

Reduction of Ground Control Requirements by Pass Processing

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Abstract

Pass processing is a technique for determining geometric correction models that requires an order of magnitude fewer control points than conventional methods for correcting satellite imagery. We present a description of the technique and results for a pass of Landsat Thematic Mapper imagery that contains 15 scenes. We show that with good ground truth only 1/2 GCP per scene on average is required. Good accuracy is still possible with only 4 GCPs to correct the entire 15 scenes. Results for interpolation, extrapolation and correcting areas with no ground truth are discussed.

1 Introduction

One of the advantages that mapping from satellite imagery offers over conventional techniques is that the number of ground control points (GCPs) required is substantially smaller. This is true even if the imagery is processed one scene at a time [2]. In this paper we describe a multiscene technique, *pass processing*, for reducing ground control requirements by another order of magnitude.

Pass processing is a method for determining geometric correction models by using GCPs from a large part of the pass (orbit) containing the desired output scene. Currently, most systems use ground truth which is located in a region the size of one scene.

The goal of pass processing is to achieve accuracy comparable to single scene processing, using the same number of GCPs. The number of GCPs required per scene is then the single-scene requirement divided by the number of scenes in the pass. There are typically tens of scenes available in a single pass.

A related advantage is that the location of GCPs is less critical than for single scene processing. In fact, it becomes possible with pass processing to correct imagery over large areas where no GCPs are available at all.

In this paper, we shall present results of a study to evaluate pass processing techniques when implemented as an extension of MacDonald Dettwiler's standard Geocoded Image Correction System (GICS). Pass processing has been implemented in a GICS for the Australian Centre for Remote Sensing. Measurements were made to determine what

accuracy can be achieved for several different distributions of GCPs: uniform, at both ends of the pass and at one end only. The accuracy when only a minimum of ground control was used was also determined.

In Section 2 we give an overview of the pass processing technique. This is followed in Section 3 by a description of our methodology for measuring accuracy. The results of our measurements are presented in Section 4.

Pass processing for the early Landsat satellites was described in [1]. The work presented here extends these results to the Landsat Thematic Mapper (TM).

2 Techniques of Pass Processing

In order to correct satellite imagery, it is necessary to determine the correspondence between pixels in the input imagery and points on the earth's surface. In GICS, this correspondence is embodied in models of the sensor, the earth and the satellite orbit and attitude.

The parameters of the models are determined from manufacturers' data, prelaunch measurements, satellite telemetry, an understanding of the physical processes involved and other *a priori* knowledge. Ground truth is used to provide corrections to the models. Corrections are made in the form of time series polynomials whose coefficients are estimated using a Kalman filter. The measurements which are input to the Kalman filter are the errors in GCP location which are determined by marking GCPs in the imagery.

The approach taken to pass processing was to extend this modelling process from a time scale of one scene to several scenes.

3 Methodology of Measurements

The methodology of accuracy measurement is the same as that described in [2]. We give a brief summary here.

Well-defined features (GCPs) are marked in the imagery to determine their input coordinates, that is, their line and pixel position in the input image. The input coordinates are then transformed to ground location using the models. The ground locations thus determined are compared with ground truth, that is, the locations as determined independently, for example, from existing maps or from field surveys.

Some of the marked points are used to determine the model (model points), while the remainder (check points) are used as independent points at which to measure accuracy.

In all our measurements, the height of the check point is used to compensate terrain effects when calculating the accuracy at that point. Also, the measurements were made using the models directly rather than measuring output products.

Our measurements are reported as two-dimensional RMS absolute accuracies, or mean square error (MSE). Thus if X_i and Y_i represent the errors at check point i in the x and y directions respectively, the total absolute accuracy (AA) is

$$AA = \sqrt{\frac{1}{N} \sum_{i=1}^N (X_i^2 + Y_i^2)}$$

4 Measurements: TM

4.1 Test Data

Our test data set consisted of Landsat-5 imagery of Path 28, acquired on April 16, 1984. It contained about 15 scenes (6 minutes 12 seconds of imagery) and covered a region from near Hudson Bay in the north to the Oklahoma-Texas border in the south.

GCPs in the Canadian part of the pass were digitized from 1:50 000 scale maps prepared by Department of Energy, Mines and Resources. In the U.S. part of the pass, US Geological Survey (USGS) 1:24 000 scale maps were used. After outliers were eliminated, 290 GCPs remained. The GCPs in Canada were generally less distinct and more difficult to mark than those in the U.S. Some regions in the U.S. (southern Minnesota and Iowa) were blessed with an abundant supply of county road intersections which served as excellent GCPs.

The region covered by the scene which is the second down from the north has not been mapped yet, so it was not possible to correct or measure the imagery there.

4.2 Reference Accuracies

To obtain a basis of comparison with the accuracy of single scene processing, we divided our pass into 15 scenes of equal length and designated one half of the GCPs in each scene as model points and the other half as check points. There were about 10 of each. The model points were then used to correct each of the scenes, using standard single-scene processing, and the accuracy was measured at the check points. The resulting reference accuracies are shown in column 1 of Table 1. This table shows the results of several tests for each scene and gives summary statistics. The summary statistics are given for the whole pass and for the U.S. scenes only, because the latter had better ground truth and so allowed a better determination of accuracy.

4.3 Uniform Distribution

The first test of accuracy using pass processing was that for the case where the GCPs are uniformly distributed over the pass. One model GCP from each scene, for a total of 14, was selected and used to build a correction model which covered the entire pass.

Scene #	1. Reference Accuracy (m)	2. Uniform Accuracy (m)	3. Interpolation Accuracy (m)	4. U.S. Interp'n Accuracy (m)	5. Extrap'n Accuracy (m)
1	31.7	35.3	21.6		
2					
3	16.0	25.9	28.0		
4	18.5	31.1	24.9		
5	37.5	32.9	34.1		
6	23.3	26.3	29.2		
7	18.4	20.9	20.5		
8	16.5	15.5	17.2		
9	8.1	11.2	12.4	10.1	
10	11.7	11.3	15.1	10.7	9.8
11	12.6	13.3	18.6	14.2	13.0
12	13.1	13.3	17.5	16.6	19.5
13	19.9	14.2	13.4	12.8	22.8
14	13.1	13.0	14.9	13.3	22.4
15	13.8	17.3	1.3	16.1	35.4
All	19.7	21.7	21.0		
USA	14.5	14.7	15.9	13.6	22.0

Table 1: Accuracy of pass processing for various configurations of GCPs.

The accuracy at each of the scenes was then measured at the same check points as were used for the references. The results are given in column 2 of Table 1.

Not surprisingly, pass processing had a levelling effect on the scenes' accuracies. For example, scene 5 caused a degradation of the accuracy of the surrounding scenes. On the other hand, scene 13 benefited from the more accurate surrounding scenes.

The accuracy over the whole pass was worse by about 2 m out of 20 m, while the accuracy in the U.S. scenes only remained the same.

4.4 Interpolation

For this test, we selected the model GCPs from those in the scenes at the ends of the pass. Seven GCPs were chosen from scenes 1 and 3, and seven from scene 15. The resulting model was used to correct all scenes in the pass. The accuracy of each scene as measured at the reserved check points are shown in column 3 Table 1.

The accuracy was generally slightly degraded which is probably due to the influence of the poor quality GCPs from scenes 1 and 3. Nevertheless, the overall and U.S. accuracies only increased by 1 m or so.

To test the accuracy obtainable when better quality ground truth is available, we repeated the interpolation test using only the U.S. scenes. Seven GCPs from each of scenes 9 and 15 were used to build the model with the accuracies shown in column 4

of Table 1. The differences are slight and there is an overall improvement from the reference accuracy of 14.5 m to 13.6 m.

4.5 Extrapolation

We had a choice for this test in that we could have used model GCPs from the poor ground truth and check GCPs from the good ground truth or vice versa. We decided on the former, because the errors in the model GCPs would tend to be reduced by the Kalman filter, whereas it would be hard to get a good estimate of the accuracy if we had to use check points with large errors. Thus for this test, we built the model with 14 GCPs from the first 9 scenes. The accuracy is shown in column 5 of Table 1.

As expected, the accuracy degrades as the scenes get further from the control points. Nevertheless, the accuracy remains at a subpixel level for five scenes beyond the GCPs.

4.6 Accuracy Using a Minimal Number of GCPs

The tests up to this point used 14 GCPs in the model. Since 14 scenes were being corrected, the average GCP requirement is thus 1 GCP per scene. Since one of the main goals of pass processing is to reduce the number of GCPs required, we tested the accuracy obtainable with a minimal number of GCPs. One would expect the accuracy to be worse with a small number of GCPs, but this might be an acceptable tradeoff in situations where GCPs are scarce.

Figure 1 shows the accuracy attainable with a given number and distribution of GCPs. Since good quality ground truth is of prime importance when only a few GCPs are to be used, for most of the tests the GCPs were taken from the U.S. scenes only and the accuracy was measured only there.

The largest errors in a systematic model are due to biases in the orbit, along and across track. As in our other tests, we modelled these errors as attitude bias errors. They can be corrected with a single GCP, preferably situated near the middle of the pass. The accuracy obtained in doing this was 52 m.

Once the orbit biases have been corrected, the linear pitch and yaw bias errors become significant. Either of these errors (but not both) can be corrected with two GCPs. The best accuracy obtained when correcting only the pitch was 51 m. By correcting for yaw instead, we obtained 33 m which demonstrates that the yaw error is the larger of the two. The optimal placement for the two GCPs is at opposite sides of the pass and near the middle of its length.

With three GCPs, it is possible to correct for the orbit biases, the yaw bias and linear pitch. With a good placement of the GCPs, an error of 22 m was obtained.

The next largest error is due to the linear variation in roll. Four GCPs are required to correct all these effects. With good placement of the GCPs, an accuracy of 16 m was obtained.

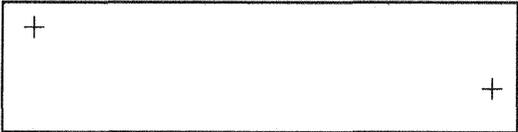
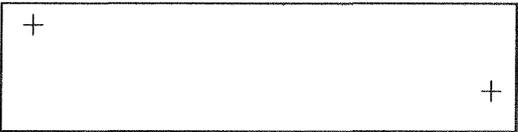
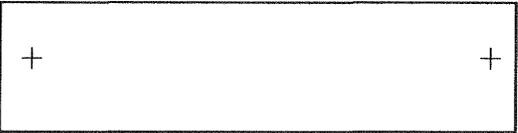
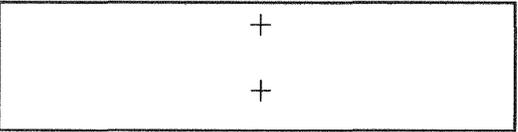
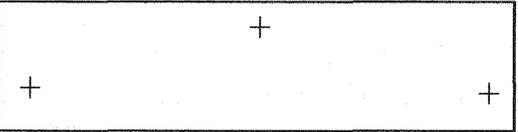
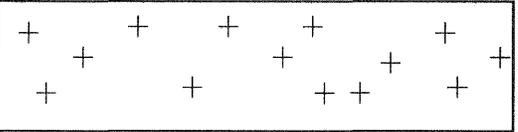
#GCPs	AA (m)	Distribution of GCPs
1	52.1	
2	64.7	
2	61.0	
2	50.5	
2	32.5	
3	22.0	
4	15.8	
14	15.2	

Figure 1: Accuracy using a minimal number of GCPs to correct 7 consecutive scenes.

For reference, we used 14 GCPs uniformly distributed over the U.S. scenes. The accuracy obtained, 15 m, is hardly better than with four GCPs.

Note that since eight scenes were corrected, a model with four GCPs represents a requirement of only 1/2 GCP per scene.

We tested these ideas, although less extensively, for the whole pass. We created models using four GCPs distributed over the whole pass instead of just the U.S. scenes. One of the GCPs came from scene 1 in Canada, and the remainder were from U.S. scenes. The accuracy was measured both in Canada and the U.S. This was repeated five times and the RMS errors were averaged. The results were:

RMS error over whole pass 25.4 m
RMS error over U.S. scenes 16.7 m.

Thus for a slight increase in error (2.2 m over the reference accuracies in the U.S.) we were able to correct 15 scenes of data with only four GCPs, a little over 1/4 GCP per scene.

5 Conclusions

The results of Section Three have shown that pass processing techniques yield accuracy comparable to single-scene processing using the same number of control points.

Single scene processing requires about 6–10 GCPs per scene. With mediocre ground truth, we only needed 1 GCP per scene. With better quality ground truth (the U.S. scenes), only 1/2 GCP per scene was required to achieve an accuracy comparable to that of single scene processing. The most dramatic reduction in GCPs was obtained by using four of them to correct a pass 15 scenes long. The accuracy was degraded somewhat but was still as good as 17 m in the U.S. scenes. No doubt better accuracy could have been obtained if the quality of the ground truth in Canada (which contributed one of the four GCPs) had been better.

Aside from the reduction in the number of GCPs required, we have demonstrated that pass processing increases the flexibility in the placement of the GCPs. By interpolating the model from GCPs at the ends of a pass, we corrected 11 scenes at once with good accuracy (16–21 m) and without using any GCPs from them. Extrapolation was also successful, with five scenes containing no GCPs being corrected to moderately good accuracy (23 m or better) by that technique.

References

- [1] Daniel E. Friedmann, James P. Friedel, Kjell L. Magnussen, Ron Kwok, and Stephen Richardson. Multiple scene precision rectification of spaceborne imagery with very

few ground control points. *Photogrammetric Engineering and Remote Sensing*, 49(12):1657-1667, December 1983.

- [2] Bruce Sharpe and Kelly Wiebe. Planimetric accuracy in satellite mapping. In *these proceedings*.