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A Technique for Improving the Quality of Stereo DEM Using Texture Filters

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Abstract : One of the most important procedure in stereo DEM generation is the stereo matching process which finds the conjugate pixels in a pair of stereo imagery. In order to be found as conjugate pixels, the pixels should have distinct spatial feature to be distinguished from other pixels. However, in the homogeneous areas such as water covered or forest canopied areas, it is very difficult to find the conjugate pixels due to the lack of distinct spatial feature. Most of erroneous elevation values in the stereo DEM are produced in those homogeneous areas. This paper presents a simple method for improving the quality of stereo DEM utilizing the texture filters. An entropy filter was applied to one of the input stereo imagery to extract very homogeneous areas before stereo matching process. Those extracted homogeneous areas were excluded from being candidates for stereo matching process. Also a statistical texture filter was applied to the generated elevation values before the interpolation process was applied in oder to remove the remaining anomalous elevation values. Stereo pair of SPOT level 1B panchromatic imagery were used for the experiments. The results showed that by utilizing the texture filters as a pre and a post processor of stereo matching process, the quality of the stereo DEM could be dramatically improved.

Key Words : DEM Extraction, Stereo Matching, Texture Filter.

1. Introduction

In the stereo DEM generation, there are two main processes which determine the accuracy and quality of the output DEM. The one is the process of sensor modeling which calculates the elements of exterior orientation using ground control points. The other is the process of stereo matching which finds the conjugate pixels in stereo imagery and then determines the elevation value of a position using the conjugate pixel's image coordinates. Finally, the DEM is generated by interpolating the elevation values of the conjugate pixels. Therefore, in order to generate DEM with high quality, it is necessary to find as densely distributed conjugate pixels as possible.

There have been proposed a lot of stereo matching techniques(Zhang *et al.*, 1995, Noh, 1997, Kim and Lee, 1998). Zhang *et al.*(1995) proposed a matching technique which utilizes the epipolar geometry. Noh (1997) proposed a method which uses the gradient

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correlation for the improvement of stereo matching efficiency.

However, those methods uses only the brightness values of the imagery to calculate the statistical similarity of candidate pixels. Regardless it is a feature based or a area based matching techniques, there has been no attempt to utilize texture information in stereo matching process.

In order to generate DEM from stereo imagery, densely distributed elevation values should be determined in the stereo matching process. Usually, in stereo DEM generation, pixels which shows higher similarity than pre-defined threshold value of similarity are regarded as conjugate pixels. And then an elevation value of a point is determined using the image coordinates of the conjugate pixels. Therefore, to generate densely distributed elevation values, the threshold value of similarity need to be set as low value as possible. However, the low value of similarity threshold produces erroneous conjugate pixels and these erroneous conjugate pixels result in anomalous elevation values. This paper presents a method which enables to use low value of similarity threshold without increasing anomalous elevation values by using the kinds of texture filters as a pre and a post processor respectively.

2. Data Preparation

Stereo pair of SPOT level 1B panchromatic imagery of Daejeon area were used for the experiment. The stereo imagery for experiments and GCP distribution are shown in (a) and (b) of Fig. 1. Total of 21 points of GCP were selected for each SPOT image.

The first procedure for stereo DEM generation is the process of exterior orientation. Exterior orientation defines the position and angular orientation of the sensor that captured an image. The variables defining the position and orientation of an image are referred to as the elements of the exterior orientation. In the case of SPOT imagery, we have a series of linear arrays each of which can be likened to a one-dimensional photograph. The position(X_t, Y_t, Z_t) of the satellite at a given time t can be linearly related to the location(X_o, Y_o, Z_o) of the satellite corresponding to the central linear array. The image tilt values(ω_t, ϕ_t, κ_t) at a given time t also can be linearly related to the image tilt angle(ω_o, ϕ_o, κ_o) of the central linear array. In this study we used the following sensor model for exterior orientation of SPOT satellite with 9 unknown parameters for each image which is similar to that of Orun and Natarajan(1994).

$$\begin{aligned} X_t &= X_o + a_1 t + b_1 t^2 \\ Y_t &= Y_o + a_2 t + b_2 t^2 \\ Z_t &= Z_o + a_3 t + b_3 t^2 \\ \phi_t &= a_4 \\ \kappa_t &= \kappa_o + a_5 t + b_5 t^2 \end{aligned} \quad (1)$$

Table 1 shows the ground control points used for exterior orientation and Table 2 shows the result of exterior orientation using the bundle adjustment method. The Z_o value of the right image(tilt angle of 26.2°) is lower than that of left image(tilt angle of -5.6°) because the coordinate system used for GCP is local Korean TM.

Once the elements of the exterior orientation were determined, a position value can be calculated from the conjugate pixel's image coordinate. In order to be found as conjugate pixels, the pixels should have distinct spatial feature to be distinguished from other pixels. However, in the homogeneous areas such as water covered or forest canopied areas, it is very difficult to find the conjugate pixels due to the lack of distinct spatial feature. Most of erroneous elevation values in the stereo DEM are produced in those homogeneous areas.

To generate densely distributed elevation values, the threshold value of similarity need to be set as low value as possible. However, too low value of similarity threshold produces erroneous conjugate pixels and these erroneous conjugate pixels result in anomalous elevation values in DEM. In this study, it is proposed to use

Table 1. Ground control points for exterior orientation.

				Left Image (-5.6°)			Right Image (26.2°)		
	Reference Coord.			Image Coord		Err.	Image Coord		Err.
ID	X	Y	Z	X	Y		X	Y	
1	265769.65	326114.67	151.69	5444.28	4286.59	0.18	5173.24	4165.57	0.19
2	260330.80	317400.26	44.72	5135.23	3327.18	Off	4872.94	3224.16	0.54
3	263041.88	300974.23	151.33	5893.59	1770.58	0.99	5367.52	1629.93	0.80
4	260706.11	286855.58	141.91	5916.50	342.00	1.33	5409.03	193.93	0.45
5	246642.09	288961.53	141.65	4509.75	277.25	0.60	4213.50	208.25	0.75
6	240755.79	292039.75	166.19	3866.00	464.25	1.86	3680.49	430.70	0.98
7	216843.37	295998.33	46.08	1455.87	392.71	1.00	1702.00	492.50	0.44
8	203754.89	298733.21	5.36	115.50	407.75	0.22	629.75	581.25	0.68
9	206839.47	311704.52	16.45	94.50	1739.00	0.77	665.75	1914.75	0.84
10	216445.95	339257.42	56.19	350.22	4625.40	1.44	983.00	4788.25	1.28
11	216529.27	350221.99	80.79	90.16	5700.07	0.78	816.60	5878.20	0.50
12	228143.86	345130.84	26.19	1342.65	5423.28	1.50	1815.25	5531.00	1.74
13	259998.94	342628.61	228.48	4488.12	5793.84	0.40	4421.36	5726.08	1.35
14	222244.78	338351.77	38.23	936.32	4646.65	0.54	1455.38	4777.17	0.26
15	238329.89	334917.79	56.82	2580.29	4620.40	0.33	2791.88	4659.40	0.03
16	253504.90	332604.38	106.00	4102.06	4684.65	Off	4055.80	4640.40	2.15
17	219217.96	324939.69	25.17	975.56	3271.92	Off	1431.25	3401.50	1.61
18	232158.49	322128.18	57.52	2298.50	3248.50	1.95	2503.13	3304.18	1.33
19	242521.74	316557.71	155.84	3435.25	2900.75	2.00	3422.95	2892.32	1.34
20	251611.01	312699.31	103.31	4408.25	2699.50	1.04	4230.58	2636.38	0.26
21	227121.91	306349.54	80.96	2197.5	1605.75	1.32	2352.13	1665.68	1.30

Table 2. Exterior orientation of SPOT stereo image pair shown in Fig. 1.

Left Image (tilt angle of -5.6°)	Right Image (tilt angle of 26.2°)
$X = 128151.56 + 2.45958*L + 6.86812E-07*L^2$	$X = 659434.20 + 1.9807*L - 8.53748E-06*L^2$
$Y = 309449.58 + 9.70137*L + 3.12364E-06*L^2$	$Y = 259302.69 + 9.83479*L + 1.35472E-05*L^2$
$Z = 823368.02 + 0.08762*L - 1.47929E-07*L^2$	$Z = 781634.40 + 0.0117702*L - 1.72922E-05*L^2$
$\omega = 0$	$\omega = 0$
$\phi = 3.05091$	$\phi = 0.498999$
$\kappa = -0.194288 + 1.54191E-07*L - 2.5382E-11*L^2$	$\kappa = -0.139003 + 1.14275E-07*L - 2.58852E-11*L2$
RMS Error : 1.076	RMS Error : 1.054

texture information of input image in order to exclude very homogeneous area from being candidate for stereo matching process. Through careful examination of various texture filters, entropy filter(Gong *et al.*, 1992) of kernel size 5 by 5 was found to be most appropriate for extracting homogeneous area from SPOT panchromatic image. The 5 by 5 kernel size entropy filtered result is shown in (c) of Fig. 1. The water covered areas appear very bright, and the dark area in the center of the image is the Daejeon city area. By applying histogram thresholding, a binary image shown in (d) of Fig. 1 could be generated. The areas shown as black color are those finally extracted homogeneous areas where stereo matching process should not be applied.

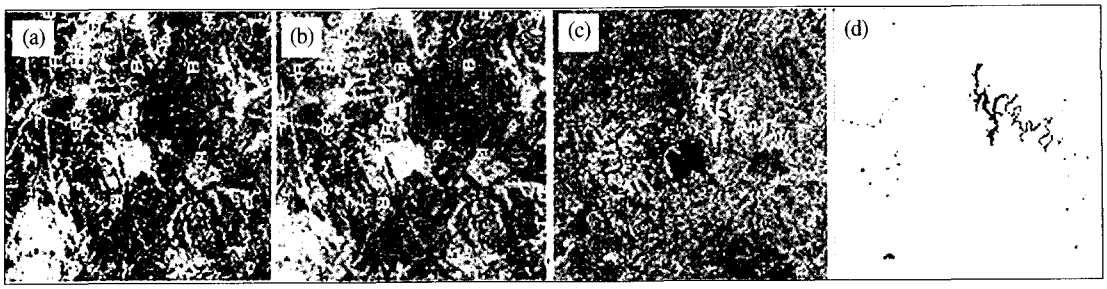

Fig. 1. (a) SPOT panchromatic image of tilt angle of 26.2o. (b) Image of tilt angle of -5.6o.(c) Result of applying 5 by 5 entropy filter. (d) Result of applying histogram thresholding to (c).

3. Experiments and Discussion

The accuracy of DEM from stereo pair of satellite image is mostly influenced by the stereo matching process. There are two kinds of matching method, area based and feature based matching. In this study, simple area based matching method was used. The kernel size for stereo matching was 15 by 11 and the normalized cross correlation coefficient was used as a measurement for similarity between the candidate pixels.

Various test results are shown in Fig 2. Elevation values generated by a correlation threshold value of 0.5 is shown in (a). Black colored pixels are where the stereo matching failed. Even though the elevation values are produced in most of the study area, there exist a lot of anomalous elevation values especially in water covered area. In order to remove those anomalous elevation values, a statistical texture filter was applied. This statistical texture filter calculates the mean value m and standard deviation value s of the surrounded pixels of a central pixel within a given kernel. If the value of the central pixel is larger than $m+a*s$ or smaller than $m-a*s$, the elevation value of the central pixel is removed and regarded as a point where stereo matching failed. a is a variable which determines the extent of filtering effect. Also if s value is less than b, the elevation value of the central pixel is removed. This statistical texture filter was applied iteratively with changing the kernel size from 17 by 17 to 5 by 5. The statistical filter applied result is shown in (b), where the value of the variable a was 2.0 and the b was 1.0. Most of anomalous elevation values could be removed effectively. Finally, DEM could be generated by interpolating the elevation values shown in (b). The Finally generated DEM is shown in (c). The spacing of the generated SPOT DEM was 20m.

Elevation values generated by a correlation threshold value of 0.8 is shown in (d). It is clear that there are much less points of anomalous elevation values compared with the result shown in (a) which is generated using the similarity threshold value of 0.5. However, there are still some anomalous elevation values exist not only in water covered area but also in some land area. These anomalous pixels should be removed before creating DEM by interpolation. The statistical filter applied result is shown in (e). And the DEM generated by interpolating the elevation values is shown in (f). There is no anomalous elevation values in the finally generated DEM shown in (c) and (f) except water covered area. Krigging method was used for the interpolation of the elevation values. These results strongly suggest to use as low value of similarity threshold as possible and then apply the statistical filter.

However, there are still some problems in the generated DEMs especially in water covered area. It is because the elevation values in water covered area could not be generated from the stereo matching. If the water covered area is large like this case, the interpolation

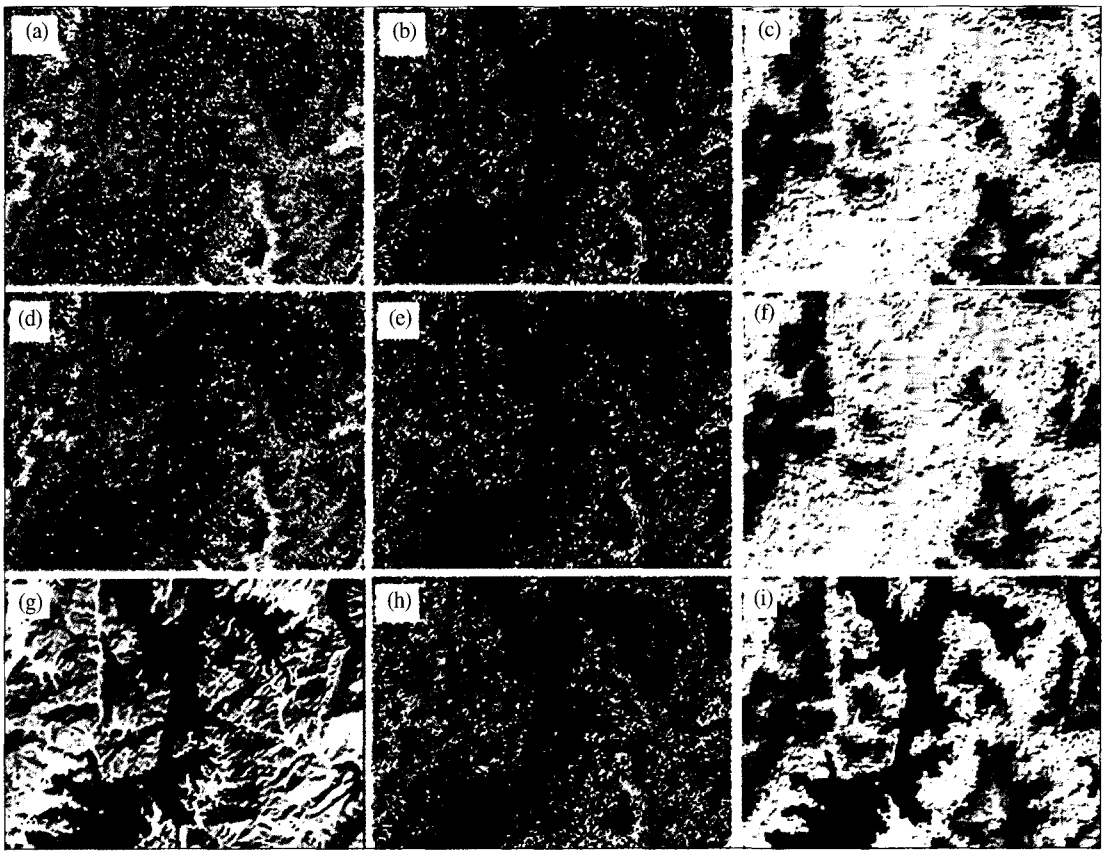

Fig. 2. Results of experiments.

(a) Elevation values obtained using a threshold value of 0.5.
(b) The result of applying the statistical texture filter to (a).
(c) DEM generated by the interpolation of (b).
(d) Elevation values obtained using a threshold value of 0.8.
(e) The result of applying the statistical texture filter to (d).
(f) DEM generated by the interpolation of (e).
(g) Orthorectified SPOT image for comparison.
(h) Elevation values obtained by the proposed method.
(i) DEM generated by the proposed method.

process can not produce reasonable elevation values for the water covered area. To overcome this problem in the water covered area, the entropy filtered result shown in (d) of Fig. 1 was utilized. For the homogeneous areas extracted by entropy filtering, a user defined elevation value was assigned as an elevation value instead of being determined from stereo matching.

The image shown in (h) of Fig. 2 is the stereo matched result with the threshold value of 0.5. The anomalous elevation values were removed by statistical filter and the entropy filtered result was also used to exclude water covered area from being the candidate for stereo matching process. The finally generated DEM is shown in (i) of Fig. 2. Orthorectified image of the same area is shown in (g) for the comparison.

4. Conclusions

A simple method for improving the quality of stereo DEM was developed and experimented with SPOT stereo imagery of Daejeon area. The proposed method

uses the entropy filter to extract very homogeneous areas such as water covered areas. The entropy filtered result was used to exclude the pixels in the homogeneous area from being the candidate pixels for stereo matching. Once the elevation values were calculated, a statistical texture filter was applied to remove the anomalous elevation values before the interpolation process. The SPOT experiment found that the proposed statistical texture filer had a prominent capability of reducing the erroneous elevation values. The experiment also found that the entropy texture filter had a capability of extracting the large homogeneous areas where the most of erroneous elevation values were produced in stereo matching process. Using these two kinds of texture filters in a different stage of stereo DEM generation process, it was possible to generate stereo DEM of high quality. Since only the qualitative appraisal of the proposed method is provided in this paper, the performance and the effect to DEM accuracy of the proposed method needs to be analysed quantitatively using some standardized data and method. Further studies are required to decide the optimum size and parameters for the texture filters with regard to the spatial resolution of the input imagery.

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