PERFORMANCE EVALUATION OF DSM EXTRACTION FROM ZY-3 THREE-LINE ARRAYS IMAGERY

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ABSTRACT:

ZiYuan-3 (ZY-3), launched in January 09, 2012, is China's first civilian high-resolution stereo mapping satellite. ZY-3 is equipped with three-line scanners (nadir, backward and forward) for stereo mapping, the resolutions of the panchromatic (PAN) stereo mapping images are 2.1-m at nadir looking and 3.6-m at tilt angles of ±22° forward and backward looking, respectively. The stereo base-height ratio is 0.85-0.95. Compared with stereo mapping from two views images, three-line arrays images of ZY-3 can be used for DSM generation taking advantage of one more view than conventional photogrammetric methods. It would enrich the information for image matching and enhance the accuracy of DSM generated. The primary result of positioning accuracy of ZY-3 images has been reported, while before the massive mapping applications of utilizing ZY-3 images for DSM generation, the performance evaluation of DSM extraction from three-line arrays imagery of ZY-3 has significant meaning for the routine mapping applications. The goal of this research is to clarify the mapping performance of ZY-3 three-line arrays scanners on china's first civilian high-resolution stereo mapping satellite of ZY-3 through the accuracy evaluation of DSM generation. The comparison of DSM product in different topographic areas generated with three views images with different two views combination images of ZY-3 would be presented. Besides the comparison within different topographic study area, the accuracy deviation of the DSM products with different grid size including 25-m, 10-m and 5-m is delineated in order to clarify the impact of grid size on accuracy evaluation.

1. INTRODUCTION

ZiYuan-3 (ZY-3), launched in January 09, 2012, is China's first civilian high-resolution stereo mapping satellite with a sun-synchronous orbit of 500-600km tilted at 97.421◦. ZY-3 is equipped with three-line scanners (nadir, backward and forward) for stereo mapping, the resolutions of the panchromatic (PAN) stereo mapping images are 2.1-m at nadir looking and 3.6-m at tilt angles of±22◦ forward and backward looking, respectively. The stereo base-height ratio is 0.85-0.95. The onboard multispectral (MS) sensor has four bands with 5.8-m resolution covering the blue, green, red and near infrared bands. The main application of ZY-3 data is to provide a routine production of 1:50,000 cartographic maps. Consequently, DSM generation based on ZY-3 three-line arrays PAN images is an important task for the mapping production applications. The primary result of positioning accuracy of ZY-3 images has been reported(Tang and Xie,2012; Tang et.al,2013; Fang and Chen, 2012), while the performance evaluation and validation of three-line arrays images of ZY-3 from DSM generation perspective has scarcely been discussed when applied in different topographical area even in China. The applicability of three-line arrays images of ZY-3 especially for DSM generation and the accuracy evaluation has not been discussed quantitatively in depth when utilizing three views images of ZY-3 three-line arrays scanners compared with two views images of different combination. The utility efficiency of ZY-3 three-line arrays images for DSM generation was not clear and should be specified for different topographic and temporal imaging situation.

Compared with stereo mapping from two views images, three-line arrays images of ZY-3 can be used for DSM generation taking advantage of one more view than conventional photogrammetric methods. It would enrich the information for image matching and enhance the accuracy of DSM generated. Before the massive mapping applications of utilizing ZY-3 images for DSM generation, a pilot study for performance evaluation of three-line arrays scanners on ZY -3 has significant meaning for the routine mapping applications. The goal of this research is to clarify the mapping application performance of ZY-3 three-line arrays scanners on ZY-3 through the accuracy evaluation of DSM generation, the first report of comprehensive evaluation of DSM generation utilizing ZY-3 three-line arrays stereo images together with ground control points would be provided when actually applied in flat area, hill and mountain area respectively . The accuracy comparison of DSM product in different topographic areas generated with three views images with different two views combination images of ZY-3 would be presented. Besides the comparison within different topographic study area, the accuracy comparison of the DSM products with different grid size including 25-m, 10-m and 5-m is made in order to exclude the impact of grid size on accuracy evaluation.

2. METHODOLOGY AND CASE STUDY

In this research, four study areas including flat area, hill and mountain area were chosen for accuracy evaluation of DSM automatic generation utilizing ZY-3 stereo images. The different combination of two views images from three line

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arrays scanner together with three views images was processed with PixelGrid software for DSM generation utilizing multi-baseline matching technique(Zhang,2006;Zhang,2005). The DSM products with different grid size were generated and compared in order to exclude the effects of grid size on accuracy evaluation. The accuracy of automatic generated DSM products was checked utilizing dense grid of check points derived from high accuracy LIDAR points cloud. The residuals was mapped against with DSM for visual inspection in order to detect the performance of DSM generation in different topographic areas within one test site in order to exclude the effect of GCP accuracy .The accuracy of DSM in different slope and aspect areas within one study area can be analyzed in order to evaluate the performance of three-line array images under the same imaging condition. The detailed analysis and comparison of DSM accuracy in different temporal and topographical dimension would be carried out for a comprehensive evaluation of the performance of three-line array images in order to specify the application for DSM generation. Compensating with the report of the previously referred primary result, the result of this study would provide a comprehensive view regarding the cartographic applications performance of three line arrays images.

In this study, the details of the four study areas chosen for performance evaluation of DSM generation are listed in table 1.

Test site	Location	Morphology
Taiyuan	N 38.48~38.91 deg E 112.22~112.91 deg	hill and mountains with altitude 800-1200 meter above sea level
Lianyungang	N 34.79 ~ 34.37 deg E 118.81 ~ 119.43 deg	mainly flat, a little bit hilly with altitude 0-609 meter above sea level
Tianjin	N 38.72 ~ 39.27 deg E 117.01~117.72 deg	predominant with flat land, altitude within 100 meter above sea level
Dalian	N 38.8~39.2 deg E 121.5~122.2 deg	Mainly hilly with altitude 0-600 meter above sea level

Table 1. The details of the four study areas

Fist, bundle block adjustment for ZY-3 satellite images is implemented based on the RFM with an affine transformation parameter. The results of bundle block adjustment for different two or three stereo view images in four test sites with different morphology are listed in Table 2-5.Table 2 lists the results of Taiyuan test site mainly covered with mountain, the altitude within this area extremely varied. The Ground Control Points (GCPs) and Check Points (CPs) are derived from 0.5m resolution DOM and 3m grid DEM generated from LIDAR data with RMSE within 1 meter. Table 3 lists the results of Lianyungang test site mainly covered with hilly topography. The GCPs and CPs are derived from 1:10,000 scale 0.5 m resolution DOM and 5m grid DEM product. Table 4 lists the results of Tianjin mainly covered with flat land. The GCPs and CPs are derived from 1:10,000 scale 0.2m resolution DOM and 2m grid DEM product. Table 5 lists the results of Lianyungang mainly covered with hilly topography. The GCPs and CPs are collected with GPS. Through comparison of three views stereo images and different two views stereo images in each test site with different morphology, we can find that the best result with least horizontal and vertical residuals particularly was achieved for Forward-Nadir-Backward three view stereo images within each test site. Besides Forward- Backward two views stereo images got the second best results especially in vertical adjustment direction.

Number ofGCPs /CPs	Stereo view methods	RMSE of check points	
		XY(m)	H(m)
17/30	Forward-Nadir-Backward	1.95	1.59
	Forward-Backward	2.14	1.59
	Forward- Nadir	1.98	3.75
	Nadir-Backward	2.19	3.12

Table 2. The results of Taiyuan mainly covered with mountain

Number ofGCPs /CPs	Stereo view methods	RMSE of check points	
		XY(m)	H(m)
4/50	Forward-Nadir-Backward	1.60	1.33
	Forward-Backward	1.84	1.33
	Forward- Nadir	1.64	2.14
	Nadir-Backward	1.50	2.49

Table 3. The results of Lianyungang mainly covered with hilly topography

Number ofGCPs /CPs	Stereo view methods	RMSE of check points	
		XY(m)	H(m)
18/46	Forward-Nadir-Backward	1.48	1.73
	Forward-Backward	1.73	1.73
	Forward- Nadir	1.44	2.87
	Nadir-Backward	1.45	2.51

Table 4. The results of Tianjin mainly covered with flat topography

Number ofGCPs /CPs	Stereo view methods	RMSE of check points	
		XY(m)	H(m)
6/11	Forward-Nadir-Backward	2.46	1.68
	Forward-Backward	2.64	1.68
	Forward- Nadir	2.67	3.64
	Nadir-Backward	2.79	4.22

Table 5. The results of Dalian mainly covered with hilly topography

3. RESULTS AND DISCUSSIONS

After bundle block adjustment and multi-baseline dense image matching, the DSM in 25 meter grid was generated automatically utilizing PixelGrid software with rendered samples listed in Appendix Figure 1 for reference and visual inspection. The accuracy of DSM automatically generated for each test site with 25 meter grid was evaluated with check points derived from the referred source data same as the ground control points. The comparison was made within different stereo view methods and test morphology shown in Figure 1.

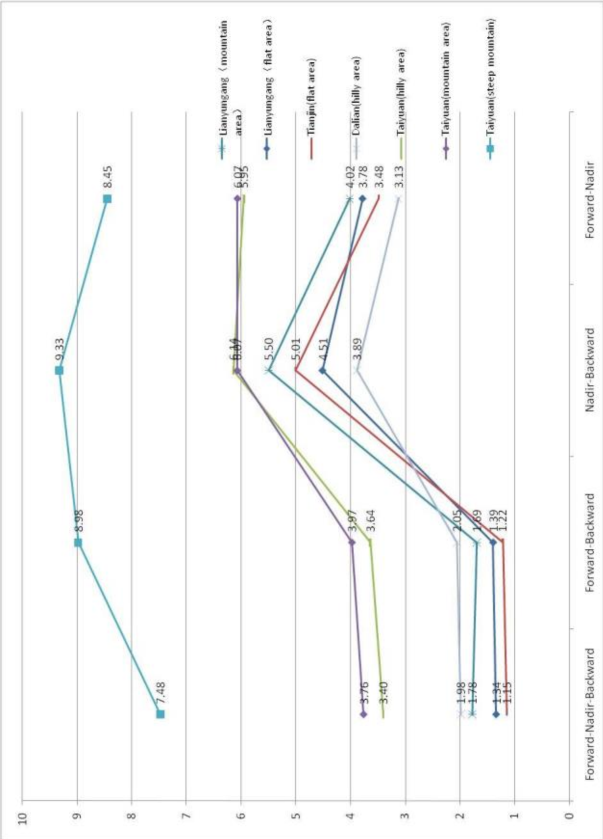

Figure 1. The comparison of DSM accuracy with different stereo view methods and test morphology.

The result shows that the DEM extracted from stereo image of ZY-3 three views achieved the highest accuracy and had great advantage than two views as expected, especially in the steep mountain area with large altitude deviation and slope. Otherwise this benefit of three views stereo images is not so obvious in the flat and hill area with low altitude deviation and slope, the accuracy of DSM extracted with automatic extraction method is similar within these areas. It is interesting to find that the DSM accuracy extracted from three views stereo images is two times higher than the DSM extracted from forward to nadir views and nadir to backward views stereo images. This proves the importance of stereo angles and base to height ratio of two views images for DSM extraction.

To further analyze the effect of grid size on DSM extraction accuracy, 25-meter, 10-meter gird size DSM have been generated for Taiyuan mountain test site, which have been evaluated with the same checking points. The comparison was made within different stereo view methods shown in Figure 2.

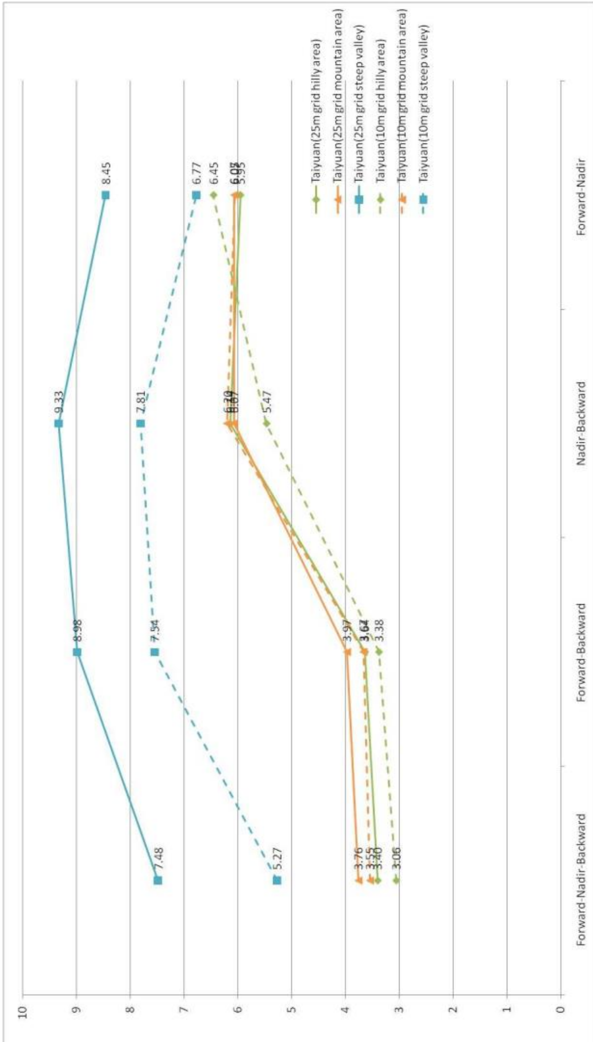

Figure 2. The comparison of DSM accuracy between 25m grid and 10m grid with different stereo view methods.

Through comparison, we found that the accuracy of 10-meter DSM is 1~2 meters higher than 25-meter DSM in hilly study site of Taiyuan, which turns to be more prominent in the steep valley area. It proves the great potential benefit for high accuracy dense grid DSM generation of ZY-3 three-line array images for steep morphology sites.

To further analyze the effect of grid size on performance evaluation of DSM accuracy, 5-meter gird size of DSM have been generated for Taiyuan mountain test site, with one sample area has been clipped, the check points with residuals larger than 10 meter (about 2 times of RMSE) was mapped against with DSM for visual inspection in order to identify the potential areas where the performance may not be as good as others, in particular to detect the performance of DSM generation in altitude extremely varied topographic areas within one test site , at the same time excluding the effect of GCP accuracy, which is shown in Figure 3 and 4. From the residual points distribution we can find that DSM generation with Forward-Nadir-Backward three views stereo images can effectively exclude the rough residuals than Forward-Backward two views stereo images , taking the advantage of one more view information to effectively enhance the accuracy of image matching as well as DSM accuracy, especially in mountain area with steep slopes.

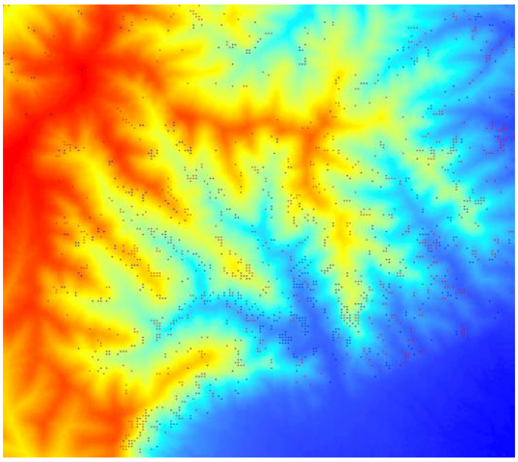

Figure 3. The checking points with residuals larger than 10-meter distribution in 5-meter grid DSM automatically generated with Forward-Nadir-Backward stereo views images

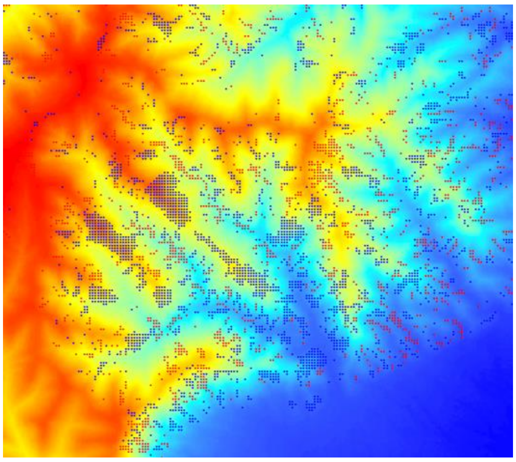

Figure 4. The checking points with residuals larger than 10 meter distribution in 5-meter grid DSM automatically generated with Forward-Backward stereo views images

4. CONCLUTIONS

From the performance evaluation of the DEM extraction, it shows that stereo images of ZY-3 three views achieved the highest accuracy and had great advantage than two views as expected, especially in the mountain area with large altitude deviation and steep slope. Moreover, the accuracy of 10-meter grid DSM is 1~2 meters higher than 25-meter grid DSM in this area, which shows three views stereo images of ZY-3 has great potential to improve the performance of automatic DSM generation than traditional two view stereo images in hill and mountain areas with extreme altitude variation .With DSM grid becomes denser, this benefits turns to be prominent through effectively excluding the rough residuals with one more observation. However in the flat and hill area with low altitude deviation and slope, this benefit of three views stereo images is not obvious same as in steep valley area, the accuracy of DSM extracted with automatic extraction method proves to be similar as two views images within these areas.

The detailed analysis and comparison of DSM accuracy with different gird size in various topographical areas offered a comprehensive evaluation of the performance of three-line array imagery to guide the application of DSM extraction, which also provides a comprehensive evaluation regarding the improvement of the cartographic applications of ZY-3 images as well as the design of followings satellites series.

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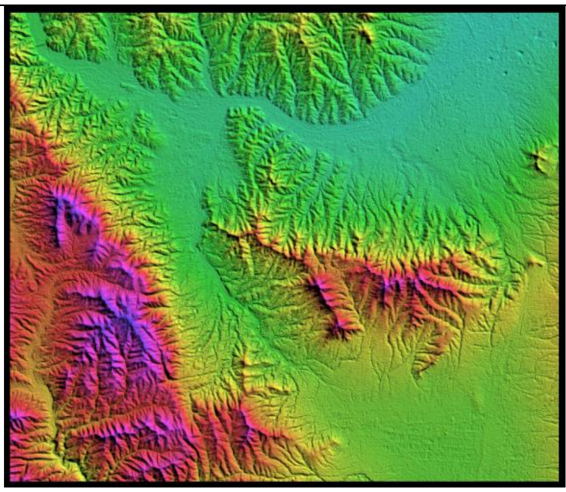
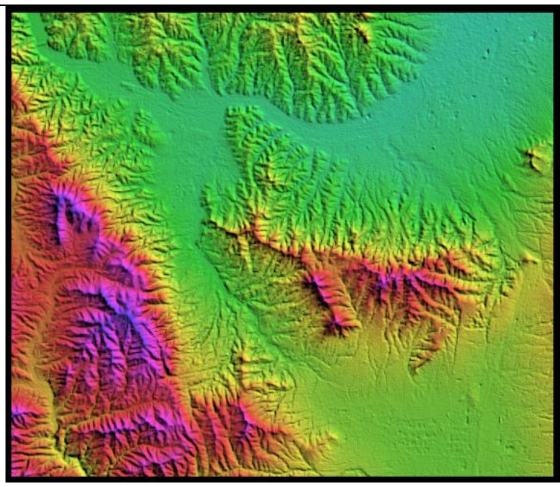
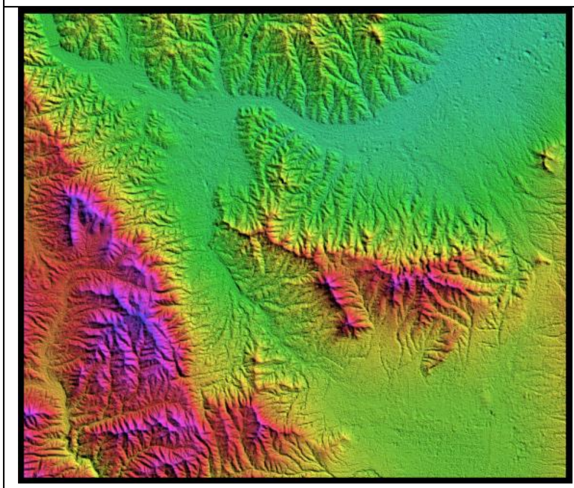
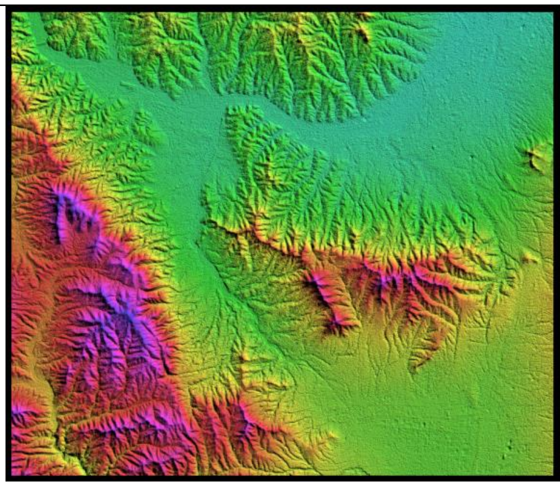
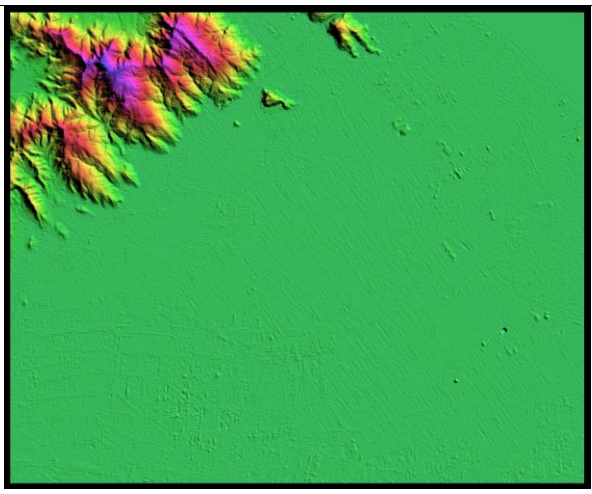
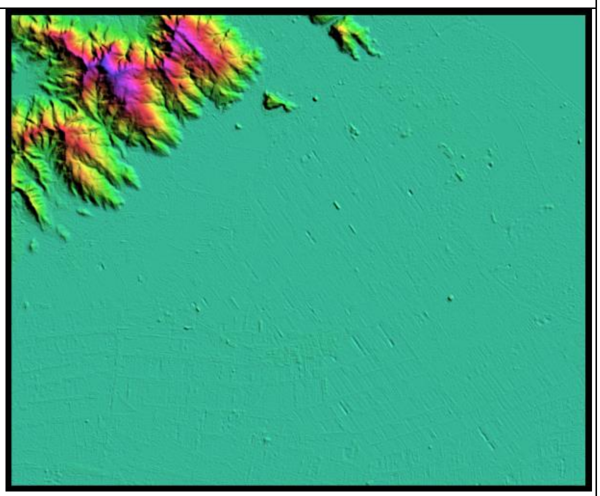
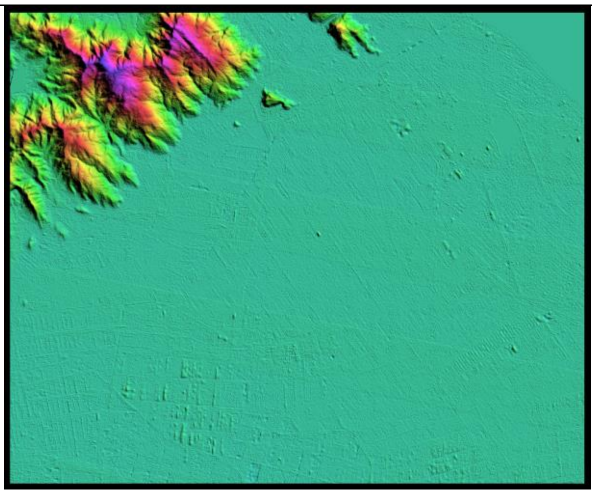
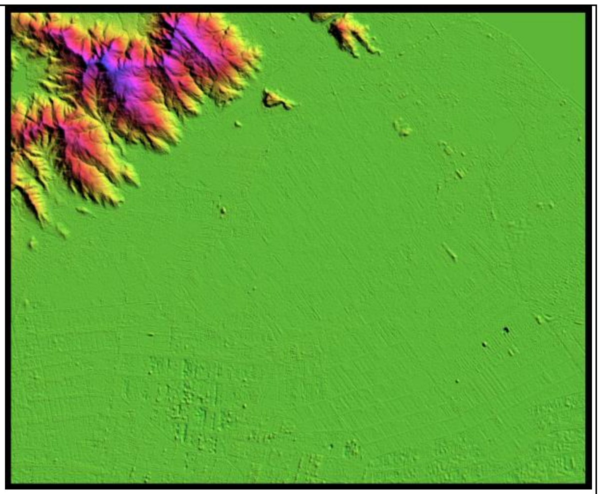
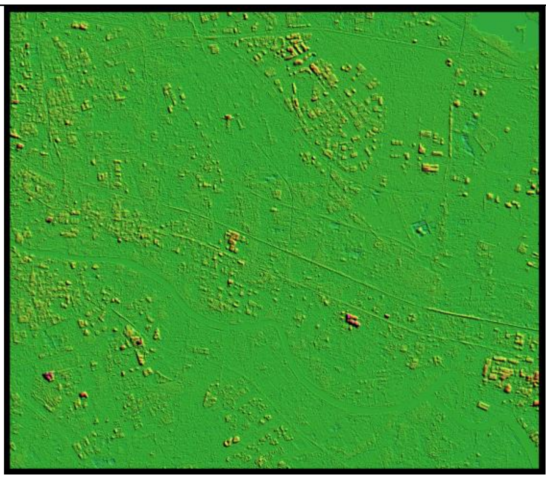
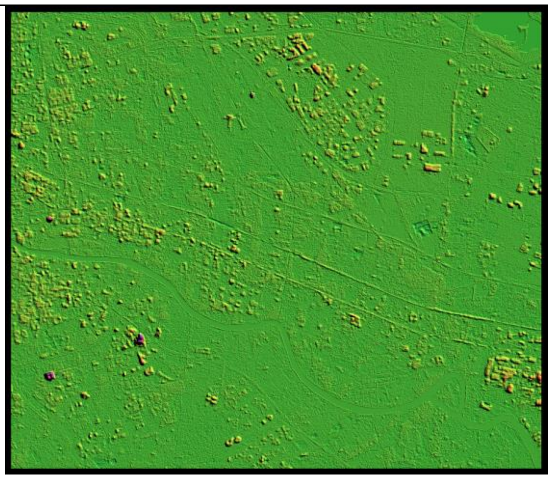
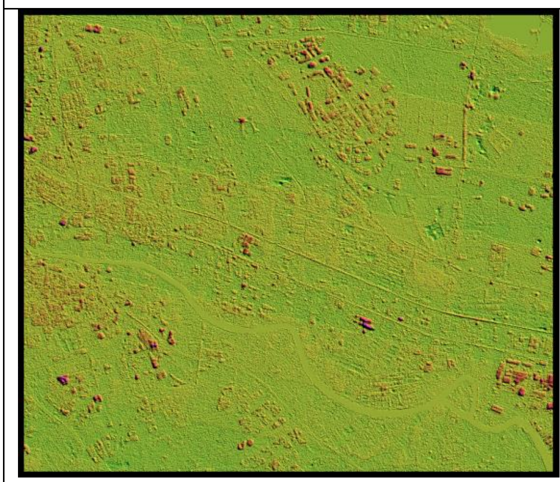
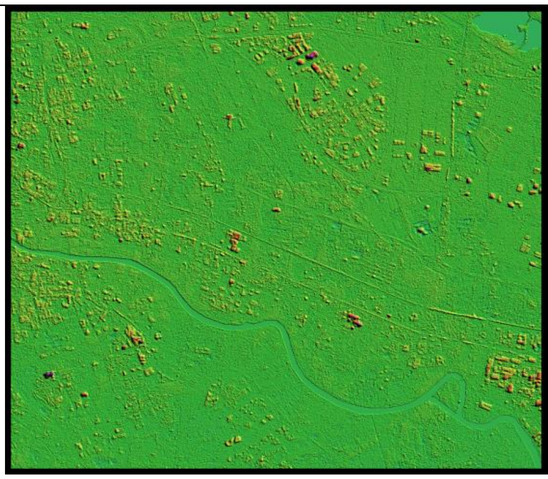
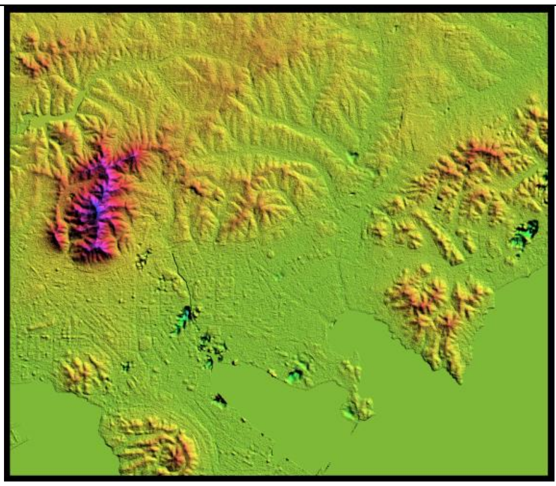
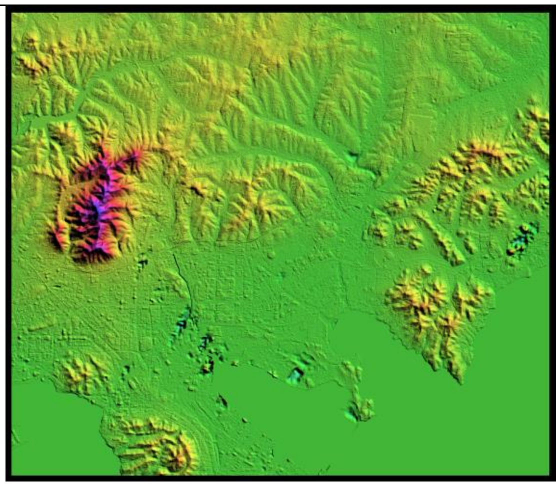
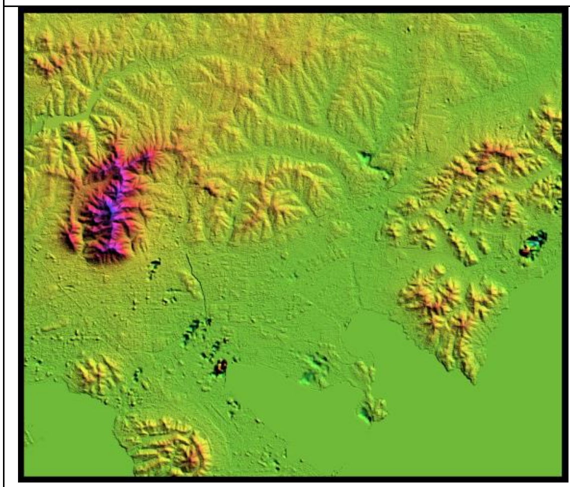
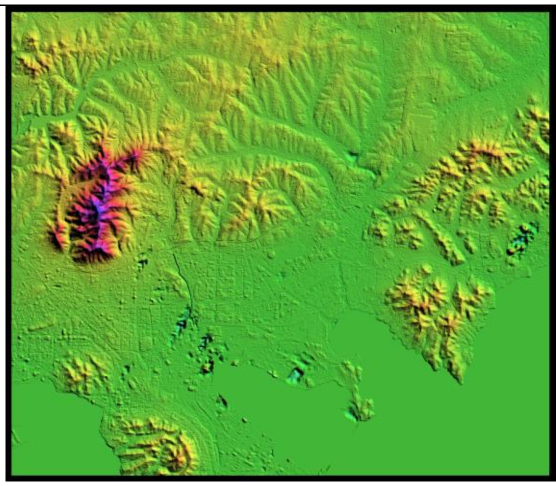
APPENDIX

The samples of DSM automatically generated utilizing PixelGrid software for each test sites with different stereo methods are attached for reference and comparison.

Test site		
Taiyuan	 A1.DSM generated from Forward-Nadir-Backward stereo views	 A2.DSM generated from Forward-Backward stereo views
	 A3.DSM generated from Forward-Nadir stereo views	 A4.DSM generated from Nadir-Backward stereo views
Lianyun gang	 B1.DSM generated from Forward-Nadir-Backward stereo views	 B2.DSM generated from Forward-Backward stereo views

	 B3.DSM generated from Forward-Nadir stereo views	 B4.DSM generated from Nadir-Backward stereo views
Tianjin	 C1.DSM generated from Forward-Nadir-Backward stereo views	 C2.DSM generated from Forward-Backward stereo views
	 C3.DSM generated from Forward-Nadir stereo views	 C4.DSM generated from Nadir-Backward stereo views

Dalian	 D1.DSM generated from Forward-Nadir-Backward stereo views	 D2.DSM generated from Forward-Backward stereo views
	 D3.DSM generated from Forward-Nadir stereo views	 D4.DSM generated from Nadir-Backward stereo views

Appendix Figure 1.The DSM automatically generated utilizing PixelGrid software for each test sites with different stereo view methods