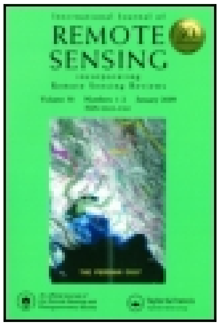

International Journal of Remote Sensing
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tres20

Determining patch perimeters in raster image processing and geographic information systems

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Available online: 27 Apr 2007

To cite this article: R. L. LAWRENCE & W. J. RIPPLE (1996): Determining patch perimeters in raster image processing and geographic information systems, International Journal of Remote Sensing, 17:6, 1255-1259

To link to this article: http://dx.doi.org/10.1080/01431169608949084

INT. J. REMOTE SENSING, 1996, VOL. 17, NO. 6, 1255–1259

Determining patch perimeters in raster image processing and geographic information systems

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(*Received 9 August 1995; in final form 10 November 1995*)

Abstract. Some authors have determined patch perimeters in raster image processing and geographic information systems by summing the number of pixels immediately surrounding the patches. We demonstrate that this method is inaccurate. When applied to satellite sensor imagery, errors ranged from overestimation of perimeter length by 34·5 per cent to underestimation by 41·7 per cent. Therefore, we developed a new method that is both accurate and relatively simple. This method determines perimeters using a standard 3 by 3 pixel moving window. The method can be used with most raster systems and has applications in landscape ecology for calculating such variables as the fractal dimension and ecotone dimensions.

Analysis of patch geometry for landscape ecology studies and applications sometimes requires a determination of the length of patch perimeters from raster remote sensing data. Landscape variables of interest may relate directly to perimeter length, such as mean patch perimeter, because, for example, of the importance of edge habitat (Chen and Franklin 1990) or ecotones (Johnston and Bonde 1989). Other variables related to patch shape describe the relationship of patch perimeter to patch area, such as the simple perimeter-to-area ratio, the fractal dimension (Burrough 1986), and the diversity index (Patton 1975). A single study may incorporate a combination of these perimeter related variables, along with other landscape metrics (e.g., Ripple *et al.* 1991). The objectives of this study were (1) to analyse the accuracy of what we believe is a common method of determining perimeter length from raster data, although most published studies do not specify their methods of making this determination, and (2) to develop an accurate method that could be easily applied with current raster programs.

The need to determine perimeter length can create difficulties for analysts working with raster-based image processing and geographic information systems, which provide area, not linear, measurements. Although it is generally possible to convert raster-based files to vector-based files that will provide linear measurements, the analyst may not be trained in the vector-based system or have such a system available.

One approach to this problem has been to create a one pixel buffer around the patches and use these 'buffer' pixels as an estimate of the perimeter (e.g., Johnston and Bonde 1989). However, this approach can lead to erroneous measurements. Figure 1 illustrates some sources of error inherent in this approach. In figure 1 (*a*), each of the outside corner buffer pixels (labelled A) would be counted as one unit of length (a unit of length being the length of one side of a pixel), when such pixels

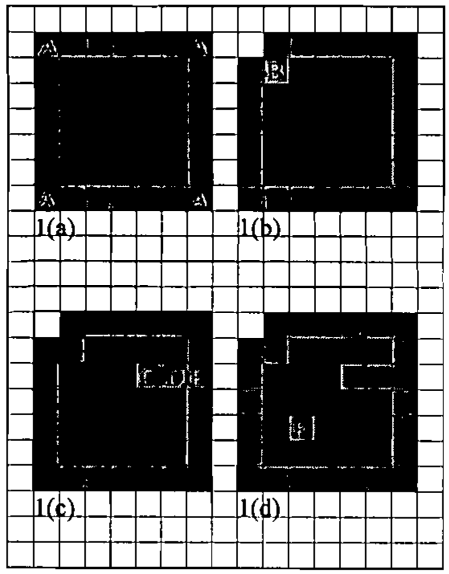


Figure 1. Examples of errors from the use of buffer pixels to estimate perimeter length (patches are shown in black and buffer pixels are shown in grey). Pixels labelled A to F show sources of these errors.

actually do not represent any length of perimeter. Thus, in figure 1 (*a*), the buffer pixel method overestimates the perimeter by four units. As a corner becomes more complex in figure 1 (*b*), the pixel marked B is counted as one unit of length, when it actually represents two units. However, there are now five outside corners that are erroneously counted, and so the total error remains an overestimation by four units.

In figure 1 (*c*), the edge begins to take on increased complexity. The pixels marked C, D, and E are each counted as one unit, although C actually accounts for three units of perimeter, D for two units, and E for none. Thus, these three pixels are counted as three units of length by the buffer pixel method, when they actually represent five units. Finally, in figure 1 (*d*), the interior of the patch takes on increased complexity. The pixel marked F is counted as one unit of length, when it actually accounts for four units.

As can be seen, the degree of error will vary with patch size, complexity, and proximity to other patches. For patches without complex edges or interiors, as patch size increases relative to pixel resolution, the per cent error in this method decreases. Figure 2 illustrates, for square patches of varying pixel size, how error decreases asymptotically with patch size in accordance with the equation:

$$P=(4*A^{0.5})+4 \tag{1}$$

where P = perimeter length (in units equal to the side of one pixel) estimated by the buffer pixel method, A = area of the patch in pixels. For large patches with complex edges and/or interiors, the buffer pixel method may significantly underestimate perimeter length as a result of errors like those demonstrated in figures 1 (*c*) and (*d*).

In our satellite remote sensing study of forest patch structure in the Pacific Northwest using Advanced Very High Resolution Radiometer (AVHRR) data resampled at a 1 km spatial resolution, 18 randomly selected study areas, each 2500 km^2, were

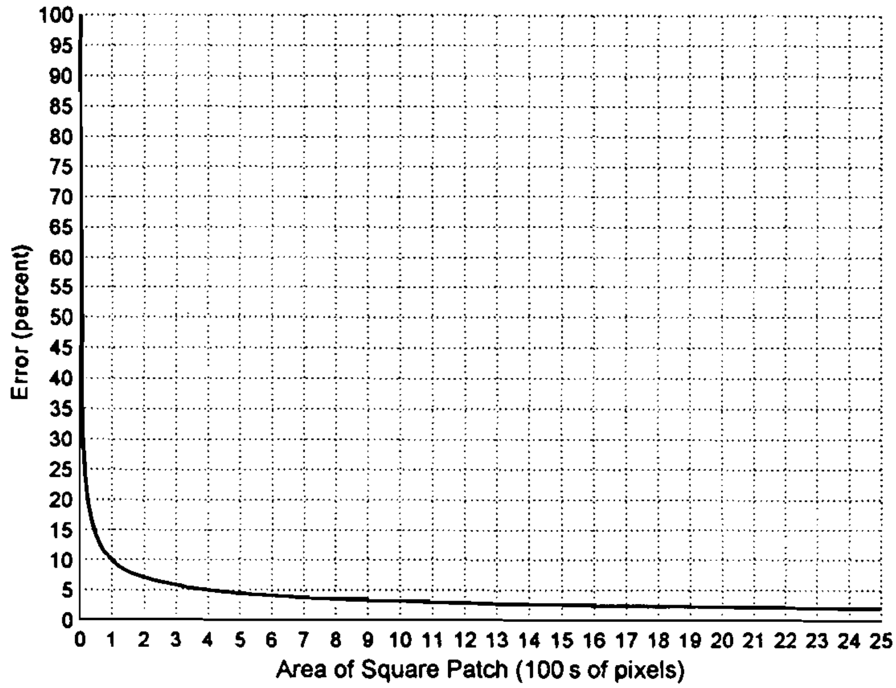


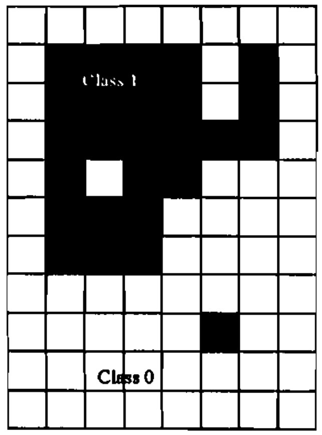
Figure 2. Per cent of error in perimeter measurement from using buffer pixels to estimate the perimeter of square patches of varying sizes. Error decreases asymptotically with increasing patch size.

examined. Using buffer pixels to measure perimeter resulted in an average 6·0 per cent underestimation of perimeter, with errors ranging from overestimation by 34·5 per cent to underestimation by 41·7 per cent. Thus, it is clear that a more accurate method of determining perimeters is needed for analysts using raster-based systems.

The following procedure will provide an accurate measurement of perimeter length in a raster-based system. The procedure is based on the principal that each non-patch pixel will border a patch on from 0 to 4 sides of the pixel. Thus, each non-patch pixel represents from 0 to 4 units of length of perimeter (the units of length being the length of one side of a pixel).

This procedure has been used with ERDAS software (ERDAS, Inc. 1990) and can be adapted to other systems by substituting the corresponding commands (ERDAS commands are provided in brackets at the end of each step):

(1) Create a binary patch layer, assigning patches to class 1 and all non-patch areas to class 0 (see example, figure 3 (*a*)). [recode]
(2) Create a 3 by 3 moving window as illustrated in figure 3 (*b*). The moving window is applied to each pixel over the entire binary patch layer, with the pixel in the centre of the window assigned a value equal to the sum of all values in the window. By assigning a value of one only to pixels actually bordering the centre pixel, and not to those pixels that are diagonally contiguous, this window is able to determine the total units of perimeter length bordering each pixel. (Areas outside of the image should be valued at 0 for moving window calculations, as is the case in ERDAS, or the pixels at the



(a)

0	1	0
1	0	1
0	1	0

(b)

0	1	1	1	1	0	1	0
1	2	3	3	2	2	1	1
1	3	4	4	3	3	2	1
1	3	3	4	4	2	2	1
1	2	4	3	2	2	1	0
1	3	3	3	2	0	0	0
1	2	3	2	1	0	0	0
0	1	1	1	0	1	0	0
0	0	0	0	1	0	1	0
0	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0

(c)

	1	1	1	1		1	
1					2		1
1					3		1
1							1
1		4			2	1	
1				2			
1				1			
	1	1	1		1		
				1		1	
					1		

(d)

Figure 3. Stages in determining perimeters. (a) sample binary patch map, black areas represent patches and are coded as Class 1, white areas represent the matrix or non-patch areas and are coded as Class 0. (b) 3 by 3 moving window, new value assigned to centre pixel is equal to the number of sides on which the centre pixels abuts a patch. (c) results of applying the moving window, original patch edges are outlined. (d) results of masking original patches (pixels in Class 0 have been left blank for clarity).

edge of the image should not be used in the subsequent analysis.) Figure 3 (c) shows the results of applying this moving window to the example in figure 3 (a). [scan]

(3) To mask the patches, change the classes in the binary patch layer to 0 for patches and 1 for non-patches, and then multiply the values in this layer by those in the layer created in step three. [matrix] The result will be a layer containing only perimeter pixels (see figure 3 (d)). (If a single layer containing perimeter and area values is desired, the original binary patch layer can be combined with this perimeter layer, weighting the patch layer by five to distinguish the patches from perimeter values.)

(4) At this point, the file will have four classes representing perimeter length. Total perimeter length for the image is computed as ((number of pixels in class 1) + (2 * number of pixels in class 2) + (3 * number of pixels in class 3) + (4 * number of pixels in class 4)).

To convert to ground units, multiply this perimeter length by the ground length of a pixel side.

The method set forth above is designed for square pixels. However, it can be adapted for pixels of other shapes by modifying the moving window and, if necessary, using multiple windows. For rectangular pixels, for example, two moving windows could be used, one to detect horizontal edges and one to detect vertical edges.

Analysis of individual classes may provide additional information as to patch structure. For example, Class 4 is entirely a function of single pixel holes in patches. The percentage of pixels in Classes 2 and 3 is a function of the irregularity of patch edges as compared to a straight line.

The method of determining perimeter length presented in this Letter uses only basic raster commands. A similar approach has been used successfully to assess spatial connectedness (LaGro 1991). When an accurate measure of perimeter length is needed, the method in this Letter can provide a significant improvement over using buffer pixels to estimate perimeter length.

Acknowledgments

The authors would like to thank Barbara Marks, Department of Forest Science, Oregon State University, for review of a draft of this paper. Partial funding for this project was provided by the U.S. Fish and Wildlife Service (grant # 144500091577, RWO # 7) through the Oregon Wildlife Cooperative Research Unit, and the National Science Foundation (grant # GER-9452810) under the auspices of the NSF Graduate Research Fellowship in Landscape Studies.

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