CONTRAST ENHANCEMENT OF SATELLITE IMAGE BASED ON
ADAPTIVE UNSHARP MASKING USING WAVELET TRANSFORM

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ABSTRACT

This paper concerns with a method for unsharp masking for contrast enhancement of satellite image. We employ the
nature of wavelet transform that separates the original image into low and high frequency sub-band images as low
and high pass filter. Particularly, a number of high frequency sub-band images consist of horizontal, vertical, and
diagonal coefficients that contain detail information. Taking inverse wavelet transform of each sub-band image
separately except low frequency one, we have each of high frequency information in horizontal, vertical, and
diagonal image. All of them are scaled by the scaling factor in each one separately. Adaptive algorithm is
implemented to results the suitable scaling factor to obtain the enhanced image corresponding with the given
criterion based on variance of each area smooth and detail area. Experimental results show that our method
performs well to high enhance in detail area and low in smooth area.

INTRODUCTION

Generally, the unsharp masking algorithm (Polese, 2000) used a high pass filter to generate high frequency
components which consist of horizontal, vertical, and diagonal components. Consequently, they are separately scaled
by scaling factors suitably resulted from adaptive algorithm Gauss-Newton algorithm implemented. As the same
concept, in order to generate the high frequency components or multi-resolution sub-band images, 2-dimensional
discrete wavelet transform (2D-DWT) and 2-dimensional inverse discrete wavelet transform (2D-IDWT) (Mallat, 1989
and Daubechies, 1992) are then applied for decomposition and to reconstruction, together. The output images of 2D-
DWT-IDWT are the horizontal, vertical, and diagonal images, only used. In this our study, the four-tab Daubechies
wavelet algorithm (db4) is only implemented. Others does not consider here. The objective of contrast enhancement is
not only increasing variance in detail area but also unchanging or low increasing variance in smooth area. The local
dynamics of each image, which consist of local dynamics of the input-output image, the horizontal, vertical, and
diagonal images are then computed. The desired local dynamic is computed by scaling local dynamic of input image
dependent on the area to require enhancement. Difference between the desired local dynamic and the output one as
error value is used for adaptive algorithm to generate the suitable scaling factor. Each high frequency image is
separately scaled by the scaling factors. The enhanced image results from summation of the scaled high frequency and
input images.

This paper is organized as follows. In Section 2 wavelet transformation is briefly described; in Section 3 adaptive
unsharp masking algorithm by using wavelet transform for contrast enhancement is described. The experimental results
and conclusions are given in Section 4 and 5, respectively.

WAVELET TRANSFORMATION

Multi-resolution wavelet transform is used to decompose image into coarser resolution images which are called
sub-bands consisting of the low frequency approximation band and high frequency detail band. Figure 1(a) shows the decomposition of the original image into a number of sub-bands. In second level, sub-bands consisting of LL, LH, HL, and HH where LL is low frequency sub-band image containing the most important feature (the highest energy sub-band). Others LH, HL, and HH are the horizontal, vertical, and diagonal images, are high frequency sub-bands containing details such as the edge information. In Figure 1(a), g and h are 1-D decomposition low-pass filter and 1-D decomposition high-pass filter, respectively. Figure 1(b) shows the reconstruction of a number of sub-bands into reconstructed image and g’ and h’ are 1-D reconstruction low-pass filter and 1-D reconstruction high-pass filter, respectively.

In this paper, the four-tab Daubechies wavelet algorithm (db4) is used for computing discrete WT (DWT) to generate coefficients. Table 1 shows the decomposition and reconstruction filter coefficients of the four-tab Daubechies wavelet, respectively.

**Table 1. Decomposition and reconstruction filter coefficients of the four-tap Daubechies wavelet.**

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<th>g</th>
<th>h’</th>
<th>g’</th>
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<td>0.2304</td>
<td>-0.2304</td>
<td>-0.0106</td>
</tr>
</tbody>
</table>

**ADAPTIVE UNSHARP MASKING ALGORITHM**

Figure 2 shows a basis block diagram of the unsharp masking algorithm. The enhanced image $y(n,m)$ is obtained as following equation:

$$y(n,m) = x(n,m) + \lambda z(n,m)$$  \hspace{1cm} (1)

where $x(n,m)$ is the input image, $z(n,m)$ is the correction image which is high frequency component from wavelet transform of the input image, and $\lambda$ is the positive scaling factor to control the level of contrast enhancement to obtain output image.
Figure 2. The basis unsharp masking block diagram for enhancing image by using wavelet transform.

The high frequency components from wavelet transform consist of horizontal, vertical, and diagonal images. Let \( z_h(n,m), z_v(n,m), \) and \( z_d(n,m) \) be horizontal, vertical, and diagonal images. \( \lambda_h, \lambda_v, \) and \( \lambda_d \) are the positive scaling factors for horizontal, vertical, and diagonal images, respectively. Rewriting (1) is then as

\[
y(n, m) = x(n, m) + \lambda_h z_h(n, m) + \lambda_v z_v(n, m) + \lambda_d z_d(n, m)
\]  

and also write (2) in vector form

\[
y(n, m) = x(n, m) + \kappa x(n, m)Z(n, m)
\]

where

\[
\kappa(n, m) = [\lambda_h(n, m), \lambda_v(n, m), \lambda_d(n, m)]
\]

\[
Z(n, m) = [z_h(n, m), z_v(n, m), z_d(n, m)]
\]

The main objective of adaptive contrast enhancement algorithm is increasing local dynamics in detail areas and unchanged in smooth areas. The operator \( g(\cdot) \) is used to compute the local dynamics for input and output image as following

\[
g_h(n, m) = x(n-1, m-1) - x(n, m-1) - x(n+1, m-1) - x(n-1, m+1) + 8x(n, m) - x(n+1, m)
\]

\[
g_v(n, m) = y(n-1, m-1) - y(n, m-1) - y(n+1, m-1) - y(n-1, m+1) + 8y(n, m) - y(n+1, m)
\]

and also for horizontal, vertical, and diagonal images

\[
g_{z_h}(n, m) = z_h(n-1, m-1) - z_h(n, m-1) - z_h(n+1, m-1) - z_h(n-1, m+1) + 8z_h(n, m) - z_h(n+1, m)
\]

\[
g_{z_v}(n, m) = z_v(n-1, m-1) - z_v(n, m-1) - z_v(n+1, m-1) - z_v(n-1, m+1) + 8z_v(n, m) - z_v(n+1, m)
\]

\[
g_{z_d}(n, m) = z_d(n-1, m-1) - z_d(n, m-1) - z_d(n+1, m-1) - z_d(n-1, m+1) + 8z_d(n, m) - z_d(n+1, m)
\]

Writing (8), (9), and (10) is in vector form

\[
G(n, m) = [g_{z_h}, g_{z_v}, g_{z_d}]^T
\]
The desired local dynamic \( g_d(n,m) \) is defined as
\[
g_d(n,m) = \alpha(n,m)g_v(n,m)
\]
where \( \alpha(n,m) \) is a variable gain given by
\[
\alpha(n,m) = \begin{cases} 
\alpha_i & \text{if } v_i(n,m) < \tau_i \\
\alpha_m & \text{if } \tau_i < v_i(n,m) < \tau_z \\
\alpha_h & \text{if } v_i(n,m) > \tau_z
\end{cases}
\]
and \( \alpha_i, \alpha_m, \alpha_h \) are selected to achieve a desired level of the contrast enhancement at output image, \( \tau_i, \tau_z \) are the threshold values, and \( v_i(n,m) \) is the local variance
\[
v_i(n,m) = \frac{1}{9} \sum_{i=1}^{9} \sum_{j=1}^{9} (x(n,m) - \bar{x}(n,m))^2
\]
where \( \bar{x}(n,m) \) is the local mean.

To update the scaling factors, \( \lambda(n,m) \), the Gauss-Newton algorithm is implemented as following
\[
\lambda(n,m+1) = \lambda(n,m) + 2\mu e(n,m)\mathbf{R}^{-1}(n,m)\mathbf{G}(n,m)
\]
where \( e(n,m) = g_d(n,m) - g_v(n,m) \) is the error of local dynamics, \( \mathbf{R}(n,m) \) is an estimate of the autocorrelation matrix of the input vector \( \mathbf{G}(n,m) \). Figure 3 shows overall system of the adaptive unsharp masking block diagram by using wavelet transform for enhancing image.

![Figure 3. The overall system of the adaptive unsharp masking block diagram.](image)

**EXPERIMENTAL RESULTS**

The data used to test result is this paper is the satellite imagery acquired by the Landsat shown in Figure 4(a). The parameters for testing result are as following: \( \mu = 0.1, \tau_i = 10, \tau_z = 200, \alpha_i = 1, \alpha_m = 4, \alpha_h = 3 \) which are chosen by experiment. The three components of horizontal, vertical, and diagonal image as high frequency component result from two-dimension wavelet transform and inverse wavelet transform which are scaled separately by \( \lambda_i, \lambda_v, \lambda_d \) from adaptive algorithm as Gauss-Newton algorithm. Figure 4(b) shows the enhanced image. As the mentioned objective of contrast enhancement, the variance based criterion is evaluated. In smooth area both the original and enhanced images shown in Figure 5(a), the variances are the same of 3.25 which means that variance of our adaptive algorithm is unchanged. In detail area both the original and enhanced images shown in Figure 5(b), the variances are of
1105 and 1895, respectively, which means that variance is increased. All results from experiment are then corresponding with the desired criterion.

![Figure 4. (a) Original satellite image (b) the enhanced image.](image)

**Figure 4.** (a) Original satellite image (b) the enhanced image.

![Figure 5. Enlarged images (a) smooth area original image (left), enhanced image (right). (b) detail area original image (left), enhanced image (right).](image)

**Figure 5.** Enlarged images (a) smooth area original image (left), enhanced image (right). (b) detail area original image (left), enhanced image (right).

**CONCLUSIONS**

The our adaptive unsharp masking algorithm using wavelet transform for enhancing image shows the performance of experiment corresponding with the desired criterion. That is, the variance in smooth area is unchanged or low enhance; the variance in detail area is more increasing or high enhance.