Two-Dimensional Seam-Point Searching in Digital Image Mosaicking

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ABSTRACT: Elimination of artificial edges in image mosaics is of importance for image interpretation and further processing. In this article, a two-dimensional seam-point searching algorithm is suggested where the grey-level difference in the vertical direction as well as in the horizontal direction is controlled. An algorithm for mosaics of multispectral images is also introduced. Experiments show that, with the method suggested, the artificial edges in the mosaics can be smoothed significantly.

INTRODUCTION

IN DIGITAL PROCESSING of remotely sensed image data, image mosaicking is required for the display and analysis of regions covered by more than one image. The images to be mosaicked may be acquired at different dates, seasons, or years. When two or more images are mosaicked (i.e., registered and combined) into a single larger image, a problem which frequently arises is the creation of spurious "edges" at the seams of the input images. These edges occur when there are perceptible discontinuities in image patterns or intensity differences within the region of overlap. The intensity differences between images are usually caused by changes in atmospheric and Earth surface conditions. For example, changes in atmospheric transmittance and sun angle will transform the grey level of the whole image. Cloud, smoke plumes, and snow cover may obscure portions of the Earth's surface. The reflectance of soil will change with soil moisture. Farms will change with time, etc. Often these spurious edges are more noticeable than the real information; this makes image interpretation more difficult.

The remote sensing images may be mosaicked to a map projection or to a reference image. Thus, the image should be geometrically corrected and registered prior to mosaicking.

The image mosaic process usually consists of four steps: (1) input image geometric registration, (2) adjustment of input image grey level, (3) a search for seams, and (4) seam smoothing. In this article, a two-dimensional seam-point searching algorithm is proposed, and a method for mosaicking of multispectral color composite images is introduced.

Seam-point searching is the process of choosing points in the overlap region which define where one image ends and the other image begins. To define a vertical seam point between two images, one point per line of overlap region is chosen. The pixels to the left of the point will come from the line segment of the left-hand image and the pixels to the right from the right-hand image. The seam point is chosen to produce the least amount of artificial edge. In digital mosaicking, the edge to minimize is not a physical edge but an edge corresponding to the grey value differences between the two overlap regions. The two methods commonly used for seam-point selection are the minimum absolute-grey-difference sum method and the least-cost path searching method (Milgram, 1975, 1977; Murai *et al.*, 1980; Peleg, 1981).

Let the pixel grey values of left and right images be represented by f and g, respectively, and suppose that the overlap region is N pixels wide. Then the pixel values of the absolute-grey-difference image in the jth row are

$$d_{j,k} = |f_{j,k} - g_{j,k}| \tag{1}$$

for $k = 1,2,3,\ldots,N$. If an edge measure computes the sums of $d_{j,k}$ over $u+1$ pixels along the jth row to find the index value of k where

$$v_k = \sum_{i=-u/2}^{u/2} d_{j,k+i} \tag{2}$$

is minimum for i from $-u/2$ to $u/2$ and for $j=r$. The seam would be at point k in row r, as shown in Figure 1.

This method of seam-point selection finds a succession of points whose horizontal positions are unrelated. Such random positioning of the seam points reduces the visual edge. It has the disadvantage of introducing discontinuities between adjacent rows. For example, if two successive seam points are in positions s and s', respectively, then the pixels in positions $s+1$ to $s'-1$ in row r will come from the right-hand image while those in the same positions in the row $r+1$ will come from the left-hand image as shown in Figure 2. If the left-hand image differs significantly from the right one in this region, a horizontal artificial edge will be seen. In order to improve the horizontal edges, Milgram (1975) suggested that the range for candidate seam points is limited in $[k-v+1, k+v]$ where k is the position of the seam point in the previous row and v decreases exponentially as a function of V_k.

In the least-cost path search method the "cost" of a seam from the top to the rth row is defined as

$$C_r = \sum_{j=1}^{r} d_{j,k_j} \tag{3}$$

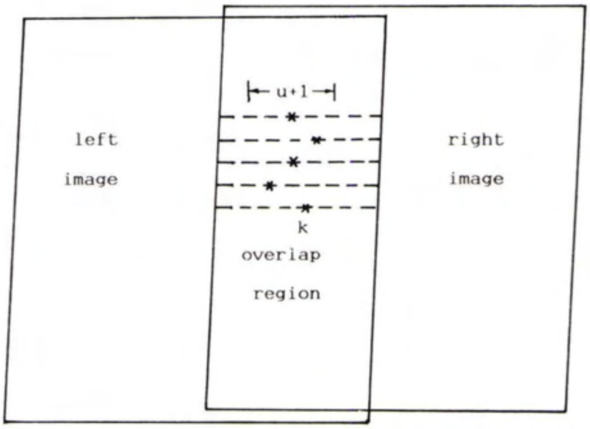

FIG. 1. One-dimensional seam-point searching method. The * represents seam points; their range in the horizontal direction is $u+1$.

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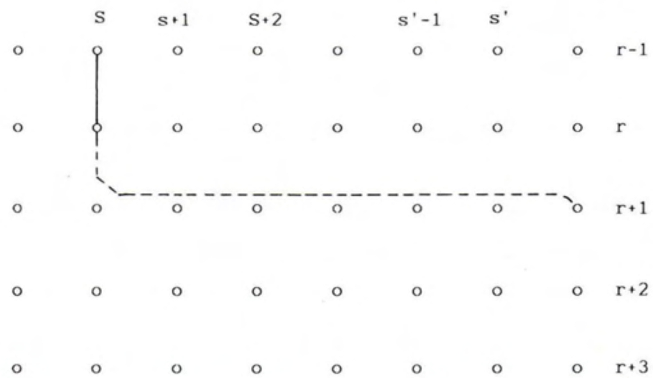

FIG. 2. Horizontal artificial edge in the one-dimensional seam-point search.

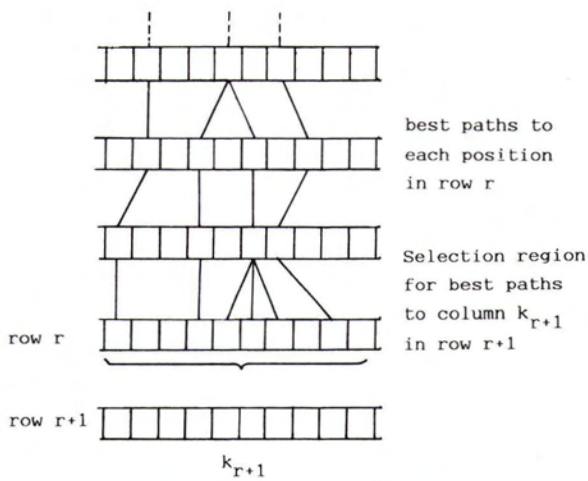

FIG. 3. Relationship of previous best paths to positions of new row.

for $1 \leqslant k_j \leqslant N$ and $|k_j - k_{j+1}| \leqslant u/2$, where k_j and k_{j+1} are the sample numbers of the seam points in the jth and $j+1$ −th rows, respectively. The least-cost path is defined as that with minimum value of C_r. Initially, the least-cost path to each position in the first row is an empty path with zero cost. Suppose that the least-cost path from the top to the row r is $C_r(k_r)$. Now, to extend the set of best path from row r to row $r+1$, each position in row $r+1$ considers a subset of the row r and its predecessor, the position whose current path cost is least. The new path to this position is the concatenation of the best path to its chosen predecessor. The cost of this new path is the sum of the cost of the best path to its predecessor plus $d_{j,k}$ for $j = r+1$, i.e.,

$$C_{r+1}(k_{r+1}) = \underset{|k_{r+1} - k_r| \leqslant u/2}{\mathrm{MIN}} [C_r(k_r) + d_{j,k}] \tag{4}$$

for $k = 1,2,3,\ldots,N$. This process repeats until $r+1 = M$, where M is the number of rows in the overlapped area. The partial paths are stored as an inverted tree. The path corresponding to a particular position in the bottom row may be determined by traversing the tree from that position upward and stacking the nodes traversed. The final contents of the stack will be the best path from the top to that position. Figure 3 shows the relationship of previous best paths to the position of new row (Milgram, 1977).

TWO-DIMENSIONAL SEAM-POINT SEARCH

The seam-point search methods described have a common problem in that the edge measures are one-dimensional. They concern the edges in the vertical direction; the horizontal edges are only controlled by the "range" searched. If all edges are considered instead, the horizontal seam is as important as the vertical seam in eliminating the artificial edges.

Let V_k and H_j be the vertical and horizontal edges measures, respectively; i.e.,

$$V_k = \sum_{i=u/2}^{u/2} d_{j,k+i} \tag{5a}$$

and

$$H_j = \sum_{i=-u/2}^{u/2} d_{j+i,k}. \tag{5b}$$

If the seam point in row r is (r,s), first search the seam point in row $r+1$ to the right. Let

$$V_{R,t} = \mathrm{MIN}(V_{r+1,s}\ V_{r+1,s+1},\ldots,\ V_{r+1,s+t}) \tag{6a}$$

be the minimum vertical edge measure of points $(r+1,s),(r+1,s+1),\ldots,(r+1,s+t)$ in the row $r+1$ for $t = 0,1,2,\ldots,N-s-u/2$, where N is the number of pixels in the row direction of the absolute-grey-difference image, and let

$$H_{R,t} = \mathrm{MAX}\ (H_{r+1,s}\ H_{r+1,s+1},\ldots,H_{r+1,s+t}) \tag{6b}$$

be the maximum horizontal edge measure of points $(r+1,s),(r+1,s+1),\ldots,(r+1,s+t)$ in row $r+1$ for $t = 0,1,2,\ldots,N-s-u/2$. The search on the right-hand side begins from $t=0$, and is continued for $t = 1,2,3,\ldots, N-s-u/2$, if the difference between $V_{R,t}$ and $H_{R,t}$, on a per-pixel bases, is less than or equal to a predefined threshold value, i.e.,

$$\frac{1}{u+1} |V_{R,t} - H_{R,t}| \leqslant \delta. \tag{6c}$$

Otherwise, the search on the right-hand side stops and starts the search on the left-hand side. In order to limit the artificial edges in the seams, the δ is selected in the range of $L/32$ to $L/64$, where L is the grey level dynamic range of the adjusted images. Similarly, let

$$V_{L,t} = \mathrm{MIN}\ (V_{r+1,s-1},\ V_{r+1,s-2},\ldots,\ V_{r+1,s-t}) \tag{7a}$$

and

$$H_{L,t} = \mathrm{MAX}\ (H_{r+1,s-1},\ H_{r+1,s-2},\ldots,\ H_{r+1,s-t}) \tag{7b}$$

be the minimum vertical edge measure and maximum horizontal edge measure of points $(r+1,s-1)$, $(r+1,s-2),\ldots,(r+1,s-t)$ in the row $r+1$ for $t = 1,2,3,\ldots, u/2$. The search on the left-hand side begins from $t = 1$ and is continued for $t = 2,3,\ldots, u/2$, if

$$\frac{1}{u+1} |V_{L,t} - H_{L,t}| \leqslant \delta. \tag{7c}$$

After finishing the searches on the left- and right-hand sides, a best seam point in row $r+1$ is selected by the formula

$$V_{r+1,s'} = \mathrm{MIN}(V_{R,t},V_{L,t}). \tag{8}$$

The best seam point in row $r+1$ is thus the point $(r+1,s')$. With this search method, there is no significant distinction between the vertical and horizontal edges if δ is set to the value less than the eye's sensitivity to the bright difference of adjacent grey shades. Figure 4 illustrates the two-dimensional seam-point search on the right-hand side.

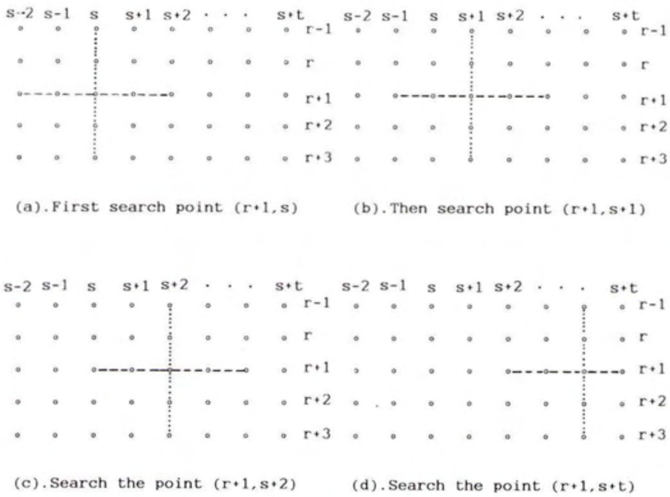

FIG. 4. Two-dimensional seam-point search. Vertical seam-search is shown as (o --- o --- o); horizontal search is shown as (o·····o·····o).

MOSAICKING OF MULTISPECTRAL IMAGES

False color images in remote sensing are usually composed of three single-band images or their combinations by assigning red, green, and blue color components to them, respectively. In mosaicking of multispectral image data, if the seam points are searched on each component separately, the location of seam points will not coincide and artificial edges may appear in the red, green, and blue components of the color composite. In order to minimize the edges in a color composite image, we propose that the seam points be searched on the image pixel values which are the weighted sum of absolute-grey-difference of three components, i.e.,

$$d_{j,k} = \sum_{i=1}^{3} a_{i,j,k} \mid f_{i,j,k} - g_{i,j,k} \mid \tag{9a}$$

where $a_{i,j,k}$ are the weighting factors, and $f_{i,j,k}$ and $g_{i,j,k}$ are the pixel grey values of the left and right images, respectively. Because the color of pixels in the color composite depends on the pixel grey values of the three components but the pixel values of the absolute-grey-difference image do not, the weighting factors are selected as the average grey values of the left and right images in the overlap region, i.e.,

$$a_{i,j,k} = \frac{f_{i,j,k} + g_{i,j,k}}{2}. \tag{9b}$$

Then we have

$$d_{j,k} = \sum_{i=1}^{3} \frac{f^2_{i,j,k} - g^2_{i,j,k}}{2}. \tag{9c}$$

SEAM SMOOTHING

Even if the images are grey-scale (contrast) adjusted and the seam points are determined using a two-dimensional search, there may still be discontinuities in the mosaic. Therefore, the final step in image mosaicking is to smooth any remaining abrupt grey-level shift in the neighborhood of seam point. Linear grey-level interpolation is used in the horizontal direction to eliminate the vertical edges (Murai *et al.*, 1980). Let $2w$ be the effected seam width to smooth. With w in each side of the seam point, the pixel grey values at point p are modified by the formula

$$Z = f_p \frac{w - p}{2w} + g_p \frac{w + p}{2w} = \begin{cases} f'_p & \text{for } -w \leq p < 0 \\ g'_p & \text{for } 0 \leq p < w \end{cases}$$

where f_p and g_p are the pixel grey values of the left and right images, respectively, and f'_p and g'_p are the smoothed pixel values. A large value of w smoothes the seam better, but it may degrade the image information somewhat in the vicinity of the seam. The tradeoff between obscuring the seam and degrading the image is determined by experimentation.

EXPERIMENTAL RESULTS

Three Landsat MSS images with path-row numbers of 156-26 (upper-left). 155-27 (lower-left) and 154-27 (right) acquired on at 29 April 1977, 1 September 1972, and 16 May 1977, respectively, were mosaicked using three different methods (Plates 1a, 1b, and 1c). Plate 1a is a simple mosaic with straight seams. It has apparent color differences and artificial edges in the mosaic because the images were acquired at different years and seasons. Plate 1b was mosaicked using two-dimensional seam-point search algorithm applied to the image of the weighted sum of absolute-grey-difference of the three image bands. it can be seen that the quality of the mosaic is greatly improved. In Plate 1c, the seam points (pixels) are registered with white dots. For the comparison of the one- and two-dimensional seam-point search algorithms, an enlargement of a single band image mosaic of the lower left part of Plate 1a is shown in Plate 2a. Plate 2b is the same image mosaicked by the one-dimensional seam-point search algorithm. There are apparent horizontal artificial edges in Plate 2b but none are evident in Plate 2a. A mosaic of another three Landsat MSS images with path-row numbers of 151-40, 150-40, and 149-40 acquired on 7 October 1983, 12 July 1983, and 25 September 1984 from left to right, respectively, is shown on the front cover. No artificial edges can be seen in this mosaic.

CONCLUSIONS

One of the most difficult problems in image mosaicking are the artificial edges which make trouble in image interpretation. The minimum absolute-grey-difference sum method and the least-cost path searching method reduce the artificial edges in one direction but ignore the other direction. The two-dimensional seam-point search method takes into account vertical as well as horizontal edges. Therefore, artificial edges can be reduced more effectively. An algorithm for mosaicking of multispectral images is also recommended, where the absolute-grey-difference images are weighted with the predominant color or colors of the false color composite. Thus, the spurious edges caused by different positioning of the seam points in the three color components can also be reduced. Practical application shows that the quality of the image mosaics is quite satisfactory.

REFERENCES

Milgram D. L., 1975. Computer Methods for Creating Photomosaics. *Trans IEEE on Computers*, Vol. C-24, pp. 1113–1119.

———, . 1977. Adaptive Techniques for Photomosaicking. *Trans. IEEE on Computers*, Vol. C-26, pp. 1175–1180.

Murai S., T. Okuda, and M. Akiyama, 1980. Digital Mosaics of Color Aerial Photographs. *14th Congress, International Society for Photogrammetry*. Hamberg pp. 570–578.

Peleg S., 1981. Elimination of Seams for Photomosaics. *IEEE Conference on Pattern Recognition and Image Processing*, pp. 426–429.

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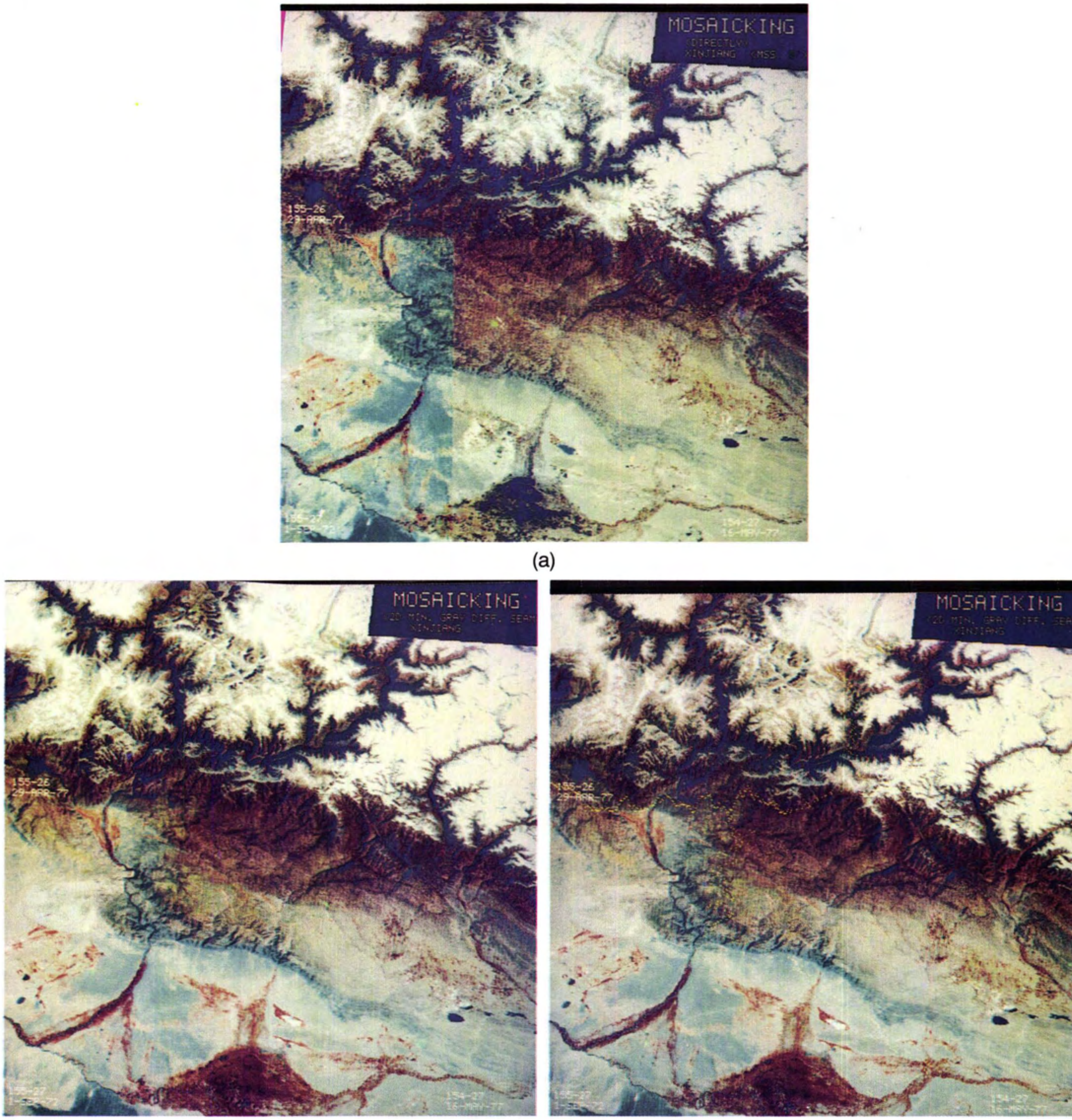
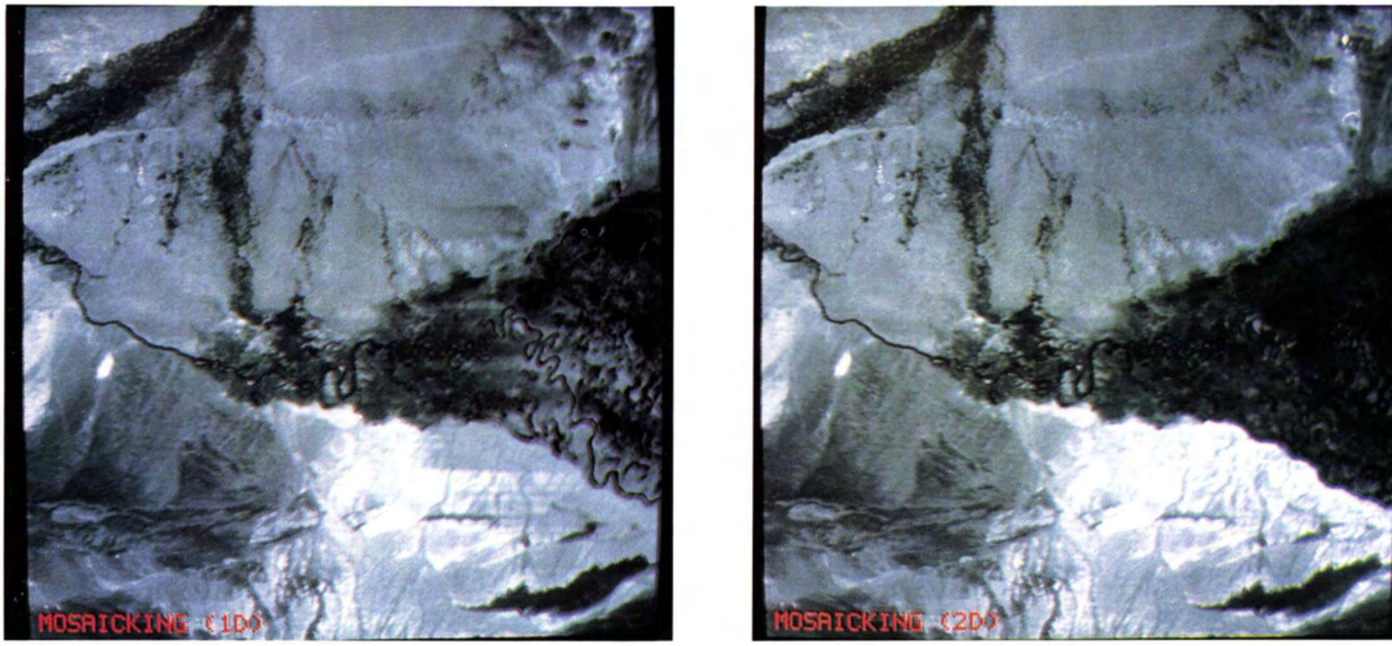


(a)

(b)

(c)

PLATE 1. (a) A simple mosaic of Landsat MSS false color composites with straight seams. Three images with path-row numbers of 155-26 (upper left). 155-27 (lower left), and 154-27 (right) were acquired on 29 Apr 1977, 1 Sept 1972, and 16 May 1977, respectively. (b) The mosaic of Landsat MSS false color composites with a two-dimensional seam-point search on the image of weighted sum of absolute-grey-difference of three components. (c) The seam points in (b) are registered with white dots.



(a) (b)

PLATE 2. (a) The mosaic of the band 7 image using the two-dimensional seam-point search algorithm. This image is an enlargement of the lower left part of the image shown in Plate 1b. No horizontal artificial edges can be seen. (b) The mosaic of band 7 images using the one-dimensional seam-point search algorithm. Horizontal artificial edges are apparent in the mosaic.

BOOK REVIEWS

Building Databases for Global Science Helen Mounsey (Editor), Roger Tomlinson (General Editor), Taylor and Francis, 242 Cherry St, Philadelphia, PA 19106-1906, 419 pp, hardcover, 1988, $77.00.

AS COMPUTING POWER INCREASES and our inventories of the location of phenomena over the surface of the Earth gets more complete, the possibility of developing computer-based spatial databases with global coverage is becoming increasingly real; indeed, some organizations have already started on the task. This book is made up of papers presented at a meeting in the U.K. in May 1988, under the auspices of the International Geographical Union, and specifically intended to bring together workers from around the world involved in this task, particularly in the light of the International Geosphere-Biosphere Project. Twenty-seven technical papers together with introduction, summary, and retrospective are included. The Table of Contents divides the contributions into four parts, although those are not separated in the body of the text. Parts Two and Three carry all the technical contributions, while the others are by way of prolog and conclusion.

Part Two is titled Review Papers and contains seven papers which are contributed by various well known individuals in geographic information system (GIS) research. The reviewer, like the editors, wish to pick out the contribution of Earl Epstein on legal and institutional issues as being particularly noteworthy, and I also found Rhind's discussion of cartographic inputs to global databases of considerable interest. Goodchild and Tobler, in separate papers of very different tone and content, explore error in spatial databases; Marble and Peuquet examine different aspects of data structure; and Simonett discusses the importance of the remote sensing-GIS interface.

Part Three is on applications. The papers are presented by a truly, and surprisingly, international group of contributors. Authors from national organizations in the China, U.K., U.S.A., and U.S.S.R. are included, as well as from international organizations such as the U.N. and the World Meteorological Organization. While a few organizations known to be creating global databases, and referred to by other authors, such as the Institut Géographique National in Paris, are not included, the coverage must be near complete. Spatial data bases derived from paper maps at a scale of 1:1,000,000 dominate the discussions, and seem to be in preparation all over the world. 1:1,000,000 is the key scale due to the compromise between national security interests on the one hand and usefulness on the other. Disappointingly, from a group of people concerned so heavily with the digital context, many authors only refer to their data by the nominal scale of the input map, not, as would be more appropriate, as a resolution or precision value for the digital data. There are, however, a number of interesting contributions here which clearly illustrate the extent of the projects, and the diversity, cooperation, and, unfortunately, repetition of those projects. It is to be hoped that one of the results of this meeting will be to prevent too much repetition of endeavor between the organizations in the future.

This volume has problems with style that are endemic to all conference proceedings, especially when they are produced so rapidly. In spite of any endeavors of the editors, the papers are highly variable and include those that are little more than notes gathered by topic, to those written in continuous prose without a heading from beginning to end. There are papers here with several pages of references and papers with none. One contribution omits at least five references specified in the text, while others make no reference from the text to papers in very full bibliographies. There is even one paper where references are