LOCAL FILTERS IN DIGITAL IMAGE PROCESSING

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ABSTRACT

This paper is a tutorial introduction to local linear and nonlinear filters. Their usefulness in a variety of common image processing tasks is discussed.

1.   INTRODUCTION

Digital image processing involves using a computer to apply a series of mathematical operators to a numerical representation of an object [4]. The desired result may be, for example, the measurement of the length of a feature, an enhanced image for display, or even a decision on whether an object meets certain specifications. This paper discusses one of several classes of operators that have been found to be particularly useful – local filters.

A local filter is an operator whose output for a pixel is a function of the input values within the neighbourhood of that pixel. This neighbourhood can be thought of as a window, since for each output pixel, only the pixel values within the window are used. The window is scanned across every position of the input image, each position contributing to one pixel in the output image. The window can be of any shape, although it is almost always symmetrical about a centre pixel, and is usually square. Local filters tend to have short calculation times since only a few input pixels are operated on for each output pixel.

2.   LOCAL FILTER DESCRIPTIONS

2.1 Point Operators

A simple class of local filters are the point operators, which are used to transform the intensity histogram by replacing all pixels of one intensity with another. Linear transformations can only stretch or compress and shift the histogram, that is increase or decrease the contrast of an image linearly and provide the image with an intensity offset. Nonlinear transformations can be used to modify the intensity histogram in all pixels above a threshold intensity are set to white and all below are set to black. Another important application of point operators is to compensate for nonlinearities in image capture and display devices [4].

2.2 Linear Filters

A linear filter, as its name suggests, replaces a pixel with a linear combination or weighted average of the pixel intensities from within the window centred on that pixel. The choice of weights depends on the application of the filter. See figure 1 for examples [9]. The theory behind linear filters is well developed and much has been written about them.

Linear filters have several undesirable limitations or deficiencies in some applications. These include the blurring of edges while smoothing noise, and a sensitivity to noise while detecting edges.

2.3 Nonlinear Filters

To overcome some of these deficiencies, a wide variety of non-linear filters have been devised. It is beyond the scope of this tutorial paper to mention all but a few. There are two broad categories of nonlinear filters: those which are simple modificat-ions of linear filters, and those which are not.

Linear filters can be usefully modified by omitting pixel values which are far removed in intensity from the central pixel, or the median value of the window. Such filters are referred to as 'trimmed' filters. Several methods have been proposed in the literature for trimming filters, the main application being to smooth noise while preserving edges [3].

'Gated' linear filters use some function of the pixel values within the window to determine which of several linear filters will provide the resultant pixel value. This gating is determined for each window position. When carried to the extreme, the weights in a window are dependent on the pixel values within that window. Gated filters can be used for all of the applications of linear filters, with generally improved results.

Nonlinear combinations of linear filters are also useful. A common example of this is in the SOBEL edge detection filter which incorporates two linear edge detection filters, one for horizontal edges, and one for vertical edges. These perform directional differentiation, and are combined to give a two dimensional gradien gradient filter by taking the square root of the sum of the squares of the two responses.

An important nonlinear filter is the RANK filter [7]. It ranks the intensity values within the window, and uses the intensity from a selected position in this ranked list. RANK filters, or combinations of them, have properties that make them useful in a wider range of applications than conventional linear filters. Some of these are detailed below.

A moment based filter has been devised for detecting edges in the presence of noise [10]. It works by calculating the 'centre of gravity' of the pixel intensities within the window. The distance of the centre of gravity from the centre of the window gives an indication of the magnitude of the edge, while the direction gives the direction of steepest ascent. Filters using other than the first moment have also been used.

3. **APPLICATIONS**

Only the major applications of local filters are discussed in this paper. Due to the restrictions on the quality of reproduction no pictorial examples are given but illustrative slides will be shown when the paper is presented. The relative advantages and disadvantages of the various filters for the applications discussed below are summarised in tables 1 to 5.

3.1 Noise Smoothing

Linear filters are good for smoothing most types of noise, however this is at the expense of edge sharpness and fine detail. These limitations can be overcome by using trimmed filters, or gated filters where the gating is based on edge activity. A particular case of RANK filters, the MEDIAN filter, is good for smoothing noise while preserving edges. For a good summary of the relative merits of the various filters, the reader is referred to [5].

With images degraded by point of 'salt and pepper' noise, as caused by transmission errors or camera hot spots, linear filters perform poorly. Provided the image is not strongly contaminated, all of the nonlinear filters mentioned above perform satisfactorily.

3.2 Edge Enhancement

Edge enhancement is often achieved by steepening the edge slope. When linear filters are used for this, ringing results on edges which are already sharp. Noise is also amplified, since this operation is high spatial frequency amplification. Gated filters can be used to minimise noise effects by applying the enhancement filter only to edges.

Another nonlinear filter which we have found to work reasonably well in this situation is the gated RANK filter; if the centre pixel of the window is greater than the man of two selected rank values, the larger RANK value is selected, otherwise the smaller is used. Since the RANK filter output must be one of the pixel values already present in the window, no new values are generated, making ringing impossible. By selecting appropriate rank values, noise amplification can also be minimised.

3.3 Edge Detection

Linear edge detection filters can be made to detect edges in one particular direction, or in all directions at once. The directional filters are less susceptible to noise than the omni-directional filters, but to detect every edge the outputs from the filters need to be processed in some nonlinear way, leading to SOBEL and other related filters. The omnidirectional linear filters can only be used where there is little or no noise.

Many nonlinear filters have been designed to improve edge direction in the presence of noise. Some of these are compared in [1] and [10]. Moment based filters are less susceptible to noise, but edges with an intensity offset are not detected as well as the same height edge without an offset. We have used RANK filters to detect edges by applying two different RANK filters, and subtracting the resultant images. If the highest and lowest rank values are used, the result is the statistical range of the pixel intensities within the window. In general if there is an edge within the window, the intensity range will be larger than that without an edge. Noise susceptibility may be improved by using other than the extreme rank values.

3.4 Line and Spot Detection

Line or spot detection is not readily achieved by using linear filters. The edge response of linear filters in this category is only marginally less than their line or spot response. Gated operators may be used to distinguish between lines and edges although this is effectively the same as checking the detected pixels within the original image to see if they are edges, lines or spots.

A method has been proposed [2] for using RANK filters to detect lines and spots without detecting edges. Briefly, a RANK filter is used, selecting the minimum pixel value. This will eliminate lines and spots of high intensity, but also shifts any edges. A second RANK filter is applied, selecting the maximum pixel value. This shifts the edges back to their original position. The resultant image is subtracted from the original image, giving any lines and spots which are lighter than the background. Dark lines and spots may be detected in a similar manner.

3.5 Special Uses of Nonlinear Filters

As stated in the previous section, there are image processing tasks in which linear filters perform poorly. When shrinking or expanding of regions is necessary, the best that can be done with a linear filter is to blur the regions. RANK filters using extreme rank values are excellent in this application [8]. When the minimum/maximum rank value is used, regions of higher intensity than surrounding regions shrink/expand respectively. This property is useful in the following applications.

When the 'skeleton' of objects within an image is to be extracted, a single pixel wide line along the length of the object is required. This can be achieved by using several iterations of a gated shrinking filter to each remove a layer of pixels. The gating is necessary to prevent the skeleton from being shrunk to nothing [6].

Cluster detection can also be performed by expanding regions until the closer ones coalesce. When the image is shrunk again, the regions which coalesced remain connected indicating clustering [8].

4. **CONCLUSIONS**

It has been shown that local operators can be applied to a wide variety of image processing tasks such as noise suppression, edge enhancement, edge detection and line detection. Linear filters work well in many applications, but have some undesirable side effects. When these are critical, nonlinear filters may be used. Nonlinear filters have been designed to overcome many of the limitations and deficiencies of their linear counterparts. The use of nonlinear filters also opens new areas of application such as skeletisation and cluster detection.

5. **ACKNOWLEDGEMENTS**

6. **REFERENCES**

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A) | 1  1  1 |    B) | 1  1  1 |    C) | -1 -1 -1 |    D) | -1 -1 -1 |
   | 1  1  1 |       | 0  0  0 |       | -1  8 -1 |       | -1 10 -1 |
   | 1  1  1 |       | -1 -1 -1 |      | -1 -1 -1 |       | -1 -1 -1 |
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Figure 1. Commonly used linear filter weights
A) Noise smoothing filter, B) Horizontal edge detector,
C) Omnidirectional edge detector, D) Edge enhancing
filter.

Tables: Comparison of tilters in different application areas.
Refer to text for fuller description.

1. NOISE SUPPRESSION – GAUSSIAN NOISE

Filter	Advantages	Disadvantages	Rating
Linear	Excellent Smoothing	Blurs edges,lose detail	Good
Gated	Retains edges	Some detail lost	Excel.
Trimmed	Retains edges	Some detail lost	Excel.
MEDIAN	Retains most edges	Blurs slightly,splotchy	V.Good

2. NOISE SUPPRESSION – "SALT AND PEPPER NOISE"

Filter	Advantages	Disadvantages	Rating
Linear	Simple	Poor smoothing	Poor
Gated		May misinterpret points	Good
Trimmed	Ignores Extremes	Some detail lost	Excel.
MEDIAN	Ignores Extremes	Blurs slightly,splotchy	V.Good

3. EDGE ENHANCEMENT

Filter	Advantages	Disadvantages	Rating
Linear	Simple	Ringing,noise amplified	Good
Gated	No noise amplification	Ringing	V.Good
RANK type	Excellent		Excel.

4. EDGE DETECTION

Filter	Advantages	Disadvantages	Rating
Linear	Simple	Very noise sensitive	Fair
Gated	Improved noise response		Good
SOBEL	Good noise response		V.Good
RANK type	Simple	Increased background	V.Good
moment	Integrates region	Contrast sensitive	V.Good

5. LINE AND SPOT DETECTION

Filter	Advantages	Disadvantages	Rating
Linear		Detects edges as well	Poor
Gated		Clumsy	Fair
Combined		Detects edges as well	Poor
RANK type	Dark or light detected		Excel.