each water penetrating band (in this case channels 1 and 2, roughly corresponding to the blue-green and green portions of the visible spectrum, respectively) was calculated to obtain the $L_{i\infty}$ values. These values are subtracted from the corresponding L_i value to adjust the signal values for atmospheric scattering etc.

A linear regression of the model equation against the (appropriate) calibration points is run, which produces coefficients and hence equations for the depth Z at any pixel. The test set of calibration points is used to test the fit of this regression. These equations are then used to produce a bathymetric image that can be processed further (smoothed, contoured, pseudocolored, etc.) depending on the desired application.

The linear regression was run on the equation

$$Z = A_0 + A_1X_1 + A_2X_2$$

corresponding to a two-channel multiband linear model. The regression yielded the following values for the constants: $A_0 = 11.2$; $A_1 = 3.14$; $A_2 = -6.76$. The multiple correlation coefficient was 0.86 for this fit.

Using the test set of calibration point data, the model yielded an overall residual mean of <0.2 m and an overall rms of <1.9 m. These residuals are shown in a histogram in Fig. 1. In the depth range of 0–5 m, the rms error was 0.88 m; in the 5–10-m range, the rms error was 1.25 m; and in the 10–16-m range, the rms error was 1.00 m.

For comparison purposes, the dual-band ratio method was applied as well. To minimize error, the image was clustered to locate areas of similar bottom reflectance using a supervised statistical clustering routine and the maximum likelihood classifier. The algorithm was then regressed against calibration points in each cluster separately. An overall residual mean of 0.093 m and an rms error of 2.66 m was obtained. A histogram of the residuals is shown in Fig. 2. In the depth range of 0–5 m, the rms error was 0.95 m; in the 5–10-m range, the rms error was 1.23 m; and in the 10–16-m range, the rms error was 1.79 m.

In comparing the two methods, both algorithms underestimated the depth in shallow water and overestimated in deeper water. This tendency produces a larger overall error than is obtained when considering the indicated depth ranges. It can be seen that the linear multiband method yields somewhat improved results, even when only two bands are available. Moreover, this method does not require the clustering and classification routines to discriminate areas of similar bottom reflectance, and a considerable savings in CPU processing time (one to several hours on a VAX 11/780 per 512- × 512-pixel image) is realized.

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References

1. N. G. Jerlov, *Optical Oceanography* (Elsevier, New York, 1976).
2. F. C. Polcyn, W. L. Brown, and I. J. Sattinger, "The Measurement of Water Depth by Remote Sensing Techniques," Report 8973-26-F, Willow Run Laboratories, U. Michigan, Ann Arbor (1970).
3. D. R. Lyzenga, "Passive Remote Sensing Techniques for Mapping Water Depth and Bottom Features," Appl. Opt. 17, 379 (1978).

4. J. M. Paredes and R. E. Spero, "Water Depth Mapping from Passive Remote Sensing Data under a Generalized Ratio Assumption," Appl. Opt. **22**, 1134 (1983).
5. D. R. Lyzenga, "Shallow-Water Bathymetry Using Combined Lidar and Passive Multispectral Scanner Data," Int. J. Remote Sensing **6**, 115 (1985).

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