Adaptive Contrast Enhancement Technique for Scanned Documents, Maps and Remote Sensing imagery

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Abstract

Remote sensing images contain features spanning almost the full dynamic range of gray values. The global techniques of histogram-based enhancement are unable to enhance such imagery. The local contrast enhancement proposed by (Beghdadi and Negrate, 1989) tends to enhance noise in homogeneous regions. We propose a method here based on edge-weighted averaging for measuring local contrast near edges, and propagate the background to interiors of homogeneous regions to produce noise tolerant local contrast enhancement. The enhancement of scanned maps and documents is considered next. Such images contain mainly line-like features, and the edge-based techniques are not suitable. We propose a technique for measuring the local contrast of such images based on the eigen-value of the Hessian of second derivatives. We then use the same propagation method to obtain enhancement of such images. The proposed techniques are illustrated with typical indoor imagery, remote sensing imagery and scanned maps.

Overview

1. Introduction

Contrast enhancement is one of the oldest problems in image processing both digital and analog. However, it is well known that there is no unique technique that works well with all classes of imagery. The classical techniques (Jain, 1989 & Rosenfeld and Kak, 1982) for digital image contrast enhancement are usually based on the analysis of the histogram, and known as point operation global methods. Linear stretching of the observed dynamic range of gray level to occupy the full available range is a very standard technique to stretch overall contrast. Non-linear functions like the exponential and logarithmic can also be used to preferentially stretch the contrast in bright and dark regions respectively. Histogram equalisation and specification are other global techniques. The global techniques completely fail when the original image is already occupying the full dynamic range, or when the contrast is varying in different parts of the image, which is usually the case for remote sensing imagery, and in scanned documents and maps. Further, the remote sensing image typically covers a very large area on ground, which may contain a wide variety of features.

The local techniques as opposed to the global ones attempt to measure the local contrast and enhance it. There is no standard definition for contrast; however, it is loosely understood as some quantity proportional to the difference in the intensity of the object and background pixels. Gordon (Gordon and Rangayan, 1984) for example proposed a method for estimating the object and background intensities as the window average over a small and large window size respectively. The contrast is then defined as the difference divided by the sum of the two averages so as to get a normalised value between –1 and 1. There is however an ambiguity in the choice of the window sizes. Later (Beghdadi and Negrate, 1989) proposed using the current pixel value as the object intensity, and estimating the background as the edge-strength weighted average of the intensities over a neighborhood window. They then proposed various schemes for enhancing the contrast thus obtained. Their scheme shows a better performance, however, a simple edge operator is used, and the ambiguity in the choice of the window size still remains, resulting in high sensitivity to noise, and a ringing effect around edges due to overshoots and undershoots.

In this paper the techniques proposed by (Beghdadi and Negrate, 1989) of local contrast enhancement of remote sensing digital imagery are extended so that the sensitivity to noise is reduced, and also the local ringing effect due to overshoots and undershoots are avoided. For another class of images, namely the scanned documents and maps, techniques for estimating and enhancing the contrast are developed.

2. Contrast enhancement

A flat facet world with additive Gaussian noise is first considered. Such a model is valid for remote sensing imagery. The edges of the flat facet should be ideally step edges in the absence of noise and blurring. Considering the limitation in the spatial resolution of such images, we can expect edges to be ramp edges (that is, more than one pixel wide), corrupted by white noise. Consider a pixel on a flat facet. To apply the basic concept of contrast, we need the value of object and background values. The object value is nothing but the intensity of the facet on which the pixel lies. The background for this facet is made of all the adjoining flat facets with which it shares its boundary. A perceptive definition of background for the pixel would be the facet on the other side of the edge closest to the pixel. Denoting the facet intensity of the pixel as Xo, and the facet value of the nearest other facet as Xb, the contrast for the pixel can be defined as

$$C = \frac{(X_o - X_b)}{(X_o + X_b)}$$

The contrast can be enhanced by increasing the magnitude of C. (Beghdadi and Negrate, 1989) suggest an enhancement as

$$C' = \sqrt{|C|}$$

The enhanced value of the pixel is then given by

$$X' = X_b * \frac{(1 + C')}{(1 - C')} \text{ if } C > 0 \text{ and}$$

$$X' = X_b * \frac{(1 - C')}{(1 + C')} \text{ otherwise.}$$

2.1 Estimation of background: Consider a pixel near the boundary of a flat facet, and consider a neighborhood around the pixel (pixel A in Figure 1). Since an edge passes through it, the background intensity should be calculated from those pixels in the neighborhood, not contained in the same flat facet as the centre pixel. Now consider the gradient magnitude as the edge strength for each pixel in the neighborhood. The pixels on and near the edge will have high strength, and the others should have ideally zero edge strength. Now consider the edge-strength weighted average of this neighborhood. This average would be the average of the intensities of the two flat facets, since each edge pixel would have this value and get the highest weight. This average is therefore a proper estimate of the background gray value. (Beghdadi and Negrate, 1989) use this estimate for all pixels. That is

$$X_b = \frac{\sum_{p \in w} E_p * X_p}{\sum_{p \in w} E_p}$$

where the average is taken over 'w' a window neighborhood, with each pixel p in the window having an edge-strength Ep, and gray value Xp. The edge-strength they use is the magnitude of the Sobel or Laplacian operator.

Consider a small part of face image shown in Figure 2a. The linearly stretched contrast enhanced image is shown in Figure 2b. Figure 3a shows the contrast image as obtained by Negrate's method described above, and Figure 3b shows the resulting contrast enhanced image by the above scheme. Figure 3b shows a considerable increase in contrast, however, it also shows an enhancement in noise evident in the homogeneous areas. This can also be seen from Figure 3a where even interiors of flat facets show high contrast.

2.2 Sensitivity to Noise: Now consider the case when no edge passes anywhere near the neighborhood of a pixel (pixel B in Figure 1). In the absence of noise, all such pixels would have zero edge strength, and the weighted average would be indeterminate (0/0). However, in the presence of noise, all pixels would contribute some edge strength, and the average would be sensitive to noise depending on the method used for measuring edge strength – gradient magnitude. The classical edge operators like the Sobel and Laplacian masks are limited in spatial extent, and are highly sensitive to noise. (Canny, 1986) has shown that use of scalable operators like the Difference of Gaussian (DoG) can help in decreasing in sensitivity to noise. The uncertainty in the exact location of the edge is also related to the scale parameter. Having an estimate of the noise level and blur factor helps in proper choice of this scale parameter.

Figure 3(c,d,e and f) show the result of using DoG operator for edge estimation with scale parameter sigma = 0.8 and 1.6. One can immediately observe the reduction in the contrast for pixels in the uniform regions (flat facets) as the sigma increases. Sobel operator can be thought of as having a sigma of 0.4.

2.3 Choice of neighborhood size: The choice of neighborhood size for background calculation depends on the scale parameter of the gradient operator. The effect of an edge would be felt up to about 3*sigma of the DoG. As Canny (Canny, 1986) has shown, the operator cannot detect edges which are closer than 3*sigma apart. Therefore, we may choose the neighborhood size to be up to twice the mask size of the DoG. Larger sizes may bring in more than one edge (more than two flat facets) and corrupt the estimate of the background. The presence of an edge passing through a pixel can easily be ascertained by examining the directional 2nd derivative in the gradient direction, which should have a zero crossing. These 2nd derivatives can also be obtained by convolving with Gaussian masks of corresponding derivatives (Steger, 1998).

The pixels whose neighborhood contains at least a few (say k) edge points will get a proper estimate of the background intensity. Usually an image contains some textural information draped over a flat facet. The contrast of the facet as a whole need to be considered ignoring

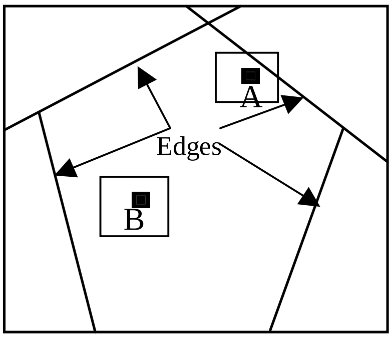
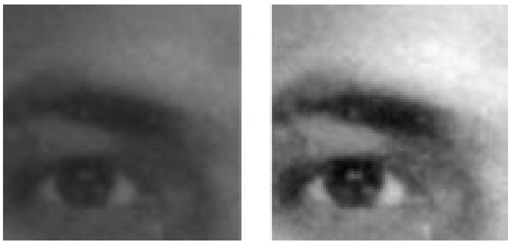


Figure 1: Neighborhood of Pixel A contains edge, neighborhood of B contains no edge



(a) (b)

Figure 2: (a) Original eye image, (b) Global Contrast stretched image

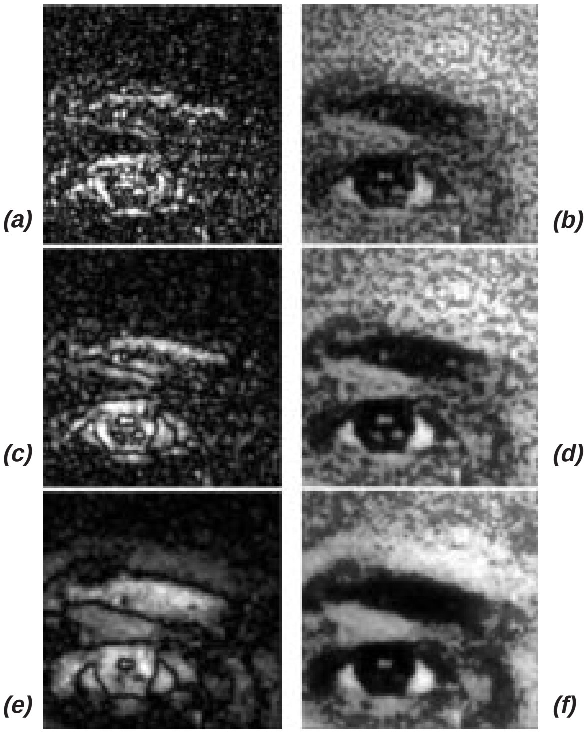


Figure 3: Contrast and enhanced images for different gradient masks. (a,b) Sobel operator; (c,d) DoG (sigma = 0.8); (e,f) DoG (sig = 1.6)

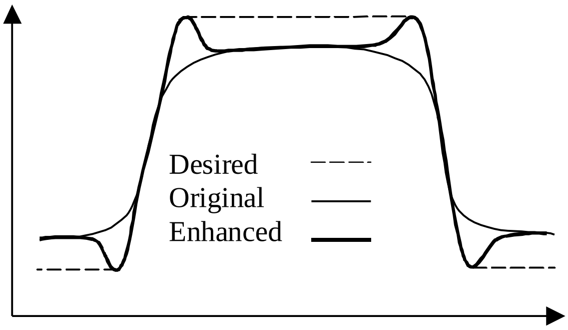


Figure 4: Profiles of original and contrast stretched edges showing the ringing effect near edges

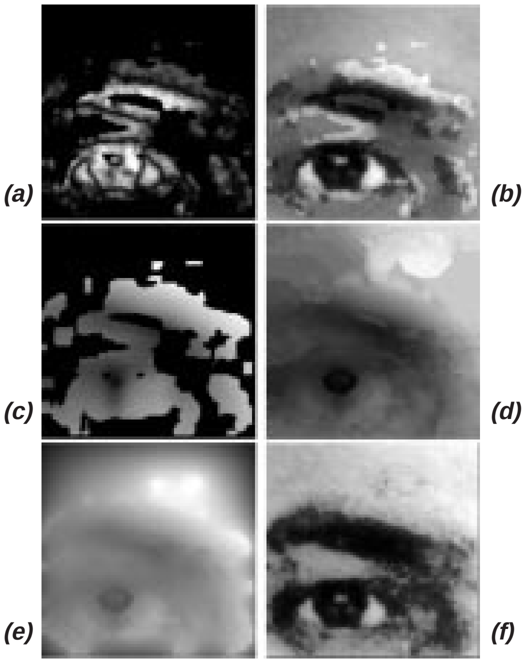


Figure 5: (a) Filtered contrast image, (b) Enhanced image using a, (c) Basic background image, (d) Propagated background image, (e) Smoothed background image, (f) Final enhanced image.

the local textural variations. This can be done by considering a suitable value of k to be the size of the corresponding Gaussian masks for the chosen sigma. When this restriction is put, the resulting contrast and enhanced images are shown in Figures 5a and 5b respectively. The contrast image looks pleasing, that is, all interiors of flat facets have zero contrast. However, Figure 5b shows a ringing effect near the edges. This effect is also present in all the previous enhanced images (3b,d, and f), but more prominent in Figure 5b due to the absence of noise.

2.4 Propagation of background: The contrast measured for interiors of flat facets have zero (or low) value, whereas, those in the neighborhood of edges have high value. An enhancement of such a contrast measure would

Figure 6: Top – Linear stretched remote sensing image, Middle – Local contrast enhancement by Beghdadi's method, Bottom – Local contrast enhancement by proposed method with sigma = 0.4 for DoG.

result in overshoots and undershoots near the edges. Consider an edge profile shown in Figure 4. The local contrast stretched profile is shown as a thick line, and the desired profile after enhancement is also shown in Figure 4 as a dotted line. The original and contrast stretched profiles are different only near the edges. This leads to the ringing effect seen in the output images in Figure 4. To avoid this ringing effect, a method of propagating the contrast/background value to the interior pixels of a facet is proposed. A heuristic technique for propagating the background value is as follows. The pixels, which have valid non-zero values of background forms the basic background image, and shown in Figure 5c. These pixels are first divided into two groups – those with positive contrast, and those with negative contrast. For each pixel which does not have a valid contrast (that is zero contrast) if it has 3 or more neighboring pixels having valid negative contrast, the maximum of such valid neighbor Xb is assigned as the minimum valid background value for the pixel. This operation is carried out iteratively on the negative contrast background image till all pixels get a valid negative contrast background value. (The assignment of valid values is done at the end of each iteration so as to avoid streaking effect.) Similarly the original pixels with positive contrast are propagated with a minima of neighbors rule to get another image.

The two final background images are then taken and the final background value for a pixel in the original image is calculated as follows. Let Xij be the intensity of the pixel, and let Mxij and Mnij be the value in the two propagated background images. If Xij lies between Mxij and Mnij, it is assigned a background value Xij (implies zero contrast). Otherwise, the value (Mxij or Mnij) nearest to Xij is taken as the background value. Figure 5d shows the resulting propagated background image. Again, since a flat facet may have different contrasts on different edges, further some may be positive, and some negative, some artificial flat facets seem to appear in the interiors of the original facets, and some smoothing is required over these propagated pixels. The smoothing used here is simple averaging over a 3x3 neighborhood for a few iterations. Figure 5e shows the final background image after smoothing, and Figure 5f shows the final contrast enhanced image using this smooth background.

A typical remote sensing image shown in Figure 6 is a part of image obtained from the PAN camera of IRS-1D satellite, and has a ground resolution of 5.8 m. It contains a wide variety of features useful in evaluating the performance of the enhancement technique. It has been enhanced using both Negrate's method and the proposed method, and the results are shown in Figure 6 Middle and Bottom respectively. The same value of sigma (=0.4) has been used, however, it can be clearly seen that even with this small sigma, it avoids the artifacts of noise evident in the uniform areas in Figure 6(Middle).

3. Contrast for Scanned documents and Maps

We now consider images obtained through scanning of documents, blue-prints, and maps. Such images essentially contain line features, and the flat facet model is not suitable. We now extend the interpretation of contrast for such images. A pixel may either be a background pixel or part of a line feature. The scalable concept of DoG can be extended for line detection (Steger, 1998). On a line pixel, the directional derivative across the line is zero, and the 2nd derivative in this direction has an extrema, which would be a maxima for dark line and minima for bright line. A reliable estimate of the line direction is given by the eigen-direction of the Hessian matrix formed by the local 2nd derivatives.

Extending the same argument as for edges, we can obtain the background value for a pixel by taking a weighted average of the neighborhood, where the line strengths of the pixels are the weights. The line strength is

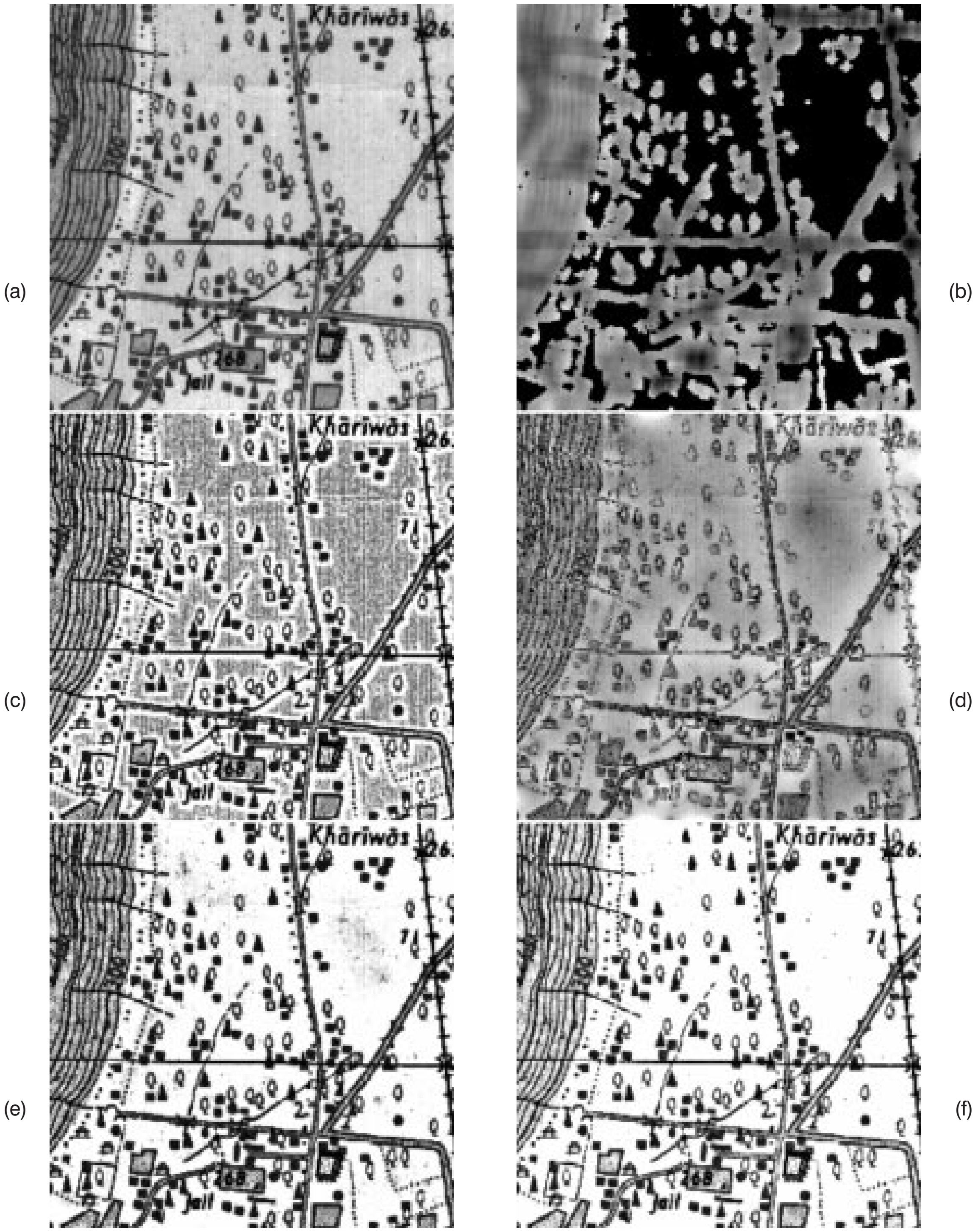


Figure 7: (a) Part of scanned map, (b) Enhancement using Beghdadi and Negrate's method, (c) Enhancement by edge-weighted background propagation, (d) Basic background image using eigenvalue-weighted average, (e) Final contrast image, (f) Final local line-enhanced image

given by the eigenvalue of the Hessian matrix. Further, using Steger's (Steger, 1998) method one can decide whether a line is passing through a given pixel by assuming a local cubic polynomial behavior. The scale parameter is chosen depending on the line width, and the window size for the neighborhood is taken as twice the size of the Gaussian mask by the same earlier argument. A similar method of propagation of background is carried out to obtain the final contrast values.

Consider a portion of a scanned map shown in Figure 7a. It contains a variety of features like contour lines in shaded background, ridge-ravine lines, roads, railway line and settlement symbols, text and some other symbols. The basic background image using the line strength is shown in Figure 7b, and the final contrast image is shown in Figure 7d. The final enhanced image is shown in Figure 7f. To compare with the edge-based contrast, the resulting enhanced images using Negrate's method, and the edge-based method of section 2 are shown in Figure 7c and 7e respectively. Negrate's method shows the typical artifacts due to noise. The edge-based method still leaves behind some noise. The line-based contrast method performs best. It is able to bring out all line-like features, and also suppresses other background. The clarity of text and every linear symbol is better in Figure 7f compared to that in Figure 7e. This is really useful as a preprocessing for binarising such scanned images.

4. Conclusions

Measurement of local contrast involves obtaining a suitable value for background of each pixel. It has been shown that the gradient weighted average provides a good estimate in the vicinity of edges. Further the use of suitable scale parameter in the gradient estimation is able to filter out noise to a large extent. For pixels not in the vicinity of edges, a technique has been proposed for propagating the background value. The complete algorithm for such a scheme is given in the appendix. The technique is suitable for remote sensing images, which satisfy the flat-facet assumption. The technique has been demonstrated for both indoor and remote sensing images.

Scanned images of maps and documents essentially contain line features corrupted with background noise. A technique for measuring the background value has been proposed based on the line strength estimated by the eigenvalue of the Hessian matrix of 2nd derivatives. The same scheme for background propagation is used to obtain enhancement of such images. The technique has been demonstrated using a scanned map and compared with the edge-weighted technique.

5. References

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Appendix

Algorithm for edge-weighted local enhancement:

1. Select scale parameter sigma based on knowledge of noise level and width of edge for derivative estimation, and generate the convolution masks for the required derivatives. Let the size of the masks be msize.
2. Calculate the gradient image using the gradient masks, and calculate the 2nd derivative for each pixel in the gradient direction.
3. Detect presence of zero crossing of 2nd derivative by simple examination of neighbors for change of sign, to generate a zero-crossing image.
4. For each pixel if the neighborhood contains at least msize edge (zero-crossing) pixels, calculate the gradient weighted average to obtain the background value for the pixel. This gives the basic background image.
5. Divide the background image into two images Mx – with positive contrast, and Mn with negative contrast by comparing with the original image value.
6. For each pixel in Mn having value zero, if it has at least 3 non-zero neighbors, assign the maximum of such values. Iterate the process till all pixels have non-zero values.
7. For each pixel in Mx having value zero, if it has at least 3 non-zero neighbors, assign the minimum of such values. Iterate the process till all pixels have non-zero value.
8. For each pixel if the original image value lies between the corresponding values in Mn and Mx, assign the original image value as the final background value. Otherwise, assign the value from Mn or Mx nearest to the original as the final background value. This gives the propagated background image.

9. Smooth the background image iteratively using a 3x3 average filter for pixels, which had zero background in the basic background image. This gives the smooth background image.
10. Calculate the contrast for each pixel, enhance it using square root, and obtain the enhanced image value from the increased contrast value. This gives the final contrast enhanced image.

Algorithm for line-weighted local enhancement:

1. Select scale parameter sigma based on knowledge of noise level and width of line for derivative estimation, and generate the convolution masks for the required derivatives. Let the size of the masks be msize.
2. Calculate the 2nd derivatives, Hessian matrix, and the eigenvalue and direction images for each pixel. This gives an eigen-value image and an eigen-direction image
3. Detect presence of zero crossing of 1st derivative within a pixel by modeling 3rd order behaviour in the eigen-direction. This gives a zero-crossing image.
4. For each pixel if the neighborhood contains at least msize line (zero-crossing) pixels, calculate the eigenvalue weighted average to obtain the background value for the pixel. This gives the basic background image.

Steps 5-10 are same as that for edge-weighted contrast enhancement.