Automatic epipolar image generation with ZY-3 TLS imagery

Duan YanSong
School of Remote Sensing and Information Engineering, Wuhan University, 129 Luoyu Road, Wuhan 430079, China
E-mails: ysduan@whu.edu.cn

Abstract. The methods of generating the epipolar image with ZY-3 TLS (Three Line Scanner) imagery are introduced in this paper. The proposed algorithms are employed by the ZY-3 Satellite Ground Data Handling System (GDHS) in China Centre for Resources Satellite Data and Application (CRESDA). The characteristic of ZY-3 TLS imagery and the principle of epipolar image generation with linear array CCD image are firstly introduced and the specific work flow aimed at ZY-3 TLS image is presented, then the practical applications of this epipolar image generation method in ZY-3 satellite GDHS are discussed. The satisfying experimental results with the developed system verify the efficiency and reliability of the proposed algorithms.

1. Introduction
ZY-3, which was launched on January 9, 2012, is the first civilian high-resolution stereo mapping satellite in China. ZY-3 is equipped with three-line scanners (nadir, backward and forward views with better than 2.1m and 3.6m resolutions, respectively) and an additional multispectral scanner. The stereo base-height ratio of ZY-3 is 0.85-0.95. The main purpose of ZY-3 data is to generate 1:50,000 scales cartographic maps, digital elevation model and digital ortho-image, and map revision. It can also be used for many other applications, such as national resource surveying and environment monitoring.

Large amount of remote sensing data has been received since the launch of ZY-3 satellite. CRESDA is responsible for the construction of ZY-3 satellite Ground Data Handling System (ZY-3 GDHS). ZY-3 GDHS performs data receiving, standard product generation and advanced product generation. The standard product generation includes the calculation of the orbit and attitude parameters of satellite image and standard scene image production. The advanced product generation includes the automatic DEM generation, epipolar stereo image production and DOM production and so on. Epipolar stereo image is an important production of the GDHS and is necessary in generation of the 1:50000 scales surveying and mapping products with the ZY-3 satellite images. Wuhan University is responsible for standard product generation and advanced product generation and the paper’s author is a member of the research team. So this paper focuses on the algorithms and module construction of the epipolar stereo image production as well as its practical running.

2. The algorithm of epipolar image generation with line array satellite images
The specialty of line array image is that each line of the image has different exterior orientation parameters. In consequence, no rigorous epipolar geometric relation exists between the stereo image pairs. Only the approximate epipolar line which has no parallax can be obtained according to
the definition of epipolar line. Up to now, there are three main methods for doing this \cite{4}. The first one is called “the simplification of the projection model”: simplifying the high order coefficients of the rational function and build the epipolar model based on the affine transformation. The second one is called “fit by polynomial”: fitting the epipolar line by polynomial based on large amount of control points. The last one is called “the projection track”: projecting the object space point corresponds to the left (right) image point onto the right (left) image and the projection track forms the epipolar line. The paper’s method is based on the promotion and demotion of the height of the projection line. Both of the former two methods employ approximation so the precision is relatively low \cite{3}. The third method is used in this paper which is described in details below.

As shown in figure 1, S and S’ are two perspective centers, one object space point (X, Y, Z) is imaged as point p in left image. The projection relation is described by RPC model. Then each point on this projection line can be uniquely projected onto the right image and forms a polyline which is called the epipolar line of point p. If p’ is the corresponding point of p, it must be on this polyline. The polyline is replaced by a straight line for the convenience of calculation. First the right image epipolar lines are obtained then the left image.

3. The design of epipolar image generation module of ZY-3 GDHS
Based on “the projection track” theory described above, codes can be written to perform the epipolar image generation with line array images. But three more problems should be taken into account to complete the epipolar image generation work with ZY-3 satellite images.

3.1. Over-resample forward and backward images
Since a Three Line Scanner is mounted on the ZY-3 satellite, nadir, forward and backward images can be obtained simultaneously. The algorithm should be extended to support three views. The method this paper employed is to take the nadir image as the reference image to collect the epipolar lines of the forward and backward images. Besides, the resolutions of these three images are different. To preserve the optimal data precision, the nadir image is still taken as the reference image. The epipolar line collection on nadir image is in 1:1 scale while the other two images are over-resampled to keep the same ground resolution of epipolar images.

3.2. Take standard scene image from strip image
The imaging period of ZY-3 satellite by each ground receiving station is about 500 seconds, which covers about 4000km×50km ground area. The strip image could be over 200GB in size. The forward and backward camera CCD lines are both formed by 4 sub-CCD line arrays with length of 4096 pixels. Every two sub-CCD overlaps 28 pixels. So the final width of forward and backward image is 16300 pixels. The nadir camera CCD line is formed by 3 sub-CCD line arrays with length of 8192 pixels. Every two sub-CCD overlaps 23 pixels. So the final width of nadir image is 24530 pixels \cite{9}. The parameters of TLS cameras are shown in table 1.

|                      | forward | nadir  | backward |
|----------------------|---------|--------|----------|
| Focus length (mm)    | 1700    | 1700   | 1700     |
| Pixel size (mm)      | 0.010   | 0.007  | 0.010    |
| CCD length (pixel)   | 16300   | 24530  | 16300    |
| View angle (degree)  | 22      | 0      | -22      |
| GSD (m)              | 3.5     | 2.1    | 3.5      |
The forward and backward strip images generated by one imaging period could be 1300000 rows and the nadir strip image could be 1960000 rows. Large volume of data brings some problems for the epipolar image generation as following:

1) The fit by straight lines of epipolar lines can’t guarantee the high precision in large range.
2) Data can’t be loaded in memory once.
3) Parallel processing can’t be used which results in very low time efficiency.

So the standard scene image unit is taken into the processing flow just as the other commercial satellites (IKONOS, WorldView) do. When dividing the image scenes, the nadir image is taken as the reference image which has the square scene shape. The range of the forward and backward image scenes are then calculated accordingly. Taking the image scene as processing unit brings many benefits. First, the fit by straight lines of epipolar lines in one scene can satisfy the precision requirement. This is proved by a lot of tests. Second, the data can be loaded into memory once now. Third, parallel processing techniques can be employed since there are no dependencies between scenes.

### 3.3. The design of processing system

ZY-3 GDHS is responsible for completing the data processing tasks within the same day as all the data received. The ZY-3 satellite cameras shot images twice a day which requires the epipolar image generation tasks to be finished in 2 hours for each image shot. To guarantee this, the whole system is designed as blew, including the hardware environment and software environment.

#### 3.3.1. Hardware environment

The hardware platform employs the cluster parallel processing techniques to accomplish the high efficiency requirements. The storage unit is composed by a few high speed disk arrays to form a logic array with data volume reaches PB level. Throughput capacity of the storage unit is about 40Gpbs. The computing nodes are composed by 100 rack servers. Each server contains two eight-core (16 threads) CPUs and with a 96GB RAM. The InfiniBands with a bandwidth of 40Gbps constitutes the backbone network of the platform. The computing nodes and storage arrays are connected to the backbone network directly while the operating consoles are connected to the platform by gigabit Ethernet. The topology of the whole hardware environment is shown in figure 2.

![The topology of the whole hardware environment](image_url)
3.3.2. Software environment

To make the most use of the hardware environment, Linux is chosen as the operating system and the Platform LSF (load sharing facility) is chosen to manage the task dispatching. The system supports OpenMP and MPI. All these configurations make the parallel processing possible.

3.3.3. The epipolar image generation module

In the hardware and software environments mentioned above, the epipolar image generation module is designed into four parts.

The first part is called “the Kernel part”. This part finishes the actual calculating tasks, namely the epipolar image generation. The inputs of this part include:

a) The path of the strip image.
b) The orbit and attitude parameters of the strip image.
c) The begin line number of one scene image relative to the strip image.
d) The end line number of one scene image relative to the strip image.
e) The orbit and attitude parameters of the reference image.
f) The path of the production images.
g) The path of the parameter files of the production images.

This part is an independent module and the inner algorithm is “the projection track” algorithm mentioned in the former section.

The second part is called “the Task part”. This part finishes tasks partition. Its output is all the epipolar stereo images and their parameters.

The third part is called “the Check part”. This part checks the processing results of all sub tasks, such as success or not and the reason of failure.

The fourth part is called “the Scheduler part”. This part manages the whole process. It calls “the Task part” to divide tasks firstly, and hands in these tasks to the LSF to do the parallel processing. Finally it calls “the Check part” to check the processing results of all tasks. The process is shown in figure 3.

![Figure 3. The schematic diagram of the parallel processing flow](image-url)

Among the four parts, the first part (the calculating part) is the most time consuming one. But thanks to the parallel processing, the whole processing time mainly relies on the number of computing nodes. There are 2400 (100×24) nodes that can be used for advanced products generation. So the
processing time decreased to 1/2400 in theory. The other three parts of our algorithm have not much calculation to do so they don’t cost time much.

4. The practical running status of the system
The ZY-3 satellite was launched in January 9, 2012. The first strip image was taken at 10:30 am, January 11. And it covers HeiLongJiang, LiaoNing, ShanDong, JiangSu, ZheJiang and FuJian provinces as shown in figure 4. The strip images of nadir, forward, backward and multispectral were transmitted into the ZY-3 satellite GDHS at 11:30 am. After data decoding, radiometric correction, orbit and attitude parameters calculation and orientation adjustment, the data entered into the epipolar image generation module. After about one hour, the epipolar image generation completed. The YingKou area of DaLian city was chosen as the main check area to evaluate the precision of the product (the images are shown in figure 5). The checking method is to randomly select 64 corresponding points on the left and right images to do forward intersection to obtain their ground coordinates. Then project them onto the epipolar images to check the offset of the y coordinates. The result is shown in table 2.

|             | RMS(σ) of parallax (pixel) | Maximal parallax (pixel) | Number of points with parallax < 1σ | Number of points with parallax < 2σ | Number of points with parallax < 3σ | Number of points with parallax≥3σ |
|-------------|-----------------------------|--------------------------|-----------------------------------|-----------------------------------|-----------------------------------|----------------------------------|
| forward-nadir | 0.283                       | 1.254                    | 38                                | 54                                | 62                                | 2                                |
| Nadir-backward | 0.306                       | 1.301                    | 34                                | 53                                | 62                                | 2                                |
| forward-backward | 0.201                      | 1.174                    | 36                                | 54                                | 61                                | 3                                |

Figure 4. The coverage of the first strip image of ZY-3

Figure 5. The TLS images of YingKou area of DaLian city of ZY-3

To evaluate the influence of epipolar images to the cartography, the coordinates of these 64 points on the epipolar images are all marked out by operators to do forward intersection. The forward
intersection coordinates obtained are then compared to the forward intersection result of the original images. The comparison is shown in Table 3.

|          | RMS(σ) (meter) | Maximal error (meter) | Number of points with error < 1σ | Number of points with error < 2σ | Number of points with error < 3σ | Number of points with error ≥3σ |
|----------|----------------|-----------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| DX       | 1.606          | 3.506                 | 30                               | 42                               | 59                               | 5                                |
| DY       | 1.459          | 3.769                 | 34                               | 43                               | 60                               | 4                                |
| DZ       | 1.234          | 3.465                 | 36                               | 45                               | 61                               | 3                                |

At 1:00 am, January 12, the second strip image of ZY-3 was received. It covers Mongolia, GanSu, QingHai, Tibet and Bengal. The JiuQuan-JiaYuGuan area was chosen as the check area to evaluate the product. And the checking result is shown in Table 4.

|          | RMS(σ) (meter) | Maximal error (meter) | Number of points with error < 1σ | Number of points with error < 2σ | Number of points with error < 3σ | Number of points with error ≥3σ |
|----------|----------------|-----------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| DX       | 1.806          | 4.206                 | 30                               | 42                               | 59                               | 5                                |
| DY       | 1.759          | 3.769                 | 34                               | 43                               | 60                               | 4                                |
| DZ       | 1.934          | 3.465                 | 36                               | 45                               | 61                               | 3                                |

Up to July, 2012, there are over 400 strips of image data have been received and processed. The coverage contains the whole China, some regions of European, Africa, Australia, North America, and South America. One scene data has been randomly selected from every continent to check the quality of the products. And the checking results are shown in Table 5.

|          | RMS(σ) (meter) | Maximal error (meter) | Number of points with error < 1σ | Number of points with error < 2σ | Number of points with error < 3σ | Number of points with error ≥3σ |
|----------|----------------|-----------------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| DX       | 1.242          | 5.223                 | 156                              | 231                              | 315                              | 15                               |
| DY       | 1.134          | 5.284                 | 164                              | 228                              | 317                              | 13                               |
| DZ       | 1.263          | 5.032                 | 168                              | 278                              | 318                              | 12                               |

These checking results prove the success of the system. The epipolar image products are in good quality and the system has been keeping running for more than one and a half years, so it is very stable and reliable.

5. Conclusion

As we know, ZY-3 satellite is a high-resolution mapping satellite, and epipolar images are widely used in surveying and mapping for stereo measurement. So, the throughput and automation in processing is most important. By taking advantages of advanced software and hardware technologies, the development of a highly-efficient operational method for epipolar image production has been accelerating, which can deal with the mass daily data of ZY-3 satellite. After processing practices of more than one year (2012-2013), the epipolar image products are randomly checked by different ways. The results proved the efficiency and reliability of the proposed method.
What’s more, the structures of the hardware and software environments in GDHS for ZY-3 satellite are proved to be very efficient. In the environment, the parallel processing efficiency of the epipolar image generation module is improved obviously and can been used in other similar systems.

As a result of the normal operation of GDHS, the method of epipolar image production promotes not only the business of satellite data services, but also the data applications of domestic satellites. We are confident that these satisfying datasets of the mapping satellite imagery will be widely used in the future.

Acknowledgments
This work was supported in part by the National Natural Science Foundation of China under Grant 41071233, National Hi-Tech Research and Development Program under Grants 2013AA12A401 and 2012AA12A301.

References
[1] Yongjun Z, Maoteng Z, Jinxin X, Yihui L and Xiaodong X 2013 On-orbit Geometric Calibration of ZY-3 Three-line Array Imagery with Multi-strip Datasets J. TGRS PP 1-11
[2] Shenghui F and Yifu C 2012 Sensor Calibration of Three-line CCD Scanners on ZY-3 J. XXII ISPRS Congress Archives XXXIX-B1 109-14
[3] Yongjun Z and Yazhou D 2009 Approximate Epipolar Image Generation of Linear Array Satellite Stereos with Rational Polynomial Coefficients China. J. Geomatics and Information Science of Wuhan University 34 1071-78
[4] Hu F, Wang M and Li D 2008 A novel epipolarity model of satellite stereo-imagery based on virtual horizontal plane of object-space China. J. ICEODPA 7285 8
[5] Hongbo P Guo Z and Tan C 2011 A General Method of Generating Satellite Epipolar Images Base on RPC Model J. IARSS 24-29 3015-18
[6] Kim T 2000 A Study on the Epipolarity of Linear Pushbroom Images J. PE&RS 66 961-6
[7] Kratky V 1989 On-Line Aspects of Stereo Photogrammetric Processing of SPOT Images J. PE&RS 55(3) 311-6
[8] Jianqing Z, Yong Z, Shunyi Z and Hongwei Z 2004 Accurate Rectification of Remote Sensing Images with High Resolution China. J. Geomatics and Information Science of Wuhan University 29 994-8
[9] CRESDA 2011 Manual of standardized data format for ZY-3 Ground Data Handling System, The interior document of CRESDA
[10] CAST 5TH 2008 Manual of camera for ZY-3 satellite The interior document of CRESDA
[11] CRESDA 2011 Manual of hardware environment and software environment for ZY-3 Ground Data Handling System, The interior document of CRESDA