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Research Article

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Batch extraction method of building height based on GF-7 satellite images

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Abstract Building information extraction is an important work content of digital city construction, and the extraction of building height information is important for applications such as urban and rural construction, geographic information update, urban change monitoring, urban cluster development planning, urban 3D modeling, and smart city establishment. In this paper, we take an urban area in Beijing as a test area, carry out digital surface model (DSM) and digital elevation model (DEM) production experiments by using the stereo image pair of Gaofen-7 (GF-7), and extract building heights in batch by using DSM minus DEM and supplemented with building contour data, and verify the accuracy of the experimentally extracted building heights by means of data comparison. The experimental results show that the method of this paper can realize the batch extraction of building height information in a large area with high accuracy of height calculation results, which is a reference for obtaining building height information in the process of urban construction planning and can improve the working efficiency.

Keywords GF-7, DEM, DSM, building heights, verify the accuracy

1. Introduction

All content should be written in English and should be in Single column. Buildings are an important part of urban planning and construction, and building height data can play an important role in urban unauthorized building monitoring, building volume ratio calculation, digital mapping, and digital city construction [1]. At present, the acquisition and updating of building height data mainly rely on traditional mapping methods and building design drawings [2], which requires a lot of manpower, material resources and time in the mapping process and is not suitable for obtaining building height information on a large scale [3], which seriously hinders the timely acquisition of geographic information data. The timely updating of geographic information data is seriously hampered [4-5]. With the rapid development of science and technology, China has been launching high-precision mapping satellites in order to conduct more accurate mapping and research on land resources and geographic information data. The use of high-resolution remote sensing images to obtain surface building data information is one of the important purposes of interpreting remote sensing data, and the Gaofen-7 satellite (referred to as GF-7) is equipped with dual-linear array stereo cameras, laser altimeter and other payloads, breaking through the sub-meter stereo mapping camera technology [6], which can acquire high-resolution optical stereo observation data and high-precision laser altimetry data, among which, the double-linear array camera on the satellite can continuously observe the ground and thus obtain ground overlapping images for acquiring stereo images. The rear-view camera includes panchromatic and multispectral (near-infrared, red, green, and blue bands), with a better than 20 km shooting width, panchromatic resolution better than 0.8 m, multispectral resolution better than 3.2 m, and width better than 20 km [7]. Compared with general optical remote sensing satellites that can only capture flat images, HMS-7 can draw three-dimensional images [8], which can provide good services for natural resources management [9] and is an important support for resource authorities and governments at all levels to obtain data on the current situation and dynamic changes of natural resources [10-11]. The Gaofen-7 satellite, one of the important satellites in the Gaofen special project, is the main force to promote space geographic informatization and is having a profound impact on the development of China's surveying and mapping industry. In this paper, we use GF-7 stereo image pair data, decode the images after image pre-processing, produce high-quality DSM and DEM digital products [12], and extract the building height information from the HDS-7 satellite images by combining the building profile vector data, select the detection points evenly in the study area, and evaluate the accuracy of the extracted building heights by using the data comparison.

2. Methods

In this paper, based on GF-7 image data, the process of extracting building height data information designed according to the research purpose and experimental requirements is shown in Figure 1. It mainly includes four parts: data pre-processing, DSM product production, DEM product production and building height calculation.

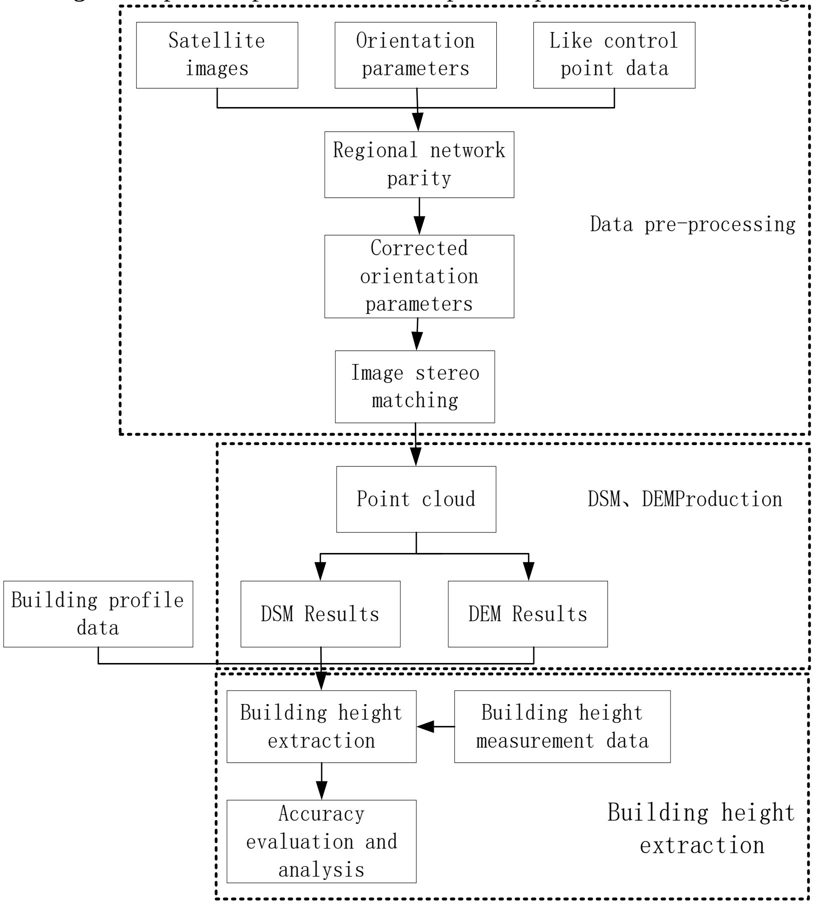


Figure 1: Technology Line

2.1 Data pre-processing and DSM production

Before generating DSM from GF-7 stereo image pairs, we need to orient the image data, i.e., perform area network leveling based on the rational function model for stereo image pairs. Based on the original satellite images, the accompanying RPC (rational polynomial coefficient) parameters and control points, the GF-7 front-view and back-view images are leveled to obtain the exact geometric relationship between the object and image sides of the images. ground point corresponding to the image coordinates [13], and the polynomial is expressed as:

$$x = \frac{p_1(X,Y,Z)}{P_2(X,Y,Z)} \qquad (1)$$
$$y = \frac{p_3(X,Y,Z)}{p_4(X,Y,Z)}$$

Where, $p_1(X,Y,Z)$, $p_2(X,Y,Z)$, $p_3(X,Y,Z)$, $p_4(X,Y,Z)$ are all cubic polynomial functions; X , Y , Z are the spatial coordinates of the ground point after normalization; x, y are the original coordinates of the image point.

The polynomial is taken to the first order that is the affine mapping model, which can be expressed as:

$$\begin{aligned} \Delta x &= a_0 + a_1 x + a_2 y \\ \Delta y &= b_0 + b_1 x + b_2 y \end{aligned} \qquad (2)$$

Where, $\Delta x, \Delta y$ is the image square correction number; x, y are the image point coordinates; $a_i, b_i (i = 0,1,2)$ are the affine mapping parameters. These parameters are saved in the RPC file.

From equation (1) and equation (2) together constitute the regional network leveling model of the high-spectrum seven stereo image pair, and the error equation can be obtained by linearizing equations (1) and (2) as:

$$V_1 = A_1 X + B_1 Y - l_1, P_1 \qquad (3)$$

Where X is the affine mapping parameter correction number of the image, Y is the object-squared coordinate correction number, A_1, B_1 are the corresponding coefficient matrices, l_1 is the initial calculated constant, and P_1 is the weight.

According to the satellite image and orientation parameters, the GF-7 stereo image pair is matched in stereo, and the image resolution used in stereo matching is generally not better than the resolution of the lower resolution image in the stereo image pair, because the resolution of the front view image in the GF-7 stereo image pair is 0.8m, so the image resolution in stereo matching is 1m. The DSM products are generated, the null areas in the DSM are interpolated, and the error points are removed from the interpolated DSM to generate high precision and high-density DSM products.

2.2 DEM Production

The DEM is also generated using the point cloud data generated in the previous section, and the point cloud data is filtered in layers using a multi-level triangular mesh terrain filtering algorithm. Firstly, a ground layer needs to be set in the point cloud data to filter out the points that do not fall on the ground, i.e., to eliminate the above-ground targets such as buildings and trees in the point cloud, and get the pure ground height; then, to fill the voids, as the non-ground points in the point cloud data are filtered out, many voids will be generated for the retained point cloud data, and it is necessary to fill the voids completely to get a high-quality DEM product, at which time To get high quality DEM products, we need to build TIN grid for DEM, and turn the discrete points in DEM data into continuous surfaces by building TIN grid, and finally get high quality DEM products.

2.3 Building height calculation

The building height is calculated by using the building profile vector data, DSM results and DEM results of the study area, and all data need to use a unified coordinate system. Before calculating the building height, the building outline vector data is converted into raster data, during the conversion process, attention should be paid to the image size setting, the value is set too high to form a mosaic in some areas, after several experimental tests, it is finally determined that the image size is set to 0.1m is the most appropriate. The DSM results and DEM results are supplemented by the building profile raster data for raster calculation, and the pure building raster data, i.e. building height information, is obtained by subtracting DEM from DSM.

3. Experimental Analysis

3.1 DEM Production

To verify the effectiveness of the method in this paper, the GF-7 stereo image pairs of six urban areas in Beijing were used as the experimental data source for building height extraction. Building outline information was extracted using ArcGIS 10.5 software.

The image used in this experiment is a stereo image pair taken by the two view GF-7 dual line array cameras, provided by the Resource Satellite Application Center, and the image was taken at 03:25 on June 4, 2021, and the data include two 0.65m resolution rear view images and two 0.8m resolution front view images (Figure 2), as well as two 3.2m resolution multispectral images, and the image covers an area of Six urban areas of Beijing, covering an area of about 1200km² , with both front and rear view images covering mountainous, suburban and urban areas, and containing elements such as roads, buildings, woods and grass.

Figure 2: Image map of the study area (local)
(a) Rear View Image (b) Front view image

3.2 Data pre-processing

The GF-7 image data pre-processing includes two parts: orthorectification and image fusion processing, and the flow chart is shown in Figure 3. The purpose of orthorectification is to accurately align the two images to the same coordinates, i.e., to align the images, and to use the aligned images for image fusion to produce a fused image with both color and high resolution, in preparation for extracting the building height.

In this study, the RPC Orthorectification Workflow, an orthorectified tool in ENVI software, was used to perform the RPC (Rational Polynomial Coefficient) file with the help of the self-contained global 900m DEM data (GMTED2010.JP2) for Both panchromatic and multispectral data were corrected and resampled to orthoimages. The remote sensing data used in this study is GF-7 remote sensing image, the orthorectification process of its panchromatic image is basically the same as that of the multispectral data, the difference is that the out put image element will be 0.65m for the panchromatic image correction and 2.6m for the multispectral output image element.

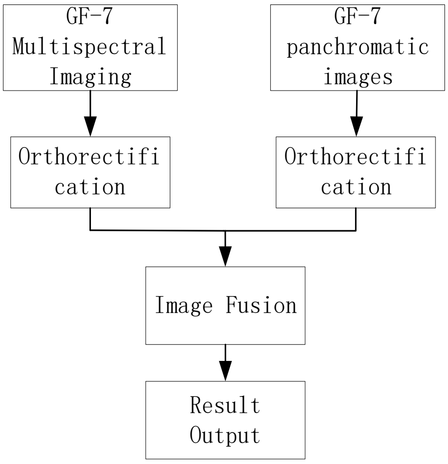
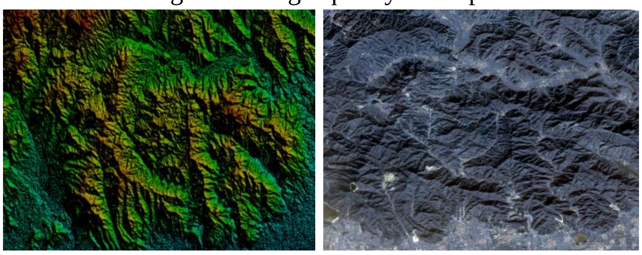


Figure 3: Data pre-processing flow chart

3.3 DSM and DEM products

This experiment performs stereo matching and generates point cloud data for the high-definition seven stereo image pairs, and uses the point cloud data to generate high-quality DSM products as shown in Figure 4.



(a) Mountain

(b) Urban area

Figure 4: Typical area matching effect in DSM

The dense point cloud is filtered in layers, and the TIN mesh is constructed for the filtered point cloud data to obtain a continuous surface, and the DEM product is generated as shown in Figure 5.

Figure 5: DEM results (local)

3.4 DEM product accuracy assisted verification

The DEM production process needs to filter out the points that do not fall on the ground, and if the point cloud data are not processed properly it will lead to more errors in the DEM products. In order to verify the quality of building height data extraction, several buildings are evenly selected in the study area, and the elevation data around the buildings are randomly extracted, as well as the ground elevation after the buildings are removed, if the elevation data around the buildings are consistent with the ground elevation after the buildings are removed, the DEM product quality is proved to meet the experimental requirements. The building height comparison data are shown in Table 1. Through the data comparison, it can be found that the difference between the ground elevation of the building location and the elevation data around the building is within 0.5m. Considering the variation of the terrain around the building, the accuracy of the DEM product obtained from the experiment is considered to meet the experimental requirements.

Table 1: Building height control results

Building serial number	Point number	Peripheral Elevation	Elevation of the building site
	1	18.402	18.532
	2	18.487	18.521
1	3	18.763	18.528
	4	18.432	18.537
	5	18.557	18.534
	1	17.748	17.525
	2	17.732	17.519
2	3	17.565	17.528
	4	17.423	17.532
	5	17.841	17.522
	1	15.004	15.231
	2	14.892	15.227
3	3	15.216	15.229
	4	15.145	15.235
	5	15.328	15.237
	1	20.083	20.432
	2	20.122	20.424

4	3	20.323	20.437
	4	20.115	20.429
	5	20.752	20.425
	1	7.986	8.328
	2	8.325	8.319
5	3	7.577	8.315
	4	8.338	8.351
	5	8.256	8.323

4. Accuracy verification and result analysis

4.1 DSM accuracy evaluation

The field inspection points were selected and measured in the field using RTK surveyor, as shown in Figure 6, and the DSM results were verified for accuracy using the inspection points, and the test results are shown in Table 2.

Figure 6: Field measurements

(a) RTK Surveyor (b) Detection points

Table 2: DSM elevation accuracy test results

Terrain category	Number of detection points	Elevation median error (m)	Elevation maximum error (m)	Prescribed mid-error (m)
Flat land	37	0.257	0.623	0.5
Hilly	42	0.732	1.157	1.2
Mountainous	33	1.134	1.986	2.5
Alpine	38	3.585	4.26	5.0

The data comparison and the verification specification show that the DSM results produced by using the GF-7 stereo image pair are accurate in accordance with the secondary accuracy index of 1:10,000 digital surface model and can better reflect the surface morphology.

4.2 DEM accuracy evaluation

The accuracy of elevation information extraction directly affects the accuracy of building height extraction, so the accuracy check of DEM is very important. the accuracy of DEM has a great relationship with topographic factors, the number and accuracy of control points, the number of points with the same name and other factors. Therefore, after producing DEM data, the accuracy of DEM should be evaluated, i.e. DEM accuracy assessment. In this paper, RTK surveyor is used to conduct field measurements of the field inspection points, and the error table between the extracted elevation value and the actual elevation value of each check point is obtained by comparing the real value of the inspection points with the DEM extracted value. In this paper, based on the control points measured in the field, some control points are extracted for DEM elevation accuracy evaluation. The field measured control points are imported into the extracted DEM to verify the accuracy of the DEM results, and the test results are shown in Table 3.

Table 3: Accuracy statistics of DEM results

Terrain category	Number of detection points	Elevation median error (m)	Elevation maximum error (m)	Prescribed mid-error (m)
Flat land	37	0.418	0.575	0.7
Hilly	32	0.931	1.332	1.7
Mountainous	41	2.016	2.876	3.3
Alpine	38	3.312	4.281	6.7

Through data comparison and checking the specification, it can be seen that the DEM results produced by using GF-7 stereo image pairs are of high quality as their accuracy meets the secondary accuracy index of 1:10000 digital elevation model.

4.3 Building height verification

This experiment uses two scenic GF-7 stereo image pairs, covering six urban areas of Beijing with an area of about 1200km^2, and the study area contains a total of 305936 buildings. The height information of 305936 buildings was extracted in this experiment, from which 200 buildings in the study area were randomly selected for height verification, and the verification method was to obtain the building height data by field measurement of the selected buildings with a total station, and to compare and analyze the building height results calculated by this experimental method, and the statistics are shown in Table 4.

Table 4: Building height calculation error statistics

Content	Number
Total number of test samples/building	200
Average error/m	1.63
Maximum error/m	9.26
Minimum error/m	0.32
Average relative error/%	6.50

The error distribution can be seen more clearly and intuitively from the error distribution histogram (shown in Figure 7), which shows that there are 88 buildings with an error of 2 meters or less, accounting for 44% of the total; 71 buildings with an error of 2 meters to 5 meters, accounting for 36% of the total; 27 buildings with an error of 5 meters to 8 meters, accounting for 13.5% of the total; and 13 buildings with an error of more than 8 meters, accounting for 6.5% of the total. 13.5% of the total number of buildings with an error of more than 8 meters, and 13 buildings with an error of more than 8 meters, accounting for 6.5% of the total number of buildings. Therefore, it can be seen that the building height data extracted by the method of this paper has high accuracy and is suitable for extracting building height information in large areas.

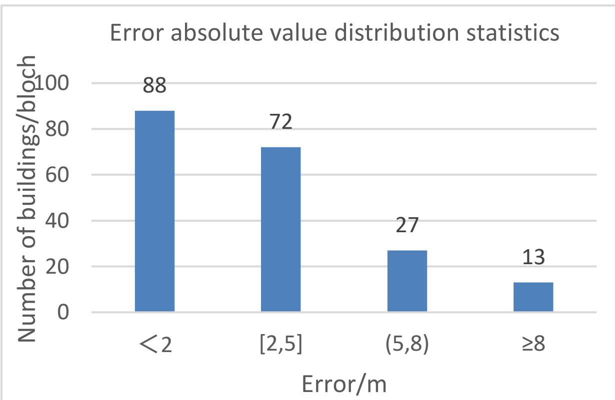


Figure 7: Error distribution chart

5. Conclusion

The method proposed in this paper can extract building height information in batch over a large area, and the method is simple and fast, and the optimal effect of calculation accuracy for building height can reach sub-meter level. In this experiment, two sets of remote sensing images of Gaofen-7 were used, covering an area of about 1200km², and 305936 buildings were extracted with a total time of 31.3h. The DSM results generated from Gaofen-7 images were 22.8G, with an image resolution of 0.5m, with a total time of 12.7h; the DEM results obtained by filtering the DSM results were 22.8G, with a total time of 8.2h. The experiment proves that the method of this paper can extract the building height information in a large area in batch, which can save a lot of human, material and financial resources and improve the overall progress of the project, and is a reference for obtaining building height information in the urban construction planning process and can improve the working efficiency.

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