Image Fusion Based on Wavelet and Curvelet Transform

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ABSTRACT

Image Fusion is a combination of two or more different images. It extracts the information from multiple source images. Wavelet based image fusion is suitable for representing the point singularities in one dimensions, but it fails to represent the edges across the curves in two dimensions. In this method, pixel level fusion based on curvelet transform detects the discontinuities across the curves. Curvelet improves the spatial characteristics and at the same time preserves the frequency characteristics. In curvelet transform operation, the image is first decomposed using the discrete wavelet transform to produce subbands at various levels. Then smooth partitioning is carried out by applying the grid of squares to the subband image, and a smooth window function is applied on that square. In the next step, each square is renormalized into unit square and then ridgelet transform is applied to get the fused image.

Keywords: Image Fusion, Wavelet and Curvelet Transform.

I. INTRODUCTION

Image fusion is a data fusion technology which keeps images as main research contents. It refers to the techniques that integrate multi-images of the same scene from multiple image sensor data or integrate multi images of the same scene at different times from one image sensor. It is a combination of two or more images and forms a new image by using certain algorithms. Image fusion is used to integrate the information of source images in order to get the more accuracy compared to original image. Image fusion concept is used in various fields like medicine, automatic change detection, machine vision and remote sensing. The image fusion algorithm based on Wavelet Transform which faster developed was a multi-resolution analysis image fusion method in recent decade [2]. Wavelet Transform has good time-frequency characteristics. It was applied successfully in image processing field [3]. Nevertheless, its excellent characteristic in one-dimension can’t be extended to two dimensions or multi-dimension simply. Separable wavelet which was spanning by one-dimensional wavelet has limited directivity.

Curvelet Transform consisted of special filtering process and multi-scale Ridgelet Transform. It could fit image properties well. However, Curvelet Transform had complicated digital realization, includes sub-band division, smoothing block, normalization, Ridgelet analysis and so on. Curvelet’s pyramid decomposition brought immense data redundancy [6]. Then E. J. Candes put forward Fast Discrete Curvelet Transform(FDCT) that was the Second Generation Curvelet Transform which was more simple and easily understanding in 2005[7]. Its fast algorithm was easily understood. Li Huishui’s researched multi-focus image fusion based on the
Second Generation Curvelet Transform [8]. This paper introduces the Second Generation Curvelet Transform and uses it to fuse images, different kinds of fusion methods are compared at last. The experiments show that the method could extract useful information from source images to fused images so that clear images are obtained.

II. WAVELET TRANSFORM

The image fusion algorithm based on Wavelet Transform which faster developed was a multi-resolution analysis image fusion method in recent decade. Wavelet Transform has good time-frequency characteristics. It was applied successfully in image processing field. Wavelets capture both time and frequency features in the data and often provides a richer picture than the classical Fourier analysis. Wavelet transform is a tool that cuts up data or functions or operators into different frequency components, and then studies each component with a resolution matched to its scale. Wavelet transform can be used multi resolution image fusion and medical image fusion at pixel level fusion scheme. Wavelets are successful in representing point discontinuities in one dimension, but less successful in two dimensions. By using wavelet transforms fusion technique, the fused images are very closely to output images.

Firstly, the image is decomposed into high-frequency images and low frequency images with wavelet transform. Then the spatial frequency and the contrast of the low-frequency image are measured to determine the fused low frequency image.

To the high-frequency image, we select the high-frequency coefficient based on the absolute value maximum principal and verify the consistency of these coefficients.

Drawbacks

DWT is not a suitable transform for edge information. For all medical images the contrast will be same so we can’t take contrast feature for Fusion.

III. CURVELET TRANSFORM

Sparse and edges representation in the 2D images destroy the Fourier transform and Wavelet transform. But Curvelet transform represents the edges effectively compare to other transforms because it is a multi scale directional transform with strong directional characters in which elements are highly anisotropic at fine scales.

Curvelet transform is to overcome the missing directional selectivity of conventional two dimensional discrete wavelet transform. It allows optimal representation of objects with discontinuities along smooth curves.

In Curvelet transform uses the angled polar wedges or angled trapezoid windows in frequency domain to resolve directional features.

Curvelet transform represents objects in the form of

\[ \| f - f_m \|_2^2 = O[m^{-2} \log_3 m] = O[m^{-2}] \]
Curvelet lets provide optimally sparse representations of objects which display curve punctuated smoothness-smoothness except for discontinuity along a general curve with bounded curvature. It is obtained Entropy, Mean, Correlation coefficient and Mean Square value better than what is achieved by more traditional methods.

Curvelets may also be a very significant tool for the analysis and the computation of partial differential equations. Curvelets also have special micro local features which make them especially adapted to certain reconstruction problems with missing data. In many medical applications Curvelet uses to reconstruct an object from noisy and topographic data.

It is based on Parabolic Scaling law

\[ \text{Width} = \text{Length}^2 \]

Curvelets are obtained by applying
- Parabolic dilation
- Rotations
- Translations to a specifically shaped function

Above functions are indexed by
- Scale parameter \( a \) (0\(<a\)<1)
- Location \( b \)
- Orientation \( \theta \)

Generalised equation for Curvelets

\[
\psi_{a,b,\theta} = a^{-3/4} \left( D_{a} R_{\theta} (x - b) \right)
\]

\[
D_{a} = \begin{pmatrix} 1/a & 0 \\ 0 & 1/\sqrt{a} \end{pmatrix}
\]

Image Fusion Based on Wavelet and Curvelet Transform

Procedures for image fusion by using curvelet transform

Images can be fused in three levels, namely pixel level fusion, feature level fusion and decision level fusion. Pixel level fusion is adopted in this paper. We can take operation on pixel directly, and then fused image could be obtained. We can keep as more information as possible from source images.
Using Wavelet Transform to decompose original images into proper levels. One low-frequency approximate component and three high-frequency detail components will be acquired in each level.

Curvelet Transform of individual acquired low frequency approximate component and high frequency detail components from both of images, neighbourhood interpolation method is used.

According to definite standard to fuse images, local area variance is chose to measure definition for low frequency component. First, divide low-frequency $C_{j_0}(k_1, k_2)$ into individual foursquare sub-blocks which are $N_1 \times M_1$ (3x3 or 5x5) then calculate local area variance of the current sub-block:

$$STD = \sqrt{\frac{\sum_{i=-N_1/2}^{N_1/2} \sum_{j=-N_1/2}^{N_1/2} [C_{j_0}(i+k_1, j+k_2) - \overline{C_{j_0}}(k_1, k_2)]^2}{N_1 \times M_1}}$$

Here $\overline{C_{j_0}}(k_1, k_2)$ stands for low-frequency coefficient mean of original images. If variance is bigger, it shows that the local contrast of original image is bigger.

Regional activity $E_{j_2}(k_2)$ is defined as a fusion standard of high-frequency components. First, divide high-frequency sub-band into sub-blocks, then calculate regional activity of sub-blocks.

$$E_{j_2}(k_2) = \sum_{i=-N_1/2}^{N_1/2} \sum_{j=-N_1/2}^{N_1/2} [C_{j_2}(i+k_1, j+k_2) - \overline{C_{j_2}}(k_1, k_2)]^2$$

Inverse transformation of coefficients after fusion, the reconstructed images will be fusion images.

**Multi Focus Image Fusion**

The two images to fuse are obtained by applying different side blurring to the same original image. The first image is obtained by blurring the left side part of the original image while the second one is produced by blurring the right side part. The fused image will contain all the features of the original image.

**Medical Image Fusion**

In medical, CT and MRI image both are topographic scanning images and have different features. In CT image brightness is related to tissue density. So the brightness of bone is higher and some of soft tissue can’t be seen in CT images. In MRI image brightness is related to amount of hydrogen atom in tissues, thus brightness of soft tissue is higher, and bones can’t be seen. By using fusion technique, it can be possible to get both information in the single output image.
IV. EXPERIMENTAL RESULTS

Multi Focus Image Fusion

In the Figure 1 (a) some part of image is lost and in Figure 1 (b) other some part of image is lost and in final image Figure 1 (c) image fusion is done by using wavelet transform. The values are tabulated as shown in the table II.

![Multi-focus lab images and their image fusion.](image1)

(a) (b) (c)

Table I. Evaluation of the Multi-Focus Image Fusion Results

<table>
<thead>
<tr>
<th></th>
<th>Correlation Co efficient</th>
<th>Entropy</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lena 1</td>
<td>1</td>
<td>7.4726</td>
<td>0.3878</td>
<td>6.4239</td>
</tr>
<tr>
<td>Lena 2</td>
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<td>7.4731</td>
<td>0.3879</td>
<td>6.4267</td>
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<tr>
<td>Fused Image</td>
<td>1</td>
<td>7.4811</td>
<td>0.3888</td>
<td>6.4421</td>
</tr>
</tbody>
</table>

![Multi-focus lab images and their image fusion.](image2)

(a) (b) (c)

Table II. Evaluation of the Multi-Focus Image Fusion Results

<table>
<thead>
<tr>
<th></th>
<th>Correlation Co efficient</th>
<th>Entropy</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blur 1</td>
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<td>0.3930</td>
<td>9.6540</td>
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<tr>
<td>Blur 2</td>
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<td>7.2564</td>
<td>0.3891</td>
<td>9.6300</td>
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<tr>
<td>Fused Image</td>
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<td>7.3533</td>
<td>0.4011</td>
<td>9.8657</td>
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</table>
Fig. 3 Multi-focus lab images and their image fusion.
(a): right-focus; (b): left-focus; (c): fused image of DWT;

Table III. Evaluation of the Multi-Focus Image Fusion Results

<table>
<thead>
<tr>
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<th>Correlation Coefficient</th>
<th>Entropy</th>
<th>Mean</th>
<th>RMS</th>
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<tbody>
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<td>Fused</td>
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<td>0.3899</td>
<td>9.3202</td>
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</table>

Medical Image Fusion

Here MRI and CT images are fused.

Fig. 4. Multi-focus lab images and their image fusion.
(a): CT image; (b): MRI image; (c): fused image of DWT;

Table IV. Evaluation of the Multi-Focus Image Fusion Results

<table>
<thead>
<tr>
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<th>Correlation Coefficient</th>
<th>Entropy</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CT image</td>
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<td>MRI image</td>
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<td>Fused Image</td>
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<td>0.4358</td>
<td>7.6981</td>
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</tbody>
</table>
V. CONCLUSION

This paper puts forward an image fusion algorithm based on Wavelet Transform and the Curvelet Transform. It includes multi resolution analysis ability in Wavelet Transform, also has better direction identification ability for the edge feature of awaiting describing images in the Curvelet Transform. This method could better describe the edge direction of images, and analyzes feature of images better. According to it, this paper uses Wavelet Transform into fusion images, then makes deep research on fusion standards and puts forward corresponding fusion projects. At last, these fusion methods are used in simulation experiments of multi-focus and complementary fusion images. In vision, the fusion algorithm proposed in this paper acquires better fusion result. In objective evaluation criteria, its fusion characteristic is superior to traditional DWT and FCT’s.

REFERENCES


