

## DEVELOPMENT OF ORIENTATION AND DEM/ORTHOIMAGE GENERATION PROGRAM FOR ALOS PRISM

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**ABSTRACT:** Orientation and DEM/orthoimage generation programs with open algorithms for ALOS PRISM were developed in order to determine error factors and to improve geometric accuracy. The programs were verified using simulation data obtained by ADS40, an airborne three line sensor like the PRISM before the launch on January 24, 2006.

The orientation program can adjust all or part of the following errors: photographic coordinates, position and attitude of the satellite, ground coordinates of the control points, mounting angles of the radiometers, the principle distances, and the principal positions. The program worked properly for the simulation data. The error factors of the simulation data were investigated; the principle distances were the primary factor, and attitude of the platform was the secondary.

The DEM/orthoimage generation program employs area-based matching with coarse-to-fine strategy. A calculation of the pixel and line number on the raw images from the ground coordinates needs long time for the PRISM. The program reduces the computation volume by interpolating the pixel and line number in ground grid space and along ground height axis. The program worked properly using the simulation data resampled into 1.6 m grid. Observing clear target settled mainly in open sky area, root mean square error was 1.13 m in vertical for the DEM, and 1.30 m in horizontal for the orthoimages. These values represent errors of the DEM and orthoimages production procedure, and pointing error on the orthoimages. Comparing the DEM with DSM obtained by LIDAR measurement, root mean square error of the DEM was 3.59 m in a mixed area of high buildings, low housing, woods, and crop fields. The error corresponds 5.7 m for the PRISM.

### 1. INTRODUCTION

**ALOS and PRISM:** JAXA (Japan Aerospace Exploration Agency) has launched the ALOS (Advanced Land Observing Satellite) satellite on January 24, 2006. The satellite has three earth observation sensors: PRISM, AVNIR-2 and PALSAR. The PRISM observes ground from 3 directions (forward-, nadir- and backward-looking) within an orbit. Pixel size is 2.5 m. One of the most important objectives of the PRISM is middle scale mapping such as 1:25,000 topographic maps.

**Program and Verification:** Orientation and DEM/orthoimage generation programs with open algorithms for ALOS PRISM were developed in order to determine error factors and to improve geometric accuracy. The programs also enable mapping from PRISM images without digital stereo plotter. These programs are verified using simulation data before the launch. The simulation data are obtained from LHSYSTEMS' ADS40 airborne digital sensor (Eckardt et. al., 2000) for

photogrammetry. ADS40 is a three-line stereo sensor like the PRISM.

## 2. ORIENTATION

### 2.1 Algorithm

**Observation Equation:** The orientation program assumes and adjusts errors of photographic coordinates, position and attitude of the satellite, errors of ground coordinates of control points, and any combination of the following additional error factors: mounting angles of the radiometers, the principle distances, and the principal positions.

Position and attitude are primary defined using star tracker, GPS receiver, and other onboard instruments. The orientation program assumes the defined position and attitude data still have error as arbitrary order of polynomial of time. Both same and different polynomials are able to apply to different observation courses.

**Solving:** Unused parameters are fixed by observation equations of parameter = 0 with extraordinary large weight. Differential coefficient of the observation equation is calculated by numerical differentiation. The normal equation is solved by LU decomposition, because the Cholesky method, widely used in least square method, may have large calculation error for normal equation generated from extraordinary large weight.

### 2.2 Data and Method

**Simulation Data:** Five courses block of ADS40 data were used for the verification. Flight height was about 2,000 m and pixel size is about 0.2 m. There were 19 known points in the block. The known points were marked on roads mainly in open sky area. Control points were selected from the known points, and remains were used as verification points.

**Control Points and Adjustment:** The block was adjusted using 0, 4 or 18 control points. Known points in the corners were used in case of 4 control points. Adjustments using all combination of 18 known points from the 19 points were executed, and RMSE (Root Mean Square Error) of all adjustment were used for the verification in case of 18 control points.

No additional error factor was used, and order of polynomial for position and attitude error was 1, in case of 0 and 4 control points. Various combinations of additional error factors and order of the polynomial are tried to determine error factors of the simulation data in case of 18 control points.

### 2.3 Result

**Error Factor:** The best two combinations makes RMSE error minimum was following in case of 18 control points. The difference was small. Where position error or principle distance was the primary factor, and attitude error was the secondary.

- (1) Position error (const.) and attitude error (const.)
- (2) Principle distances and attitude error (const.)

Because height of the known point No. 5 is 358 m, and heights of the other known points are 8 - 37 m against flight height 2,000 m, position error in z direction and error of principle distance are hardly distinguished. Therefore top of the Mt. Tsukuba without marking was observed to determine the error factors. The error factor (2) gave 0.46 m better height than the error factor (1) at the top, and the error factor (2), principle distances and attitude error (const.), was selected.

**Number of Control Points:** RMSE of the verification points were as table 1 by adjustment with 0, 4, and 18 control points.

Table 1. RMSE of the Orientation

Number of Control Points	Horizontal Error	Height Error
0	0.37 m	1.09 m
4	0.23 m	0.37 m
18	0.21 m	0.22 m

### 3 DEM AND ORTHOIMAGE GENERATION

#### 3.1 Algorithm

The DEM generation program adopts multi-steps area-based triplet matching with coarse-to-fine strategy (Schenk, 1999). Vertical line locus (Gyer, 1981), which scans along vertical direction, is used to determine matching height of a certain point. The evaluation function is sum of three correlation coefficients: between forward-nadir, nadir-backward and forward-backward pair.

Because orientation parameters are function of time for linear array imaging sensor, a calculation of pixel-line coordinates (pixel number and line number as real value) from ground coordinates needs much more time than for frame image sensor. In order to decrease the calculation of pixel-line coordinates, the coordinates are interpolated, orthoimages are generated, and correlation coefficients are calculated as follows.

- (1) The coarse DEM is shifted, and an upper DEM and a lower DEM are generated.
- (2) Pixel-line coordinates on the grid points of the upper and lower DEM are calculated.
- (3) Pixel-line coordinates for the upper and lower DEM are interpolated in horizontal space.
- (4) Pixel-line coordinates are interpolated in vertical space between upper and lower DEM surface.
- (5) Orthoimages for the certain height are generated using the interpolated pixel-line coordinates.
- (6) Correlation coefficients for the height at all the grid point of the fine DEM are calculated.

Improved median filter is applied for each step to avoid large error.

#### 3.2 Data and Method

**Data:** ADS40 data used in the orientation were used for the DEM and orthoimage generation, but the images were reduced into 1/8, where pixel size was about 1.6 m.

**Evaluation at Know Points:** DEM and orthoimages were generated around the marked know points used for the orientation. Vertical error of the DEM and horizontal error of the orthoimages were evaluated at the points. The generation and error evaluation were executed in course by course, 29 evaluations were obtained from 19 know points.

**Comparison with LIDAR DSM:** DEM over 400 m by 400 m was generated in order to compare with DSM obtained by LIDAR (Light Detection and Ranging, or ALSS: Airborne Laser Scanning System). The test area was mixture of high buildings, low housing, woods, and crop fields.

### 3.3 Result

Table 2 shows errors at the known points and errors comparison with LIDAR DSM. Figure 1 shows error vector at the known points. Figure 2 shows error distribution of DEM compare with LIDAR DSM.

Large error comparison with LIDAR DSM appeared at the following place, where (2) is not true error.

- (1) High buildings and around them
- (2) Reconstructed buildings
- (3) Boundary between woods and crop fields.
- (4) Trees lining street, independent trees
- (5) Boundary of DEM generation area

Figure 3 shows mosaic orthoimage of the whole block.

## 4. DISCUSSION

### 4.1 Interpolation Error

**Reduction of Calculation:** The interpolation of pixel-line coordinates in horizontal space reduced calculation of the coordinates 1/100, and the interpolation in vertical space reduced 1/50 - 1/100 in this case; total 1/5,000 - 1/10,000 times reduction.

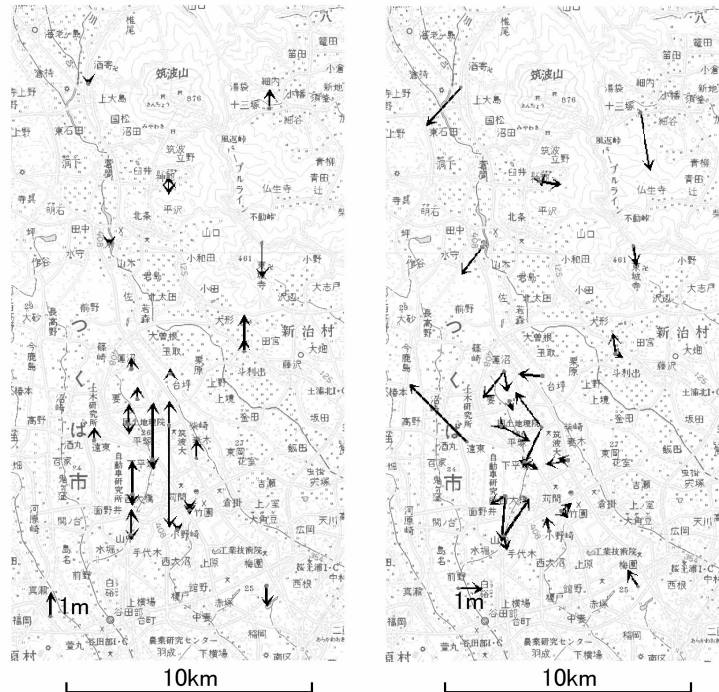


Figure 1. Error Vector at the Known points

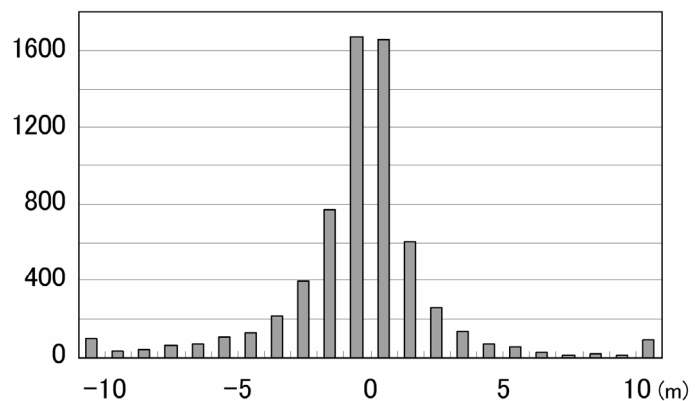


Figure 2. Error distribution of DEM comparison with LIDAR DSM

Table 2 Errors of the DEM and orthoimages

	RMSE	Minimum	Maxium
Horizontal error of orthoimages at known points	1.30 m		3.36 m
Vertical error of DEM at known points	1.13 m	-4.19 m	2.36 m
Vertical error of DEM compare with LIDAR DSM	3.59 m	-27.51 m	27.19 m

**Error Evaluation:** The interpolation may cause error with non-linear part of various factors such as variation of position and attitude, lens distortion, position error of CCD cells, atmospheric correction. Except variation of position and attitude, because effects of the factors are small and change smoothly with pixel-line coordinate, non-linear part is much small, therefore interpolation error can be neglected. Because the PRISM is boarded on the satellite, non-linear variation of position and attitude is much smaller than the simulation data obtained by airplane, interpolation error excepted to be neglected.

#### 4.2 Error of DEM and Orthoimage

**Evaluation at Know Points:** Because orientation error was 0.21 m in horizontal and 0.22 m in vertical, errors of the DEM and the orthoimages at the known points, shown in table 2, represent errors of the DEM and orthoimage production procedure, and pointing error on the orthoimages.

**Comparison with LIDAR DSM:** RSME of the DEM from 1.6 m resolution image was 3.59 m compare with LIDAR DSM. It corresponds 5.6 m for 2.5 m resolution PRISM image. However the used orientation data include too small error. Because planning attitude accuracy is  $2 \times 10^{-4}$  degree (3-sigma), and planning position accuracy is 1 m (3-sigma), orientation accuracy of PRISM image is estimated to 0.87 m (1-sigma). Combining the RMSE of the DEM from simulation data and the estimation of orientation accuracy, the RMSE is evaluated to correspond to 5.7 m for PRISM.

There are many DEM source data other than the PRISM in urban area. DEM production from the PRISM is expected to be used in more rural area than the test site. More precise DEM may be obtained by the PRISM in this situation, if we ignore height of forest.

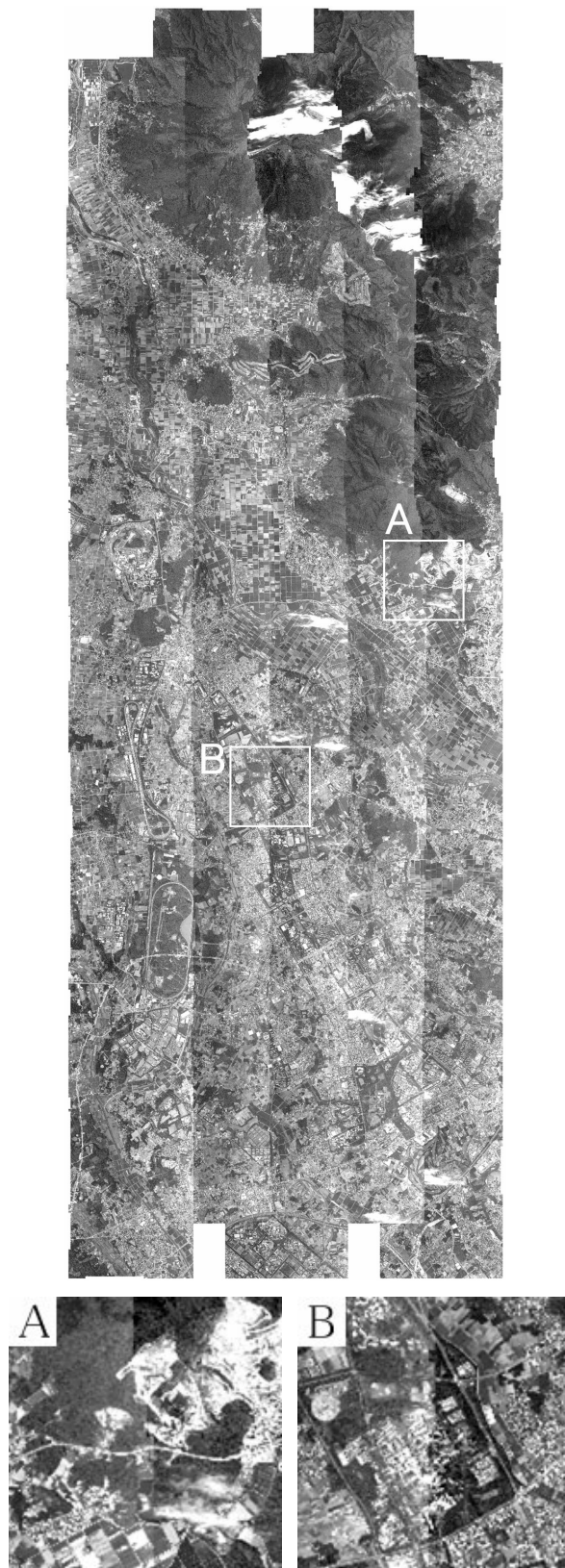


Figure 3. Mosaic Orthoimage of the whole Block

**Mosaic Orthoimage:** Linear objects such as roads are smoothly joined between courses on figure 3. It supports the DEM and the orthoimages were generated appropriately.

## 5 CONCLUSIONS

Orientation and DEM/orthoimage generation programs for the ALOS PRISM with open algorithms were developed. The program worked appropriately using simulation data. Maps can be drawn using these programs without digital stereo plotter.

Numerical differentiation and fixing parameters by extraordinary large weight are worked well for solving least square method.

Error factors of the simulation data are clarified. Error factors of the PRISM are expected to be clarified in same way.

Observing clear target, RMSE of DEM was 1.13 m and RMSE of orthoimages was 1.30 m from 1.6 m resolution image. Comparing the DEM with DSM by LIDAR measurement, RMSE of the DEM was 3.59 m. The error corresponds to 5.7 m for the PRISM.

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Algorithms and source files are open at <http://gisstar.gsi.go.jp/ALOS/>