Evaluation of various filter kernels for extraction of linear features from satellite imagery

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Abstract

Edge-enhancement filters, among others, are tools for image enhancements, which provide the user with more options for delineating linear features. The aim of this paper is to study various filter kernel combinations to ascertain their value and usability for extraction of linear features in particular. Twelve different filter kernels of 3x3 matrices were studied, which included six of zero-sum kernel type and six of high-pass filter type. Eleven filters showed satisfactory result for edge-enhancement. The use of filters for extraction of linear features from satellite imagery was found to be very suitable, and it shows that other filters may be defined according to the purpose of the user.

1. Introduction

Satellite imagery is used extensively in various application fields by professionals like agriculture scientists, marine biologists or forest conservationists etc. These images are taken from different platforms and sensors with various image characteristics such as spatial, spectral or radiometric resolution. The remote sensing expert needs to adopt interpretation techniques according to the image characteristics and the results expected.

A remote sensing professional engaged in mapping work will create a digital cartographic model representing the real world in point, line or area features[2]. The level of information extracted in these circumstances, depends mainly on the spatial resolution of the satellite imagery, the required output, the skill of the interpreter and the various extraction techniques.

Economic consideration dictate that more information be extracted from relatively less expensive imagery. So techniques such as filters have to be employed to extract more information. Filtering is a broad term, which refers to the altering of spatial or spectral features for image enhancement[1]. A new image is computed from the old one depending upon the pixel values of the neighboring pixels and the kernel coefficient [2]. The most effective use of filters is in noise reduction (smoothing) or for edge enhancements (for extraction of linear features). In this paper the edge-enhancement filters are studied.

2. Objective

Numerous filter kernel matrices exist; however, they are generally not applied to their full potential because of a general lack of knowledge of when to apply what filter or what result to expect from a given filter. Filters may be used for noise reduction, speckle reduction, edge-enhancement etc. In the context of extraction of linear features from satellite imagery, the aim of this study is to:

a. Study edge-enhancement filters of two types, namely the high-pass filter kernels and the zero-sum filter kernels
b. Study standard filters and define new kernels
c. Study their suitability for linear feature extraction from satellite imagery

3. Methodology

Firstly, filters of different types are studied. Then high-pass filter kernels and zero sum kernels of 3x3 matrices of various combinations are defined. The filters are then applied on the same image for comparison. A code is written in Erdas Imagine software for implementing this. The code is run for all the filter kernels separately. Two separate decision criteria are defined for zero sum kernels and high-pass kernels. The decision criteria for zero sum kernels are: (a) visibility and interpretability of edges and (b) enhancement in a particular direction, for example, north, south or their diagonals. The judgment criteria for convolution filter are: (a) image quality (whether degraded or not) and (b) sharpness of edges. These are then compared and the best suitable kernels for each category deduced.

4. Data

Although filters can be best applied to lower spatial resolution imagery, where visual interpretation is difficult, yet, in this study IKONOS image of the year 2000 of a section of Balaju area was taken because of the following:

a. Image availability
b. Linear features such as roads, rivers and bridges in all directions, e.g. north, south, east, west, NE and SW
c. Linear features of varying dimensions available
d. Ease of identification of linear features for verification of results
e. Ability to project these results to lower spatial resolutions images

5. Filters

Filter operations are usually carried out on a single band. To define a filter, a kernel is used. A kernel defines the output value as a linear combination of pixel values in a neighborhood around the corresponding in the input image. For a specific kernel, a so-called gain can be calculated as follows: gain=1/Ý'3fki

One application of filtering is to emphasize the local differences in grey values, for example related to linear features such as roads, canals, geological faults, etc. This is done using the edge enhancing filter, which calculates the difference between the central pixel and its neighbors. This is implemented using negative values for the non-central kernel coefficients. The sharpening effects can be made stronger by using smaller values for the centre pixel.

Convolution filtering is one method of spatial filtering. It is the process of averaging small sets of pixels across an image. It is used to change the spatial frequency characteristics of an image. A convolution kernel is a matrix of numbers that is used to average the value of each pixel with the values of surrounding pixels in a particular way. The numbers in the matrix serve to weight this average toward particular pixels. These numbers are called coefficients, because they are used as such in the mathematical equations.

The following formula is used to derive an output data file value for the pixel being convolved (in the center):

$$V = \left[\frac{\sum_{i=1}^{q}\left(\sum_{j=1}^{q} f_{ij} d_{ij}\right)}{F} \right]$$

Where:

*f*ij = the coefficient of a convolution kernel at position i,j (in the kernel)

*d*ij = the data value of the pixel that corresponds to fij

q = the dimension of the kernel, assuming a square kernel (if *q*=3, the kernel is 3x3)

F = either the sum of the coefficients of the kernel, or 1 if the sum of coefficients is 0

V = the output pixel value

In cases where *V* is less than 0, *V* is clipped to 0.

The sum of the coefficients (*F*) is used as the denominator of the equation above, so that the output values are in relatively the same range as the input values. Since *F* cannot equal zero (division by zero is not defined), *F* is set to 1 if the sum is zero.

5.1 High Pass Kernels

A high-frequency kernel, or high-pass kernel, has the effect of increasing spatial frequency. High-frequency kernels serve as edge enhancers, since they bring out the edges between homogeneous groups of pixels. Unlike edge detectors (such as zero-sum kernels), they highlight edges and do not necessarily eliminate other features. The following is an example of high pass kernel.

-1	-1	-1
-1	16	-1
-1	-1	-1

5.2 Zero-Sum Kernels

Zero-sum kernels are kernels in which the sum of all coefficients in the kernel equals zero. When a zero-sum kernel is used, then the sum of the coefficients is not used in the convolution equation, as above. In this case, no division is performed (F = 1), since division by zero is not defined.

This generally causes the output values to be:

- Zero in areas where all input values are equal (no edges)
- Low in areas of low spatial frequency
- Extreme in areas of high spatial frequency (high values become much higher, low values become much lower)

Therefore, a zero-sum kernel is an edge detector which usually smoothes out or zeros out areas of low spatial frequency and creates a sharp contrast where spatial frequency is high, which is at the edges between homogeneous groups of pixels. The resulting image often consists of only edges and zeros. Zero-sum kernels can be biased to detect edges in a particular direction. For example, the following is an example of South biased kernel:

-1	-1	-1
1	-2	1
1	1	1

6. Analysis

6.1 Kernel definition

The filter kernels defined in this study are 3x3 matrices and are divided into two groups, the zero-sum kernels and the high-pass kernels, depending upon the sum of the coefficient. There are 6 kernels in each group, with two standard kernels available in text books and software and the rest designed for the purpose of this study. The kernels are numbered A through L in the table 1 below and the corresponding images obtained are also numbered similarly in sec. 7, table 2.

Zero-sum kernels:

A			B			C			D			E			F		
-1	-1	-1	1	1	1	1	1	-1	-1	1	1	1	1	1	-1	-1	1
1	-2	1	1	-2	1	1	-2	-1	-1	-2	1	1	-8	1	-1	-2	1
1	1	1	-1	-1	-1	1	1	-1	-1	1	1	1	1	1	1	1	1
South bias			North bias			West bias			East bias			Standard			Test		

High-pass kernels:

G			H			I			J			K			L		
-1	-1	-1	-1	1	-1	-1	-4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	16	-1	1	16	1	-4	21	-4	-1	9	-1	-1	10	-1	-1	12	-1
-1	-1	-1	-1	1	-1	-1	-4	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
Standard (Gain=1/8)			Test			Test			(Gain=1)			(Gain=1/2)			(Gain=1/4)		

Table 1 : Filter kernel matrices

6.2 Coding and implementation of filter

The coding was done on the Model Maker of the Erdas Imagine software with the model shown below[3] .This was then run for each filter kernel and the output studied.

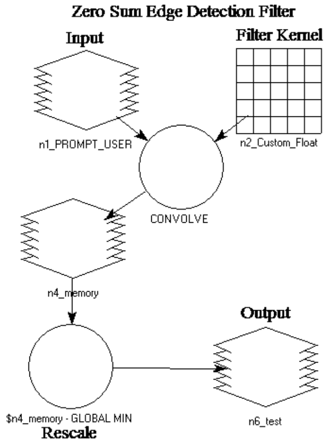

Figure 1 : Model for implementation of filter in software

7. Results and discussion

The following table shows the result of applying the filter in the image. They are placed in the same order as the applied kernel from sec. 5, table 1.

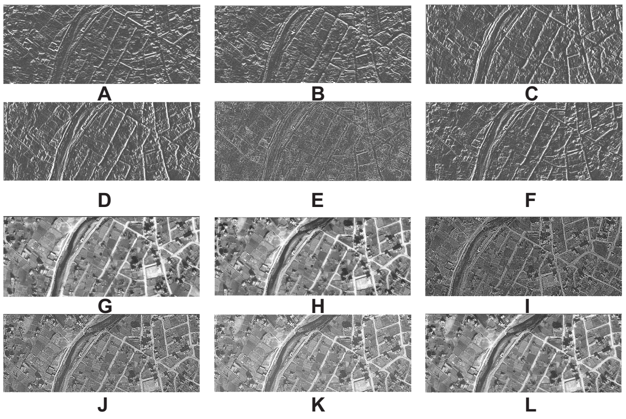

Table 2 : Images after applying the filters

7.1 Decision criteria

Zero-sum kernel: (a) visibility and interpretability of edges and (b) enhancement in a particular direction, for example, north, south or their diagonals.

High-pass kernel: (a) image quality (whether degraded or not) and (b) sharpness of edges.

Filter	Remarks
A	Edge well detected, north-south lines not visible, east-west lines more visible
B	Edge well detected, north-south lines not visible, east-west lines more visible
C	Edge well detected, east-west lines not visible, north-south lines more visible
D	Edge well detected, east-west lines not visible, north-south lines more visible
E	Edge well detected, lines generally clear
F	Edge well detected, north-east to south-west (diagonal) lines more clear
G	Image very clear, edges sharp for all directions, good image contrast
H	Image very clear, edges sharp for all directions, good image contrast
I	Edges clear, lots of noise
J	Edges clear, image degraded
K	Edges clear, image degraded
L	Edges clear, good image

Table 3 : Description of results after application of filters

From table 3, it can be seen that although certain results look promising, yet the others have there own purpose as well. As expected, the zero-sum filters, table 3, (A – F), enhance the edges at the cost of image quality. Thus, if the objective is to make the edges clear in some direction, any of these filters can be applied according to the purpose. However, if the requirement is to have the edges enhanced *and* also to view good quality images, the high-pass filters, table 3, (G – L) give good results, except the kernel I, which is a mixture of averaging filter and high-pass filter.

8. Conclusion

The objective of the study has been fulfilled. Edge-enhancement filters of two types, namely, zero-sum and high-pass kernels, have been studied in different combination of coefficient values. In doing so, it has fulfilled an intrinsic intention of this paper of making the reader aware of edge-enhancement filters, when to apply what and what results to expect from which filter. Standard kernels have been analyzed along with kernels defined for this study. The third objective of examining the suitability for linear feature has been fulfilled. Except one filter, all the filters have succeeded in giving an edge-enhanced acceptable quality image. The results show that kernels can be and should be defined and applied according to the purpose of the remote sensing expert.

References

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