Refinement of Disparity Map using the Rule-based Fusion of Area and Feature-based Matching Results

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Abstract

In this paper, we presents a new disparity map refinement algorithm using statistical characteristics of disparity map and edge information. The proposed algorithm generate a refined disparity map using disparity maps which are obtained from area and feature-based stereo matching by selecting a disparity value of edge point based on the statistics of both disparity maps.

Experimental results on aerial stereo image show the better results than conventional fusion algorithms in the disparity error.

This algorithm can be applied to the reconstruction of building image from the high resolution remote sensing data.

Introduction

Stereo reconstruction has received a lot of attention in the computer vision and remote sensing communities. The traditional 3D reconstruction method involves matching of stereo pair image. Stereo matching is a critical task to find corresponding points from reference and target image pair resulting disparity map for 3D information. In general, Algorithms for stereo correspondence can be classified to two categories : area-based and feature based matching [1]. Area-based matching gives dense 3D information and gives more better accuracy in the natural terrain, but it has problems in the matching at the depth discontinuities. Feature-based matching provide more accurate information in the man-made structures in terms of locating depth discontinuities but it gives sparse 3D information. Since both categories have advantages and disadvantages as stated above, any single technique does not performs well in the arbitrary circumstances. Therefore, many recent researches have been made to use the advantages of both matching algorithms from the use of complex primitives obtained from perceptual grouping [2] to the use of both intensity and edge information [4]. As the other approaches, post processing techniques to improve the disparity map [1,3] through the fusion of both matching results were recently proposed.

In this paper, we propose a new disparity refinement method through the fusion of area and feature-based matching results using edge information and the statistics of disparities in the patch.

Review of the Previous Work

The conventional disparity refinement techniques using the fusion of area and feature-based matching results largely depend on the characteristics of matching results. Therefore, it is important to know the performance characteristics of matching algorithms.

As conventional fusion techniques, Mckeown used two algorithms to refine disparity using area and feature-based matching results. One approach is to use disparity histogram, and the other is to use gray level difference.

In these approaches, the area-based matching algorithm used by Mckeown calculates gray level differences of points between reference and target in the window and decide the point pair with minimum

difference in gray level as matched pair [3]. The feature-based matching algorithm used by Mckeown extracts intensity components and direction components from both images, and find points with the most similar waveform of both components on the epipolar line [3].

The fusion algorithm using disparity histogram calculates the histogram of segmented area firstly and sets the disparities of them by the disparity with maximum frequency in that area. In the selection of "area", Mckeown used various image segmentation techniques.

This algorithm has disadvantages of depending on the image segmentation results and selecting false disparities in the depth discontinuity positions.

And the second algorithm using gray level difference get the gray level values of corresponding points of reference and target images based on the disparity values obtained from area and feature-based matching, and compares the gray level differences of two points obtained from both matching results. The disparity of point with minimum difference is recorded in the final disparity map. This algorithm has an advantage of easy implementation, but has a disadvantage of selecting wrong disparities if there are large gray level difference between two images.

Proposed Disparity Map Fusion Algorithm

The main goal of disparity map fusion is to obtain improved disparity map by fusing two stereo matching result using statistics of disparity maps and edge information.

The area-based matching algorithm used in this paper as follows : firstly, divide all pixels in the stereo images into edge pixels and non-edge pixels using edge extraction results of both images. For edge pixels, matching is performed using edge matching window, and the adaptive window matching using edge information is peformed for non-edge pixels [4].

The feature-based matching result is obtained from line segment-based feature matching algorithm [5].

These two matching algorithms have different performance characteristics with two matching algorithms used in the conventional McKeown's fusion algorithms, so conventional fusion algorithms can not be applied directly to the fusion of disparity maps used in this paper.

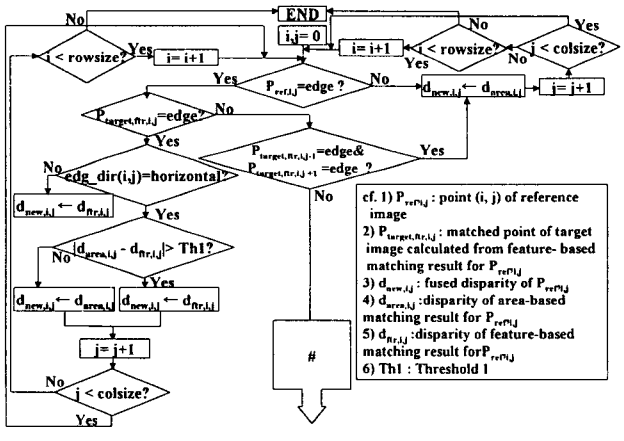
To overcome this defect in the conventional algorithms, we propose a new rule-based fusion algorithm.

The basic assumption in the proposed algorithm is that generally area-based matching result is better than interpolation result of feature-based matching result in the matching of non-edge pixels, and most feature-based matching result is better than that of area-based matching in matching of the edge pixels [1,3].

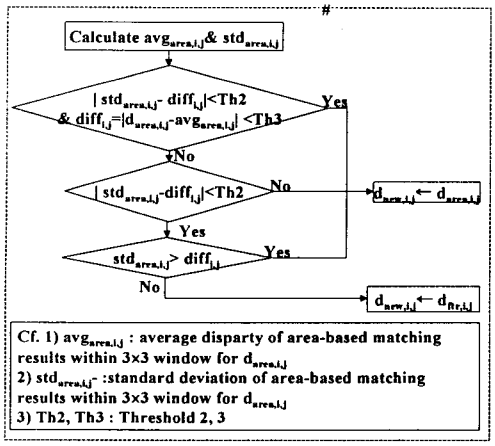
The characteristics used in the proposed fusion are variance of disparities in the 3×3 window, edge image, and the direction of edge.

The procedure of proposed fusion algorithm can be explained as follows :

1) The area-based and feature-based matching results, the edge extraction results of reference and target images are used as inputs of proposed fusion algorithm.
2) The existence of disparity for each pixel is examined in the both matching results.
3) If disparity value of a point exists on the only one of matching results, it is accepted as disparity of that point in the new disparity map.
4) If disparity value of a point exists on the both matching results, the disparity of that point in the new disparity map are selected using rules in Fig. 1.
5) Step 1)-4) are repeated for all points in the images.



(a)

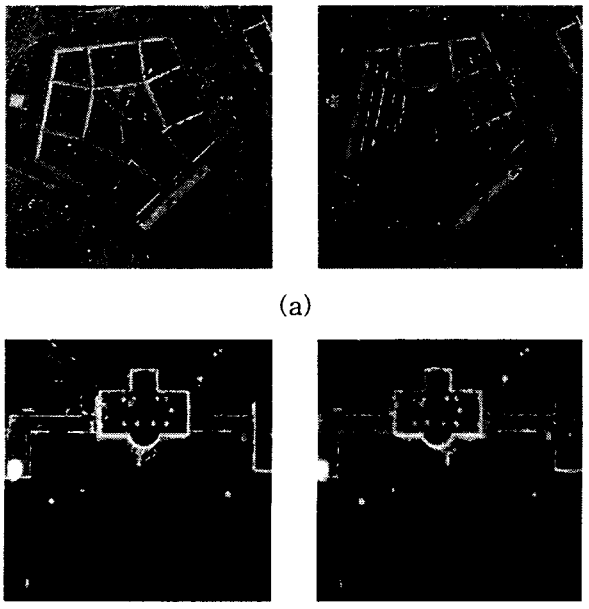


(b)

Fig. 1. Flowchart of proposed fusion rule
(a) Total flowchart. (b) Detail flowchart of # part.

Experimental Results and Discussion

As test images, pentagon 512 × 512 and white house 256×256 aerial stereo images are used as shown in Fig. 2.



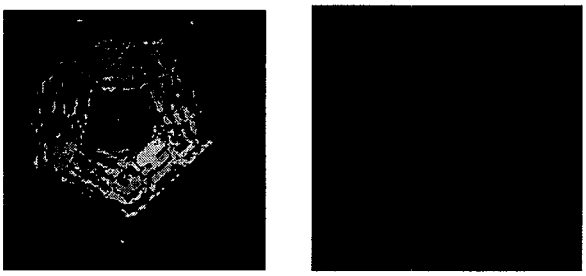
(a)

(b)

Fig. 2. Experimental stereo image pairs.
(a)Pentagon 512×512 (b)White House 256×256

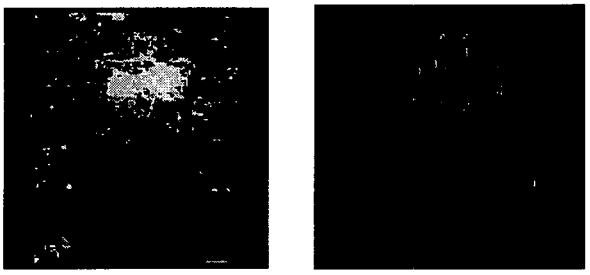
The area and feature-based matching algorithm [4,5] are applied to both image pairs. Both matching results without interpolation were used as inputs to the fusion algorithms because interpolation may change the characteristics of matching results. Conventional two fusion algorithms and proposed algorithm are applied to both disparity maps. We compared the RMSE of disparity error and the number of pixels with under ±1 pixel error between before and after fusion.

Fig. 3. and 4 shows the disparity maps using area and feature-based matching algorithms. Fig. 5 and 6 shows the fused disparity maps for edge pixels using conventional and proposed fusion algorithms. Because the fusion is mainly performed on the edge points, the difference between before and after fusion results does not look appear reliably. Fig. 7 and 8 shows the 3 dimensional plots of Fig. 3 to 6, respectively. From the comparison results of conventional and proposed algorithms, it shows the boundary of buildings better in the proposed algorithm results than other results. Fig. 9 shows 3 dimensional plots of proposed fusion algorithm for whole pixel in the Pentagon and White House Images.



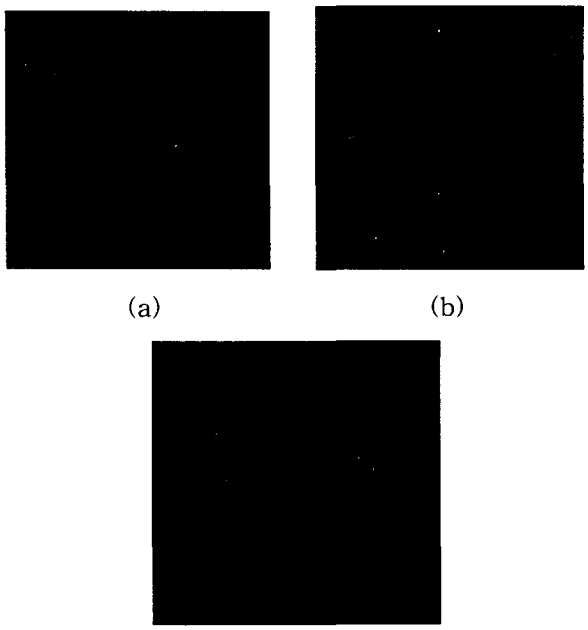
(a) (b)

Fig. 3. Area and feature-based matching results of Pentagon image
(a) Area-based (b) Feature-based



(a) (b)

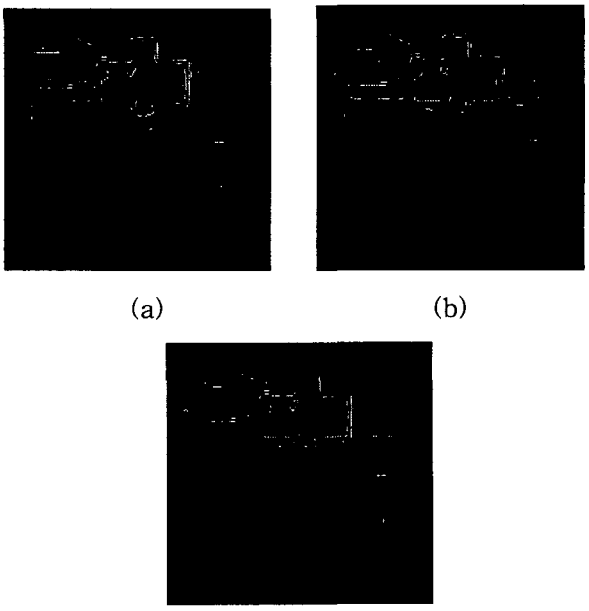
Fig. 4. Area and feature-based matching results of White House image
(a) Area-based (b) Feature-based



(a) (b)

(c)

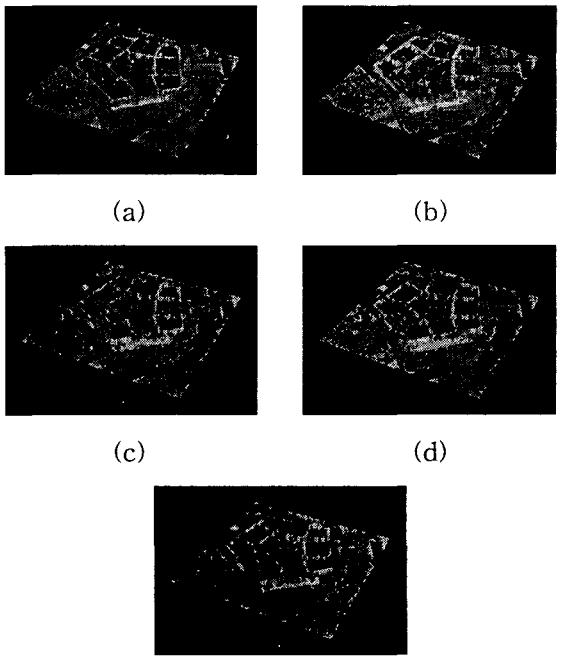
Fig. 5. The fused results (disparity maps) of conventional and proposed algorithms for Pentagon Image (Edge pixels only).
(a) Histogram fusion (b) Gray level difference fusion (c) Proposed fusion



(a) (b)

(c)

Fig. 6. The fused results (disparity maps) of conventional and proposed algorithms for White House image (Edge pixels only).
(a) Histogram fusion (b) Gray level difference Fusion (c) Proposed fusion

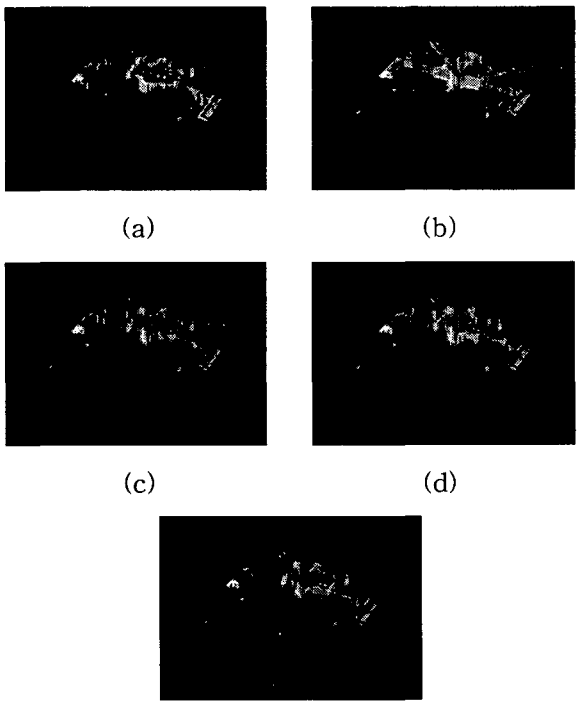


(a) (b)

(c) (d)

(e)

Fig. 7. 3 dimensional plots of disparity maps for Pentagon image.
(a) Area-based matching (b) Feature-based matching
(c) Histogram fusion (d) Gray level difference fusion
(e) Proposed fusion



(a) (b)

(c) (d)

(e)

Fig. 8. 3 Dimensional plots of disparity maps for White House image
(a) Area-based matching (b) Feature-based matching
(c) Histogram fusion (d) Gray level difference fusion
(e) Proposed Fusion

(a) (b)

Fig. 9. 3D plots of proposed algorithm for whole pixels in the Pentagon and White House images (a) Pentagon image (b) White House image

To clarify the performance of proposed algorithm, we obtain 100 test points for Pentagon image pair, and 50 test points for White House image pair as a quantitative analysis. The table 1 shows the RMSE of disparity error and the ratio of the number of pixels with under ± 1 pixel disparity error of each algorithm about the total number of matched points for both images.

From the experimental results of Pentagon image pair, feature-based matching result showed the better RMSE than that of area-based matching results for edge points. Among the results of fusion algorithms, proposed algorithm showed the best results in terms of both RMSE of disparity and the number of pixels with under ± 1 pixel error as shown in the table 1.

Compared to the RMSE of feature-based matching, the increased RMSE of the proposed fusion algorithm for edge points was caused by the increased number of pixels in the disparity map, and the inclusion of more pixels with large disparity error in the newly added pixels.

As an another measure, we compared the RMSE and the number of pixels with under ± 1 pixel error for the common points in the area-based matching, feature-based matching and fused results as shown in the table 2. In the results in the table 2, feature-based matching showed the better RMSE than area-based matching. But, in terms of the number of pixels with under ± 1 pixel error, area-based matching result showed slightly better result than feature-based matching result. In the comparison of fusion algorithm , two conventional fusion algorithms showed worse results than proposed algorithm, and two matching results. In the fusion result using disparity histogram, the RMSE increased than those of both matching results, and the number of pixels with under ± 1 pixel error decreased than those of both matching results.

In the fusion result using gray level difference, the amount of increasing RMSE was smaller than that of fusion using histogram, but the number of pixels with under ± 1 pixel error was smaller than that of fusion using histogram.

The proposed algorithm showed best results than the any other results in terms of both RMSE and the number of pixels with under ± 1 pixel error.

We also calculated the percentage of true selection in the fusion of two disparity maps by manual inspection for each fusion algorithms. The percentages of each algorithm are shown in the table 2 also. As shown in the table 2, the percentage in the proposed algorithm was much higher than any other conventional fusion algorithms.

For the White House image pair, similar results with Pentagon image pair were obtained as shown in Fig. 4, 6, 8, 9 and in the table 1 and 2. The percentage of true selection in the proposed algorithm was lowered by 12% at this time than that of Pentagon image pair. This error in the selection of disparity appears to be caused by the false matching. Future studies are needed to improve these errors.

Table 1. RMSE and the number of pixels with under ± 1 pixel error
(cf. Area: area-based matching, Feature: feature-based matching, Hist. Fus.: Disparity Histogram Fusion, Diff. Fus.: Gray Level Difference Fusion, Prop. Fus.: Proposed Fusion, RMSE : Root Mean Square Error, NOP under± 1 : the Number Of Pixels with under± 1 Pixel Error) (a) for Pentagon Image (b) for White House Image

(a) Unit of RMSE : pixels

Algorithm	Kind / Measure	Edge	Non-edge	Total
Area	RMSE	3.33	1.78	2.84
	NOP under± 1	37/51	28/31	65/82
Feature	RMSE	1.90	-	1.90
	NOP under± 1	24/34	-	24/34
Hist. Fus.	RMSE	3.41	1.78	2.91
	NOP under± 1	36/51	28/31	64/82
Diff. Fus.	RMSE	3.37	1.78	2.87
	NOP under± 1	30/51	28/31	58/82
Prop. Fus.	RMSE	2.66	1.78	2.36
	NOP under± 1	39/51	28/31	67/82

(b) Unit of RMSE : pixels

Algorithm	Kind / Measure	Edge	Non-edge	Total
Area	RMSE	3.33	1.78	2.84
	NOP under±1	37/51	28/31	65/82
Feature	RMSE	1.90	-	1.90
	NOP under±1	24/34	-	24/34
Hist. Fus.	RMSE	3.41	1.78	2.91
	NOP under±1	36/51	28/31	64/82
Diff. Fus.	RMSE	3.37	1.78	2.87
	NOP under±1	30/51	28/31	58/82
Prop. Fus.	RMSE	2.66	1.78	2.36
	NOP under±1	39/51	28/31	67/82

Table 2. RMSE and the number of pixels with under ±1 pixel error in the common edge points (cf. Definitions of each words are same as table 1.) (a) for Pentagon Image (b) for White House Image

(a) Unit of RMSE : pixels

Measure \ Algorithm	Area	Feature	His. Fus.	Diff. Fus.	Prop. Fus.
RMSE	2.65	1.91	2.81	2.74	1.02
NOP under±1	27/34	24/34	26/34	20/34	29/34
NOP and Percentage of Sucess Fusion			27/34 79%	20/34 59%	34/34 100%

(b) Unit of RMSE : pixels

Measure \ Algorithm	Area	Feature	His. Fus.	Diff. Fus	Prop. Fus
RMSE	1.83	1.81	1.49	1.83	1.25
NOP under±1	14/18	12/18	14/18	14/18	16/18
NOP and Percentage of Sucess Fusion			15/18 83%	15/18 83%	16/18 88%

Conclusion

In this paper, we presented a new rule-based disparity map fusion algorithm to improve the stereo matching results. We set the disparity selection rule using the statistical characteristics of disparity maps obtained by area and feature-based matching, and also using edge information. Experimental results showed that disparity map from stereo matching can be refined by the proposed fusion algorithm.

The research on the disparity map refinement algorithms using the fusion of various stereo matching results have not been done than other algorithms to refine stereo matching results. Therefore, much future work are needed to make the better fusion algorithm.

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