

An Efficient Novel Multi-resolution Wavelet Hybrid Matching Method For Satellite Images

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ABSTRACT

This novel feature-based method is able to reduce the computation overheads without compromising the matching accuracy of satellite images. It incorporates the bi-orthogonal wavelet filter using B-splines designed by Yu and Ho [1]. The bi-orthogonal wavelet filter is used to perform multi-resolution edge extraction and multi-resolution matching. Edges are matched using adaptive matching windows that vary their shapes according to the directions of the edges. An adaptive searching range is applied because the searching range of each edge point may be different. Moreover, the matched results for low resolution levels are utilized for interpolating high resolution mismatched pixels. Detailed comparison with other new feature-based algorithm on SPOT and aerial stereo images was performed. The results obtained show that the proposed algorithm was computationally more efficient as well as achieving an overall improved matched accuracy.

Keywords: wavelets stereo matching multi-resolution edge extraction

1. INTRODUCTION

Binocular stereo vision processes estimate 3D surfaces using a pair of stereo images taken from different points of view. Areas or features in two-dimensional images, corresponding to the projections of the same 3D points, are matched. The process involves identifying corresponding features in two views and using their relative displacements together with geometry to estimate their height. The stereo matching of satellite images is a difficult problem that continues to challenge researchers since it contains a large amount of details. Thus identification of the corresponding points in two images, which are cast by the same point in real world, is an important step in the stereo analysis. During matching, shape similarity and search range will mainly determine the matching accuracy

Many methods have been proposed in stereo matching. Unfortunately, till now no methods can be applied in the practical application yet. This field still under exploitation and new algorithms are continued to be proposed to achieve good results. All methods can be classified into largely two classes: feature-based and area-based matching.

We can say that matching of features is a search problem. Most of previous methods on stereo matching¹⁻⁴ fixed the searching range to a certain size during the whole process. Usually the images are divided into many small blocks, non-overlapped or overlapped. The search of shape similarity is performed within the corresponding block. If the matching window is too small and does not cover enough intensities variation, it gives a poor disparity estimation, because the signal to ratio is low. If the window is too large, then the position of maximum correlation may not represent the correct matching due to different projective distortions in left and right images. Furthermore, unchanged searching range may cause time-consuming problem or increase mismatch.

Due to the drawback mentioned above, a novel multi-resolution wavelet hybrid matching method based on feature information is proposed in this paper. In section 2, we provide a detail description on our new method: a brief introduction on bi-orthogonal wavelet characteristics, adaptive matching window and adaptive searching range. The matching and comparison results are presented in the section 3.

2. PROPOSED STEREO MATCHING ALGORITHM

2.1 Bi-orthogonal wavelet

Wavelet transform is an orthogonal (or bi-orthogonal) transform^{5,6}. Compared to a normal FFT or DCT orthogonal transform, wavelet transform is a new time-frequency two dimensional signal analysis method. Harr described the first wavelet basis in 1910 now known as the Harr wavelet basis. However, this wavelet does not form a continuous basis. In the 1980s, researchers such as Coifman, Daubechies⁷, Mallat⁸ and Meyer performed many pioneering work in wavelets, especially in multi-resolution and fast wavelet transforms. As a result, wavelet transform began to find more and more applications in digital signal and image processing.

Although the theoretical basis of orthogonal analysis is very sound, it is not simple to derive an orthogonal wavelet basis. Normally, the basis of orthogonal wavelet transform is neither compact support nor continuous. This means it is not a straightforward task to design linear FIR filters based on orthogonal wavelets. Moreover, the application of wavelet transforms in image processing requires linear phase FIR filters. Yu and Ho⁹ have designed several kinds of wavelets and FIR filters through B-splines. Bi-orthogonal wavelets are based on two multi-resolution analyses: $\{V_m\}$, $\{W_m\}$ and $\{\tilde{V}_m\}$, $\{\tilde{W}_m\}$. They satisfy the following conditions:

$$V_m \perp \tilde{W}_m, \tilde{V}_m \perp W_m$$

And their Z-transforms satisfy¹⁰:

$$|H(z)| |\tilde{H}(z)| + |H(-z)| |\tilde{H}(-z)| = 1 \quad (|z|=1)$$

These filter banks all have the following important characteristics:

- Satisfy bi-wavelet analysis conditions;
- Bases are compact support and continuous;
- High efficiency;
- Linear phase;
- Signal can be reconstructed exactly.

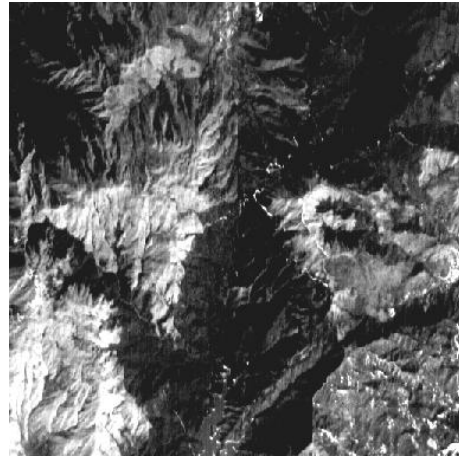
Typically, a wavelet transform includes a filter pair: a high-pass filter and a low-pass filter. In this paper, the wavelet FIR filter designed by Yu and Ho⁹ is used for image transformation. Unlike ordinary applications, we choose only low pass filter to filter our images. The implementation steps will be described in section 2.2.

2.2 Multi-resolution edge extraction

The proposed method is performed on a subset of a SPOT stereo image pair taken from the scene of Hongkong from different view angles. The resolution of the stereo image pair is 10 meters. Hongkong terrain area (512×512) is cut from the HongKong stereo image pair for our experiment as shown in figure 1.



(a) Left subset image



(b) Right subset image

Figure 1 Subset of SPOT stereo image pair for our experiment

Our method is a feature-based matching system^{11, 12, 13}. Bi-orthogonal wavelet transform is first applied to extract the edges. Using this wavelet transform, multi-resolution¹⁴ edges are extracted. Therefore under different resolution levels, different edge details are extracted according to a specific application. We modified Starck-Murtagh-Bijaoui algorithm¹⁵⁻¹⁸ due to the good edge extraction result of this method. Our edge extraction procedure are described as follows:

Begin {

1. Use low pass filter on the stereo image pair, transform level j depends on edge extraction process.

$$C_j(k) = \sum h(l)C_{j-1}(k + 2^{j-1}l) \quad (1)$$

where $h(l)$ is lowpass filter, then the wavelet plane can be obtained:

$$W_j(k) = C_{j-1}(k) - C_j(k) \quad (2)$$

2. Place a threshold T on the wavelet plane, discard the pixel value which is smaller than T
3. Sobel operator is applied to solidify edge in resolution level j
4. Reconstruct the image

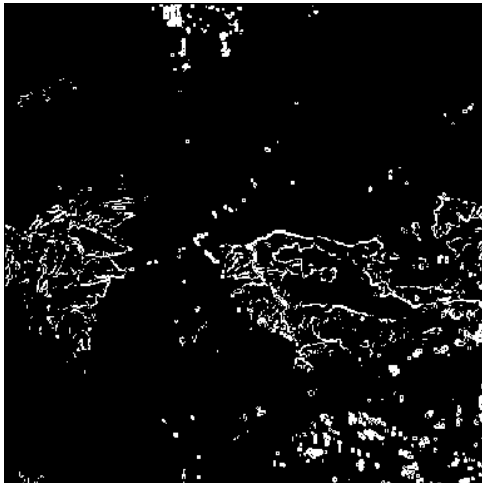
$$C_{j-1} = C_j + w_j \quad (3)$$

j is wavelet transform level

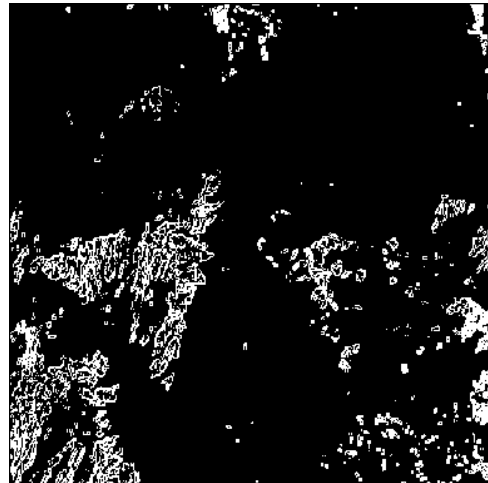
5. Increase j and continue to perform wavelet transform

}

And j will determine whether more or less fine edges are extracted or not. Figures 2 and 3 show edge extracted images in two different edge scales.

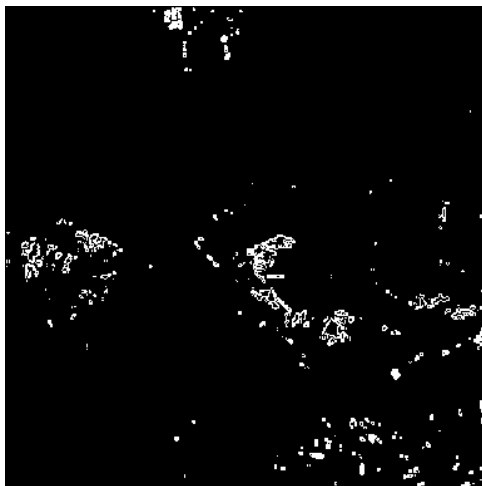


(a) Left edge extraction

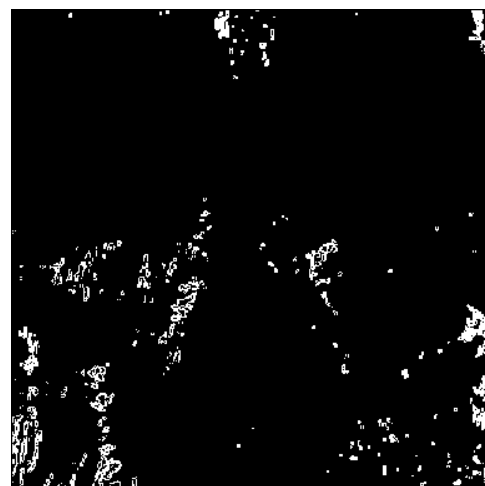


(b) Right edge extraction

Figure 2 Edge extraction in a high resolution level ($j=5$), more fine edges



(a) Left edge extraction



(b) Right edge extraction

Figure 3 Edge extraction in a low resolution level ($j=12$), less fine edges

2.3 Adaptive matching window

After edge thinning²⁰, adaptive matching window (figure 4) is applied to the left edge image. The window size is determined according to the directions of edge pixels. The matching window shape is rectangular. At first the initial window is only one pixel wide. Then in the left edge image, inside the initial matching window, the central pixel's direction is compared to all of its neighbor pixels. And this window is expanded toward that direction in which the neighbor pixel has the same direction as the central pixel. The window searches 8 directions and continues to expand according to specific edge directions until it reaches its permitted maximum size. So each window size may be different according to the specific edges. After that the edge pixels inside the window are regarded as a template. And the template will be placed on the right

edge image and search within the searching range. Normalized cross-correlation between two edge pixels is then calculated and the two pixels with the highest correlation coefficient are selected as a matched pair.

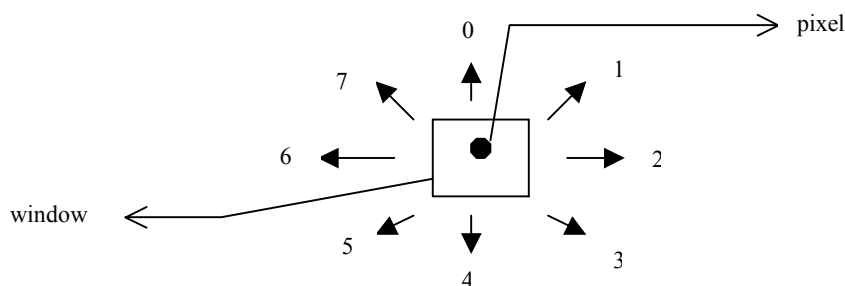


Figure 4 Adaptive match window

2.4 Adaptive searching range

Searching range is a key problem. If the range is too large it will be very time-consuming and produces more falsely matched points; however, small range will be faster but causes less accurate match. Our proposed method uses an adaptive searching range on the right edge image by making use of some known information of the satellite images. We use some known control point coordinates to rectify stereo image pair using the software ERMAPPER. As a result, Easting and Northing coordinates of each pixel point are obtained. With these Easting and Northing coordinates information, each 2D pixel point's position is estimated in the left and right images. After that the "shift" of the alternative matched pixels on the left and right images can be determined. And then the "shift" is used as the searching range. For example, in figure5, we choose 4 pixel points (4 points are marked out in figure 5) from the experimented stereo image pair. From table 1, the Easting, Northing coordinates and corresponding image coordinates, "shift" and alternative searching range are presented. This means that every pixel point's searching range is specifically determined.

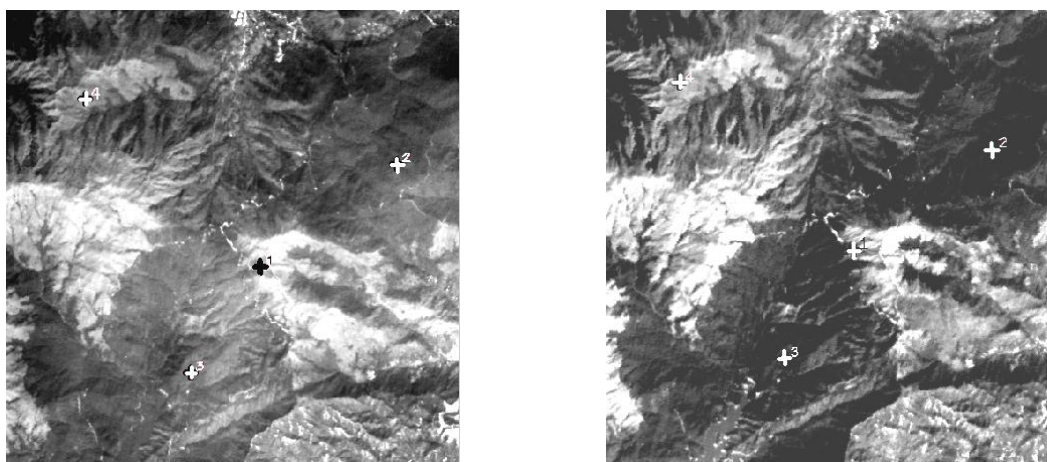


Figure 5 Example of selected points for illustration of adaptive searching range

Easting	Northing	Left Image		Right Image		"shift"		Alternative searching range
		Cell x	Cell y	Cell x'	Cell y'	Δx	Δy	
826021.45E	2481143.33N	280.25	297.04	279.56	272.32	0.69	24.72	0.69×25
827575.58E	2482310.42N	434.67	164.67	432.97	154.27	1.7	10.4	1.7×10
825242.25E	2479963.75N	201.33	391.33	200.24	384.94	1.09	6.39	1.09×6
824055.58E	2483057.09N	83.67	102.00	82.97	73.60	0.7	28.4	0.7×28

Table 1 Selected points "shift" and alternative searching range

2.5 Construction of final disparity Map

After matching in higher resolution levels (such as $j \leq 4$ in equation (1)), we then perform matching in lower resolution levels (such as $j > 4$ in formula (1)) in a similar manner. In order to get more accurate digital elevation model file, we need to acquire more matched points. So in practice, we perform multi-resolution matching from $j=1$ to $j=4$ or higher. The low resolution level matched results are used to interpolate high resolution level falsely matched points. For example, $j=3$ level matched results are used to interpolate $j=2$ level matched results. The algorithm are described as follows:

Begin {

- 1) Select a matched pair p_{left_j}, p_{right_j} (such as point 3 marked in figure 5), the normalized cross-correlation coefficient between p_{left_j} and p_{right_j} in resolution level 2 ($j=2$ in equation (1)), marked as C_2 ;
 - 2) The same as for p_{left_j} and p_{right_j} , its normalized cross-correlation coefficient between left and right image in resolution level 3 ($j=3$), marked as C_3 ;
 - 3) If $C_2 > C_3$, keep level 2 matched results, else if $C_2 < C_3$, replace level 2 matched results with level 3 matched results;
 - 4) Go back to step 1) for next pixel point
- }

Keep this comparison until all levels' matched results have been compared and combined. Finishing this step we can acquire the final disparity map. And figure 6 shows our experiment results after 4 level of interpolation

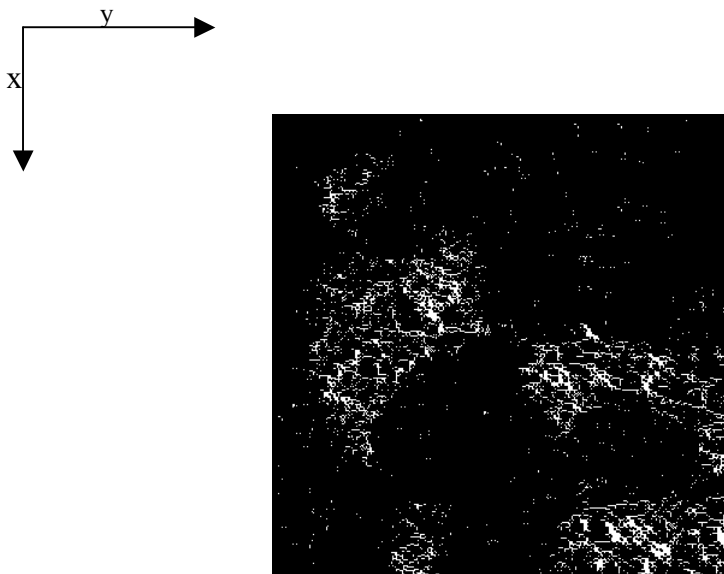


Figure 6 Final disparity Map

3. COMPARISON

Past researches mainly on feature-based stereo matching^{[21][22][23]} intended to fix the search range and the template window size. The basic idea of these algorithm is:

1. After feature (edge) extraction, the edge images are divided into many small blocks, non-overlapped or overlapped

2. Fixing matching window, saying 20×20 or other size
3. Fixing the searching range to certain size, can be 1×64 (epipolar constrain) or other size; use the improved formula to match similarity
4. During the whole matching process, the search of shape similarity is performed within the corresponding block.

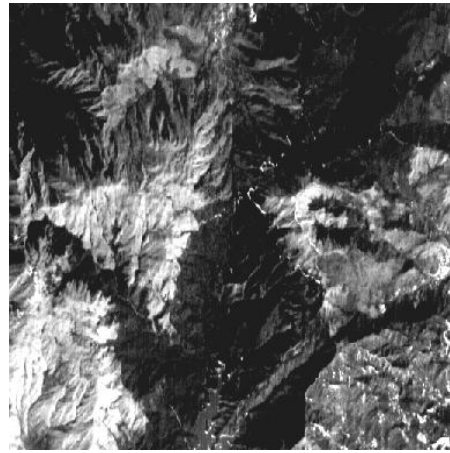
For comparison the method proposed by Goulermas, et.al.^[24] that offers good matching performance is chosen to compare with our method. Performance trade off is performed by computing computation and matched rates. All experiments are performed on the same PC(Pentium II 450M). The general computation formula is shown as follows:

$$Computation = (template\ size) \times (search\ range) \times (edge\ pixel\ number) \times Multi-resolution_levels \quad (4)$$

In Goulermas et.al algorithm, the above formula does not include the last item because their algorithm does not have multi-resolution matching. The last item in equation (4) does not affect our method's computation because it is only an addition instead of multiplication. The comparison results are shown in the following.



(a) Left image



(b) Right image

Figure 7 Hongkong terrain

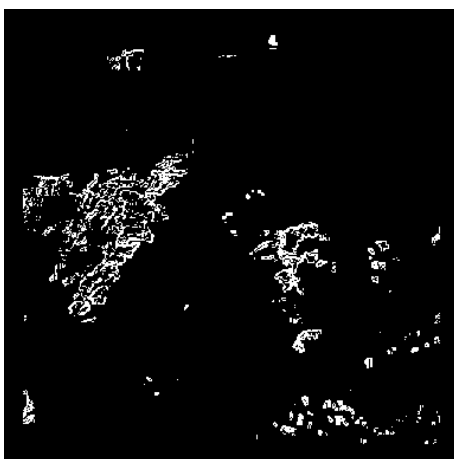
Assume the computation of Goulermas et.al algorithm is T hours.

	Goulermas et.al algorithm	#Proposed algorithm
Computation	T (hour)	$\approx T/4$ (hour)
Edge pixels	20137	20546
*Matched pixels	13760	14304
Matched rates	68.33%	69.62%

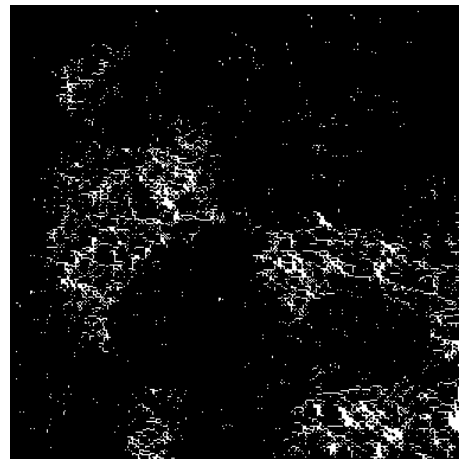
*Matched pixels: since left image edge pixels are different from the right image edge pixels, here we chose the mean value of the left edge pixel number and the right edge pixel number.

#Proposed algorithm calculates the edge pixels from average edge pixels from different resolution level.

Table 2 Computation and match rates of the two algorithms on Hongkong terrain



(a) Goulermas et.al algorithm



(b) Proposed algorithm

Figure 8 Comparison of the two algorithms

Simulation also performs on other stereo images Pentagon, Street, Ship.

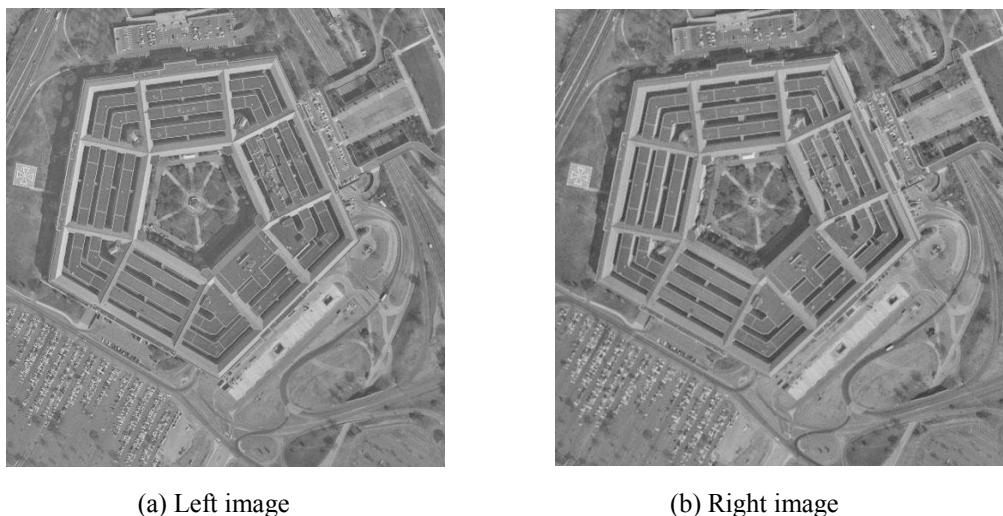


Figure 9 Classical Pentagon building

T and other information are the same as shown in table 2

	Goulermas et.al algorithm	# Proposed algorithm
Computation	T (hour)	$\approx T/2$ (hour)
Edge pixels	50046	50301
*Matched pixels	44005	44531
Matched rates	87.93%	88.53%

Table 3 Computation and match rates of the two algorithms on Pentagon building

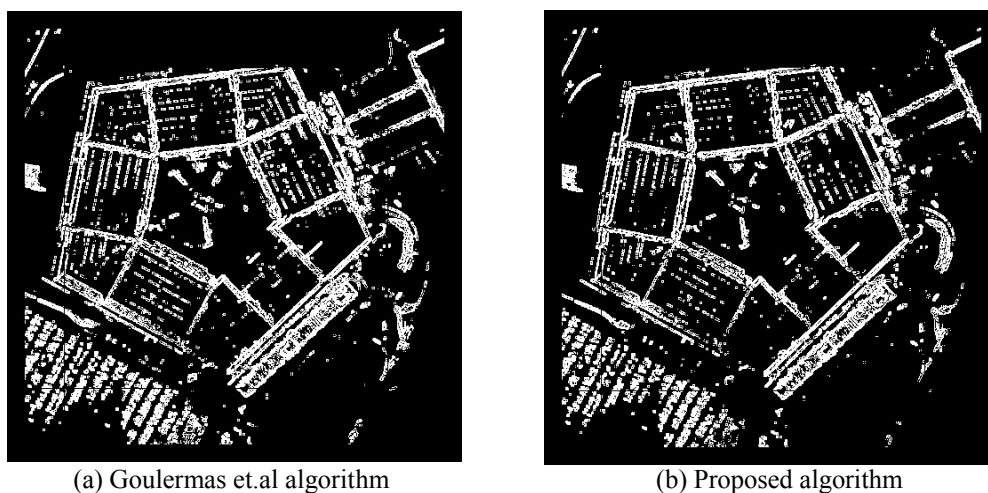


Figure 10 Disparity map of the two algorithms on Pentagon building

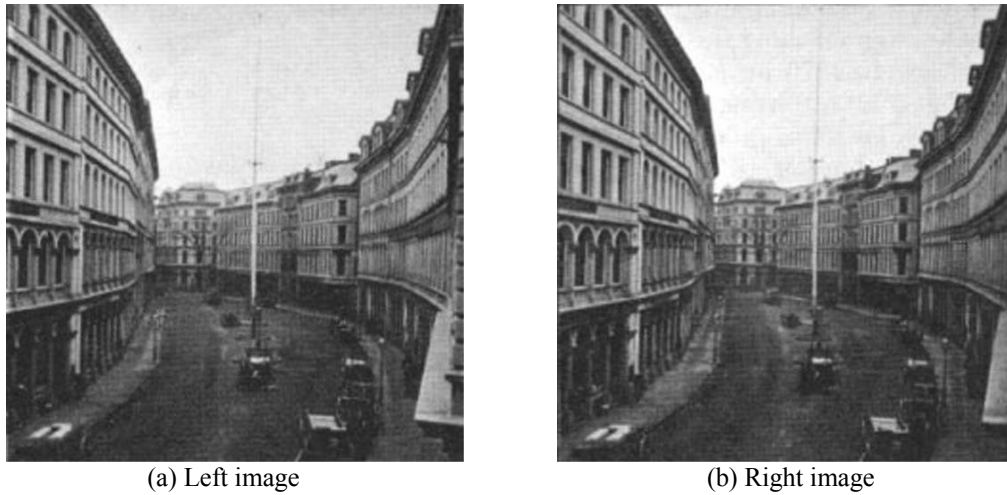


Figure 11 Street

T and other information are the same as shown in table 2

	Goulermas et.al algorithm	# Proposed algorithm
Computation	T (hour)	$\approx T/2$ (hour)
Edge pixels	27242	27301
*Matched pixels	20974	21156
Matched rates	76.99%	77.49%

Table 4 Computation and match rates of the two algorithms on Street

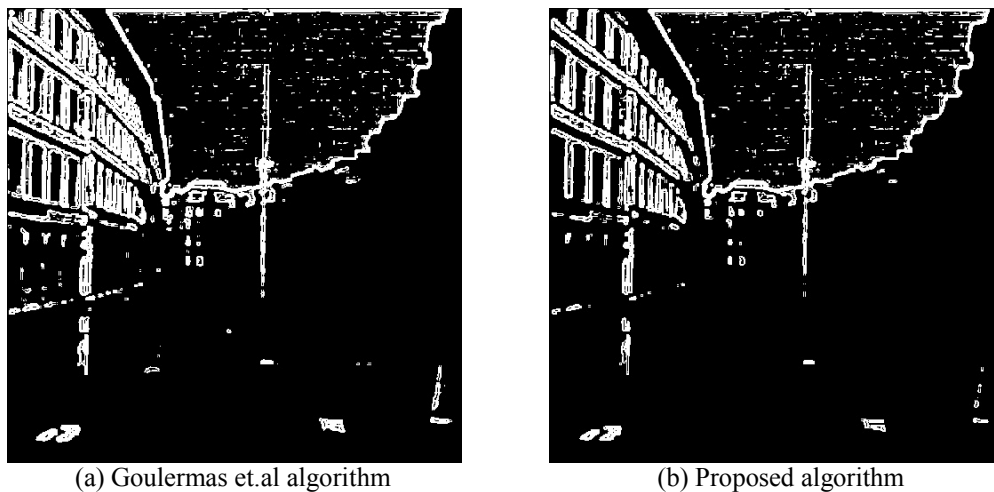


Figure 12 Disparity map of the two algorithms on Street



(a) Left image



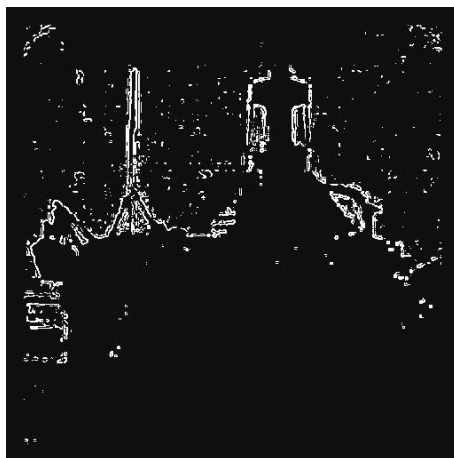
(b) Right image

Figure 13 Ship

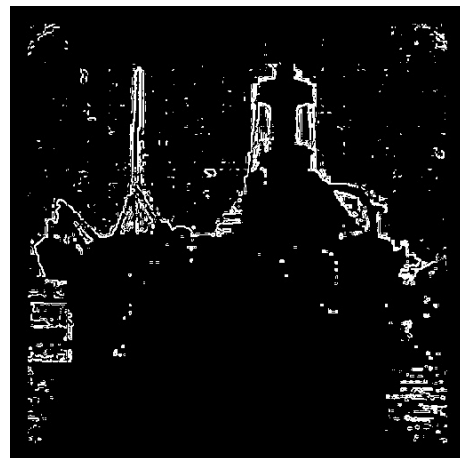
T and other information are the same as shown in table 2

	Goulermas et.al algorithm	# Proposed algorithm
Computation	T (hour)	$\approx T/5$ (hour)
Edge pixels	18860	19100
*Matched pixels	11882	12390
Matched rates	63.03%	64.87%

Table 5 Computation and match rates of the two algorithms on Ship



(a) Goulermas et.al algorithm



(b) Proposed algorithm

Figure 14 Disparity map of the two algorithms on Ship

4. CONCLUSION

In conclusion, we presented a novel multi-resolution hybrid matching method based on wavelets to reduce stereo matching time. Wavelets are used to perform multi-resolution edge extraction first, then adaptive matching window and adaptive searching range are used to match, at last the matched results we obtained in multi-resolution levels are combined to reduce mismatch. Our method is faster because in stereo matching process, adaptive matching window is used instead of fix-size matching window, thus reduce the repeating computation of overlap part in window partition during matching. The results show that our method is time saving while improving matching rates 0.5~1.5% in the experiment images compared to Goulermas et.al algorithm.

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