Fast and Efficient Satellite Imagery Fusion Using DT-CWT and WZP

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Abstract—**Among the various image fusion methods, wavelet-based method provides superior radiometric quality. However, fusion processing is not simple or flexible because many low- and high-frequency subbands are often produced in the wavelet domain. To address this issue, a novel dual-tree complex wavelet fusion method that uses wavelet domain zero-padding (WZP) is proposed. Experiments conducted using high-resolution satellite images demonstrated promising results in terms of computation cost.**

Keywords-image fusion; dual-tree complex wavelet; wavelet domain zero-padding.

I. INTRODUCTION

Satellite imaging sensors typically supply a low-resolution multispectral (LRM) image and a high-resolution panchromatic (HRP) image separately because of physical and technological constraints [1]. Among the many image fusion methods that are currently available, discrete wavelet transform (DWT) methods provide superior fused images that maintain the radiometric information of the LRM image. Although the DWT-based methods are spectrally consistent, there are two problems. First, DWT is shift-variant and exhibits artifacts because of aliasing in the fused image [2]. Second, these fusion methods have a high computation cost and complexity. The first problem can be overcome by the dual-tree complex wavelet transform (DT-CWT), which is nearly shift-invariant and directionally selective in two or more dimensions [3]. Additionally, if fused data from specific fusion method are nearly identical with other fused data from a more computationally efficient method, the latter method is ideal for a large quantity of remote sensing data. This paper proposes a fast and efficient DT-CWT fusion method to address the second problem. In Section 2, the proposed DT-CWT fusion method is presented and result and conclusion are drawn in Section 3.

II. DT-CWT AND IMAGE FUSION

A. DT-CWT

Kingsbury [4] introduced a new type of wavelet transform known as the DT-CWT, which exhibits a shift-invariant property and improves directional resolution compared with the DWT. The DT-CWT with the complex wavelet function and complex scaling function decomposes an image into one complex scaling subband and six complex wavelet subbands at each decomposition level.

B. Perfect Reconstruction with WZP

An image can be decomposed into a series of low- and high-frequency subbands using the specific wavelet transform. Perfect reconstruction (PR) means that the final image is the same as the original image. WZP was used to produce super-resolved imagery by filling the unknown high-frequency subbands with zeros and applying the inverse wavelet transform [5]. The WZP method can be conversely applied in image fusion. That is, the known low-frequency subbands can be filled with zeros. Then, by performing the inverse wavelet transform, only a single high-frequency image in the spatial domain is produced. This approach can be applied to the DT-CWT. That is, the low frequency of the original image can be easily discarded. The PR condition and WZP method of the DT-CWT are shown in Figure 1. This approach can be simply implemented as an additive wavelet method.

C. Proposed DT-CWT Fusion Method

The procedure of the proposed DT-CWT with additive-wavelet (AW) fusion method can be summarized as follows:

1) Perform histogram matching between the HRP image and intensity image.

2) Decompose only the histogram-matched HRP image.

3) The low-frequency subbands of the decomposed HRP image are filled with zeros.

4) An inverse DT-CWT (IDT-CWT) is conducted to produce the wavelet plane (WP). The WP is the sum of the high frequencies and contains the detailed geometric information of the HRP image.

5) The WP is added to the resized LRM image, and finally, the fused HRM image is generated.

This fusion method can produce the same type of fused imagery produced by the conventional AW methods. However, the proposed method is simpler and more flexible in that this method fused in the spatial domain. The method is illustrated in Figure 2.

III. RESULT AND CONCLUSION

In this study, we used WorldView-2 satellite images. In our experiments, the LRM image size was 512 × 512 pixels, and the HRP image size was 2048 × 2048 pixels. We

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compare our fusion method with DT-CWT with the substitute-wavelet (SW) method [3]. We compared the fusion processing time based on the computation cost. The reported times were measured in the Matlab 2014b environment and on a quad-core 2.5 GHz personal computer platform using the average elapsed time of 20 trials. Table I demonstrates the elapsed time. The DT-CWT with the SW method was very slow because of the decomposition of the LRM image and the substitution process in the wavelet domain. On the other hands, the proposed method is nearly five times faster than the DT-CWT with the SW method. If the histogram matching were performed with each LRM image rather than the intensity image, the elapsed time would be increased in proportion to the total number of bands. Most significantly, the proposed fusion method increases flexibility because the wavelet domain fusion is simplified to the spatial domain by adopting the WZP method. Also, Table II shows the performance comparisons of the fused images. The results indicated that the proposed fusion method provides a less distorted fused image compared with DT-CWT with SW method. Thus, the proposed approach facilitates the general and less computationally intensive fusion method using the DT-CWT.

TABLE I. ELAPSED TIME COMPARISON

Fusion Methods	Elapsed Time (Sec)
DT-CWT with SW [3]	17.2759
Proposed method	3.2554

TABLE II. QUALITY INDICES

Fusion Methods	D_λ	D_S	QNR
DT-CWT with SW [3]	0.0269	0.0172	0.9564
Proposed method	0.0249	0.0165	0.9590

ACKNOWLEDGMENT

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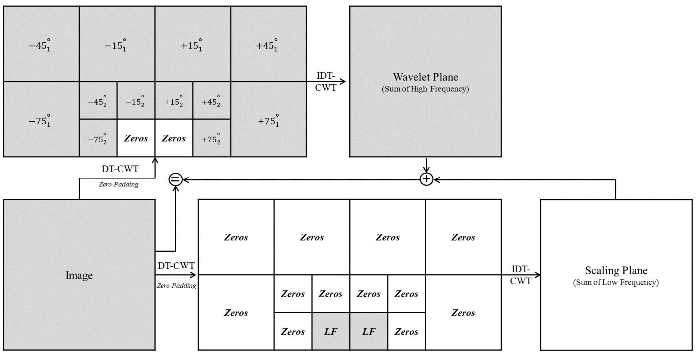

Figure 1. PR condition and WZP of the DT-CWT.

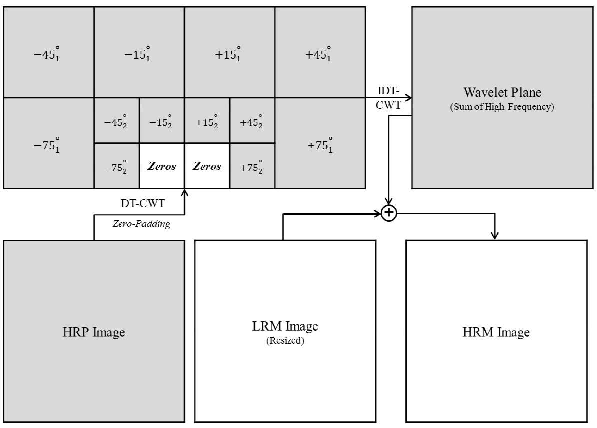

Figure 2. Proposed DT-CWT fusion method with the AW method.