SPOT 5 HRS STUDY - AUTOMATIC DTM EXTRACTION REGIONS 1 (MONTMIRAIL - FRANCE) AND 7 (RASHT - IRAN)

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ABSTRACT:

With improved spatial resolution of available satellite images and the ability to collect the stereo images within a short time period, the importance of satellite images for generating elevation information has grown. Most of the users try to use satellite images because of the reasonable time and cost for ordering. The speed of information generation by satellite sensors from planning to execution is much higher than the conventional ways such as aerial photography process. Therefore, high-speed and high-accuracy software tools are required for information extraction from satellite images. Automatic DTM extraction from the satellite images is yet the challenging task. Different algorithms and software tools have been developed. In this study, the performance of two commercial remote sensing software tools, OrthoEngine of PCI Geomatica V8.2.3 and the OrthobasePro of ERDAS Imagine V8.6 and V8.7, have been evaluated for automatic DTM extraction from the SPOT 5 stereo pan imagery. The capability of SPOT 5 stereo pan images for DTM generation is analyzed, and the performances of the software tools for the orbit modelling and automatic image matching are discussed.

1. INTRODUCTION

Automatic DTM extraction process from satellite images can be generally divided into two components:
1- Orbit modeling
2- Automatic image matching
These two components are important in the success of automatic DTM extraction process. The first one is correct orbit modeling. The second one is the successful image matching process. In the high resolution images, the orbit modeling of the sensor is one of the most important parts because all equations for orthorectification and DTM extraction are based on that, but the problem in the orbit modeling is the lack of knowledge of the sensor attitude in the time t. Any error in the orbit modeling causes error in the other parts of DTM generation process and the accuracy of the generated DTM. For example, image matching process usually is done on epipolar images. Therefore, any error in epipolar resampling process, which uses orbit modeling, causes difficulties and errors in the matching process. Also, for two matched points, the accuracy of the ground coordinate is directly dependent on the accuracy of the orbit modeling.

In this report, two commercial softwares, PCI Geomatica v8.2.3 and ERDAS Imagine v8.6 and v8.7, are used to evaluate the automatic DTM extraction for SPOT 5 imagery. The goal is to find the accuracy of the DTM which is derived automatically by them. This accuracy shows two things:
1- The usefulness of the SPOT 5 stereo images for DTM generation
2- The art of the software in orbit modeling and automatic image matching.
The data used in this research are:
1- Two stereo HRS SPOT 5 along track (Rasht, IRAN), DTM of that region, the digital maps used for generating the DTM.
2- Two stereo HRS SPOT 5 along track (Montmirail, FRANCE), DTM of that region.
Because of some problems in the second data, just the first one is used in this report.

In section 2, the results of PCI Geomatica v8.2.3 will be shown and then, in section 3, the results of ERDAS Imagine v8.6 and v8.7 will be shown.

2. PCI GEOMATICA

The PCI Geomatica is commercial software which enables user to process images for mapping purposes. This software consists of different modules. The module which handles the orthorectification and DTM extraction is OrthoEngine. It is capable for different kinds of sensors like aerial imagery, optical satellite imagery and radar imagery. This research is for evaluating the capability of the software in handling SPOT 5 stereo imagery for automatic DTM generation.

In use of the OrthoEngine, there are some stages that should be followed. In the following, the steps will be described.

2.1 Project definition

The first step is to define the kind of project for OrthoEngine. The Toutin’s model for SPOT 5 in Satellite Orbit Modeling has been selected, which is shown in Figure 1.

About this model, in the PCI website has been written: “The model, a cooperative development between PCI Geomatics and the Canada Centre for Remote Sensing (CCRS, Natural Resources Canada), was developed by Dr. Thierry Toutin at CCRS and is a rigorous 3D parametric model based on principles related to orbitography, photogrammetry, geodesy and cartography. It further reflects the physical reality of the complete viewing geometry and corrects all geometric distortions due to the platform, sensor, Earth, and cartographic projection that occur during the imaging process.”

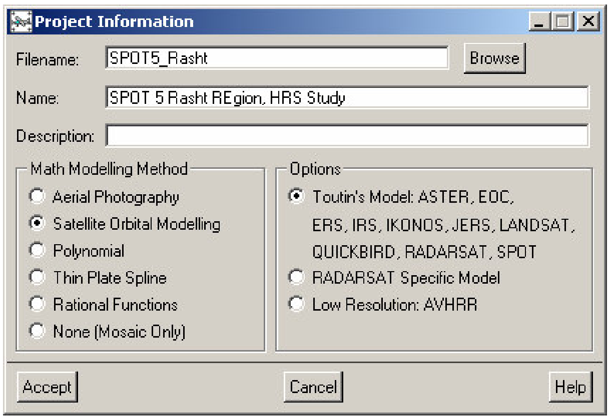

Figure 1. Modeling selection in OrthoEngine v8.2.3

One of the problems about this model is that the user has no idea about the model and one doesn't know how the model handles the satellite orbit metadata. Thus, the user has no idea what will happen if the accuracy of one parameter increases or decreases. Also, the other problem is that the user just can decide based on the error analysis over check points and he has no ability to adjust the model.

The rigorous model for SPOT 5 in PCI software can handle SPOT 5 Level 1A.

2.2 Data Input

The PCI software has the capability to read *the DIMAP (tiff) format*, which SPOT IMAGE distributes the data in that format.

2.3 Ground Control Point, Check Point, and Tie Point Collection

In this stage the Ground Control Points (GCPs), Check Points (CPs) and Tie Points (TPs) will be selected. For Rasht region, with using the provided digital maps, the 17 GCPs and CPs (all of them are full control point) have been selected. These points are in accuracy of 1:25000 maps. Figure 2, Figure 3, and Figure 4 show the distribution of the GCPs and CPs.

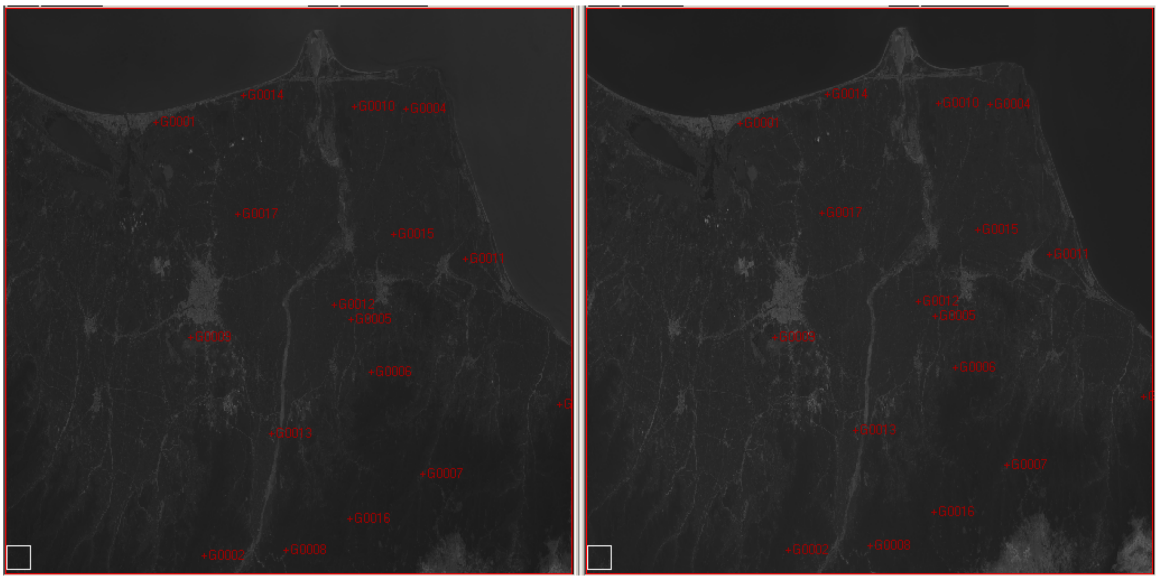

Figure 2. the distribution of GCPs/CPs in the raw images

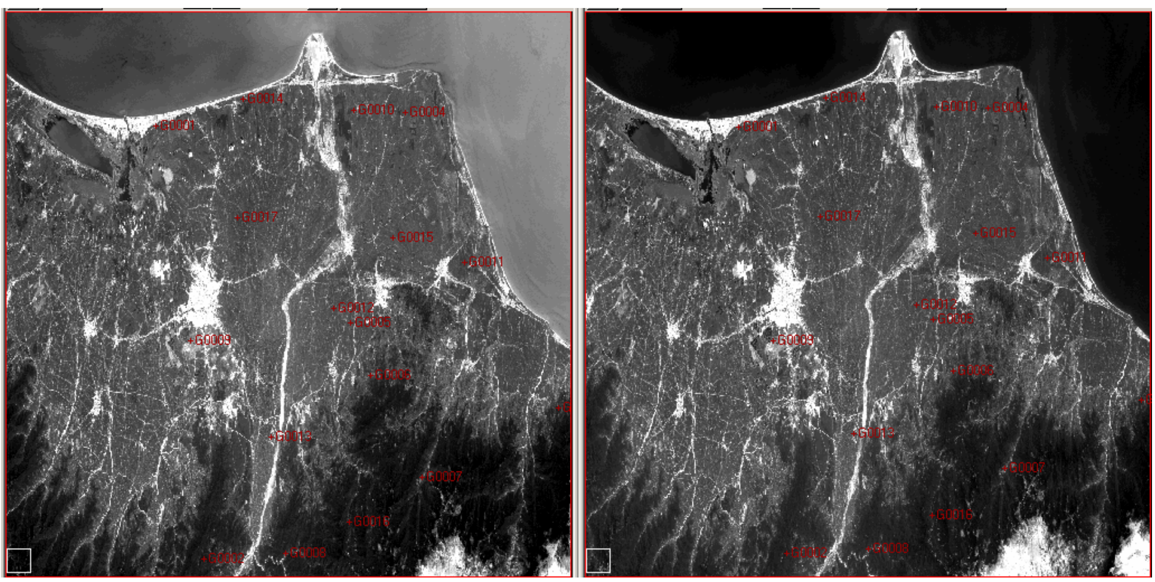

Figure 3. the distribution of GCPs/CPs in the enhanced images

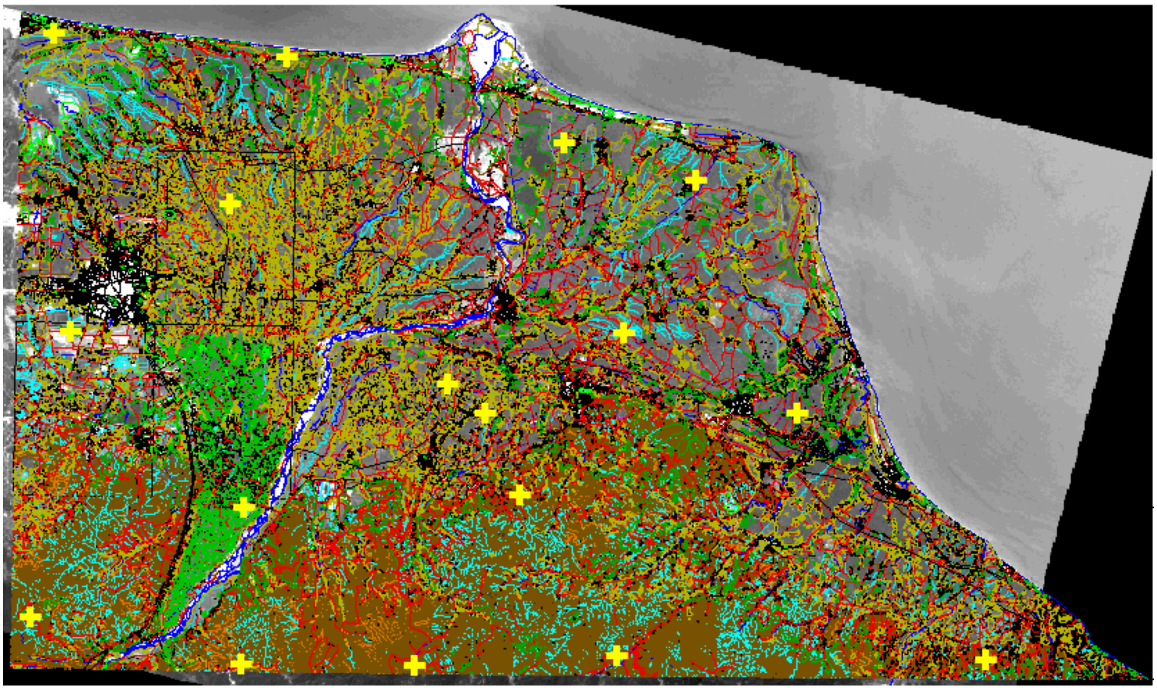

Figure 4. the GCPs distribution in the digital maps

As it is shown in figures 2 to 4, the digital maps do not cover the whole imagery area and they cover about 60%-75% of the whole images. In GCP and TP selection, two factors were considered:

1- In GCPs selection, it was tried to distribute them in the entire image. As a result, this kind of coverage makes the error to be distributed in the entire image homogenously and doesn't let extrapolation happen in the image.

2- In TPs selection, the software has the ability to extract them automatically with image matching techniques. Thirteen tie points automatically were extracted. In Figure 5 and Figure 6, the distribution of tie points is shown.

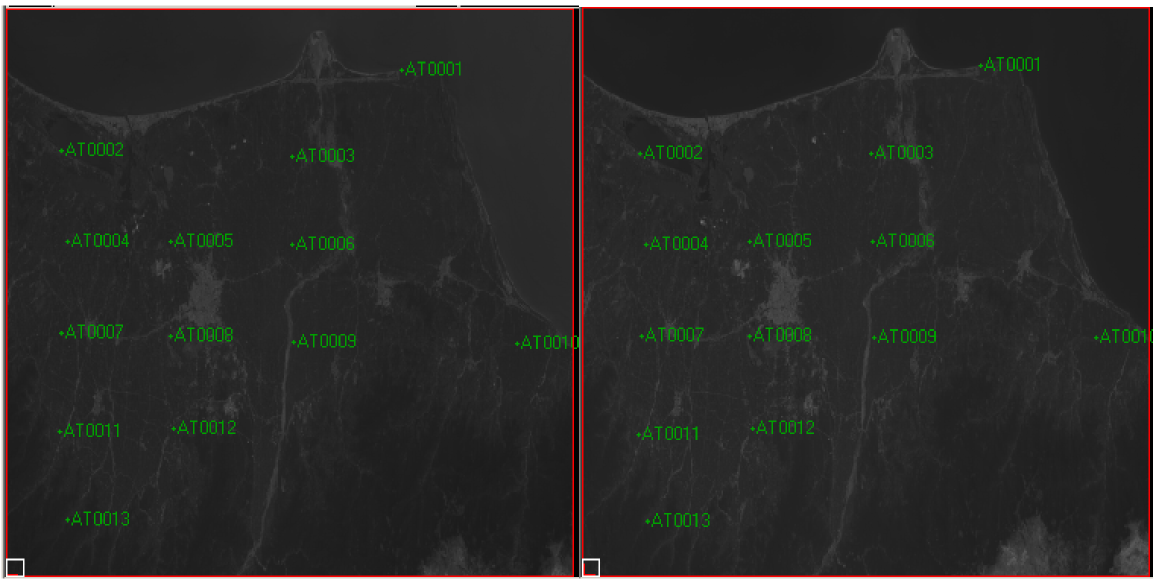

Figure 5. Automatic extracted tie points

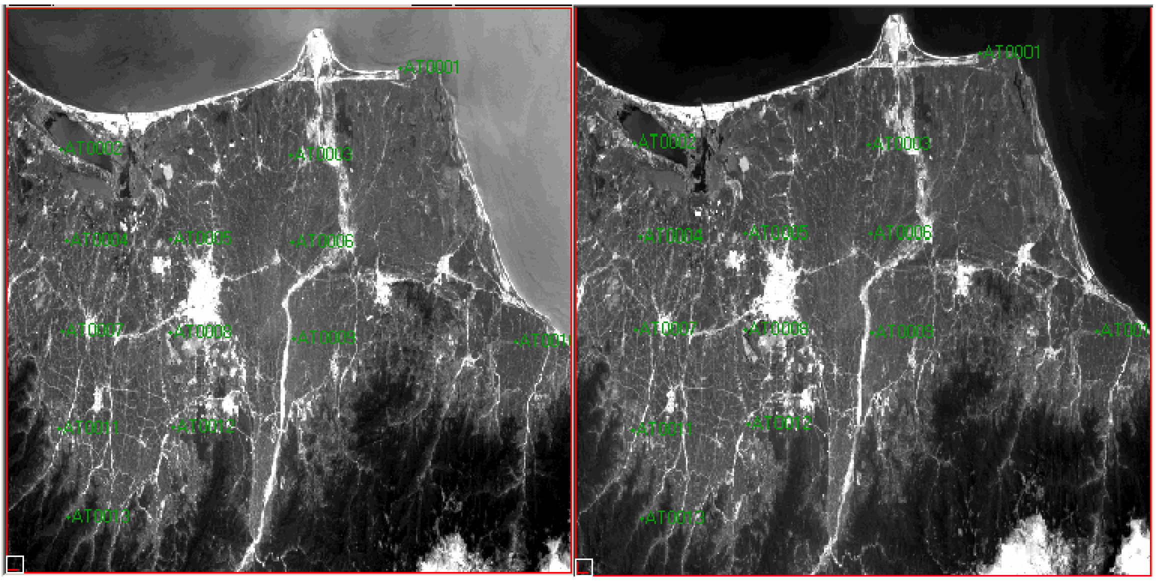

Figure 6. Automatic extracted tie points

2.4 Model calculation

In this stage, the adjustment calculations will be done on the rigorous model to solve the parameters. Some tests have been done to find out how many GCPs are needed and are logical for solving model to achieve a reasonable accuracy.

The test has been done with changing the GCPs to CPs and vice versa. Also, removing and contributing tie points in the calculations have been tested. The criterion for the test is based on the RMSE of the GCPs and CPs. The results of the test for PCI OrthoEngine using the Toutin's model for SPOT 5 data are:

1- When the number of GCPs goes up and becomes more than 7 points, the role of tie points in the calculations will be small.
2- The minimum number of GCPs for solving the model with logical error in each image is six. Also, it is logical to have six GCPs in each image in practical projects. Thus, six GCPs per each image are used in this study.
3- When the user uses minimum number of GCPs, 6 points, the tie points makes a normal error distribution in the entire image.

The result for 6 GCPs for each image and 13 tie points is:

Residual Info for 2 Images (Residual Units: Image Pixels)
No. of GCPs: 12 , X RMS = 0.49, Y RMS = 0.43
No. of CPs: 22 , X RMS = 0.67, Y RMS = 3.04
No. of Tie Points: 13 , X RMS = 0.15, Y RMS = 0.04

Residual Info for 2 Images (Residual Units: Metres)
GCPs: X RMS = 4.85, Y RMS = 2.21
CPs: X RMS = 8.90, Y RMS = 13.99
Tie Points: X RMS = 1.40, Y RMS = 0.37

Please see the Appendix I for more information about the used points.

2.5 Creating Epipolar Images

After solving the orbit modelling parameters, the images will be resampled in epipolar lines. In the epipolar images, Y parallaxes are minimized and X parallaxes are remained. This makes the search area for matching process to be narrow and it makes the matching computation to be simpler and faster.

2.6 Automatic DEM Extraction

The next step is to extract DTM automatically from epipolar images. This software uses correlation function for image matching. The algorithm of DTM extraction asks from the user to give the minimum and maximum height in the region. Also, the correlation coefficient for each DTM cell could be saved in another image.

2.7 Geocoding Extracted DEM

This process projects the generated DTM from epipolar images to the ground coordinate system.

In the whole process, no edit has been done on the extracted DTM because the goal is to find the accuracy of the automatic extracted DTM.

2.8 The DTM result

Table 1 and Table 2 show the error analysis on GCPs and CPs in the generated DTM.

ID	GCP Elevation (m)	GCP calculated Elevation (m)	Difference (m)
G0001	-25.8	-34.9	9.1
G0002	566.9	583.1	-16.2
G0005	5.4	8.1	-2.7
G0007	499.7	459.6	40.1
G0010	-22.5	-34.3	11.7
G0011	-22.3	-24.9	2.7

Table 1. Error analysis on GCPs in generated DTM by PCI

ID	CP Elevation	CP calculated Elevation	Difference
G0003	258.6	213.1	45.5
G0004	-22.2	-29.2	7
G0006	157.2	141.2	15.9
G0008	219	233.1	-14.2
G0009	11.9	30	-18.1
G0012	1.6	1.5	0.1
G0013	49.4	67.5	-18.1
G0014	-22.1	-36.9	14.9
G0015	-21.5	-21.3	-0.2
G0016	474.2	453.2	21
G0017	-11	-8.5	-2.5

Table 2. Error analysis on CPs in generated DTM by PCI

The result of Table 1 could be summarized as:
No. of GCPs : 6
RMS Error : 18.7
Average Error : 7.4
Maximum Error : 40.1
(Unit: Metres.)

The result of Table 2 could be summarized as:
No. of CPs : 11
RMS Error : 18.8
Average Error : 4.7
Maximum Error : 45.5
(Units: Metres)

Figure 7 shows the general view of the generated DTM. The black areas inside the image are the place that matching was unsuccessful.

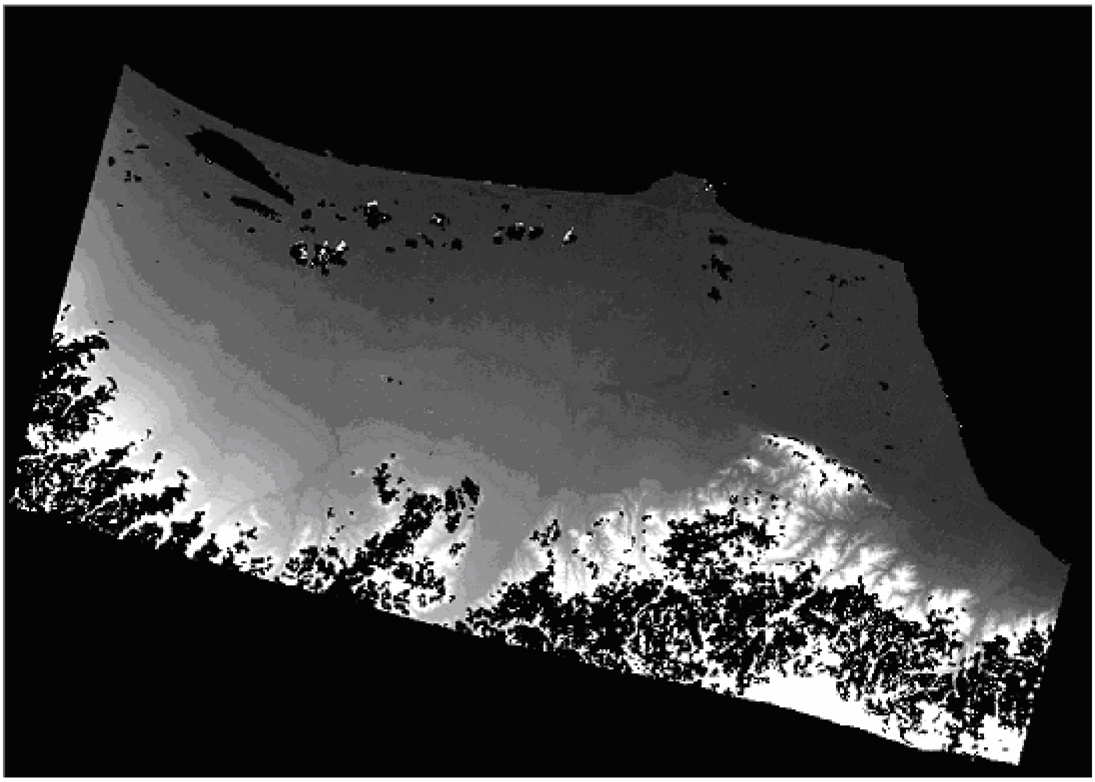

Figure 7. The automatic DTM generated by OrthoEngine

For evaluating the DTM, the generated DTM subtracted from the provided DTM of the Area. The provided DTM as it was mentioned previously doesn't cover the entire images and the coverage is about 60-75%. Therefore, the evaluation has been done on the common area. Because of the non stability in the coastal line, the area for the comparison is selected as Figure 8.

The difference image is shown in Figure 9. In some areas, there are some gross errors to the mismatching. It means that the software has accepted two points as a pair but in the reality they are not. It is different form the regions that the software declares them as not matched place. In Figure 9, some of them are indicated by the red color.

The result of the difference, which is shown in Figure 9, is:

- Median = -8.4 m
- Mean = -28.1 m
- Standard Deviation = 66.9 m

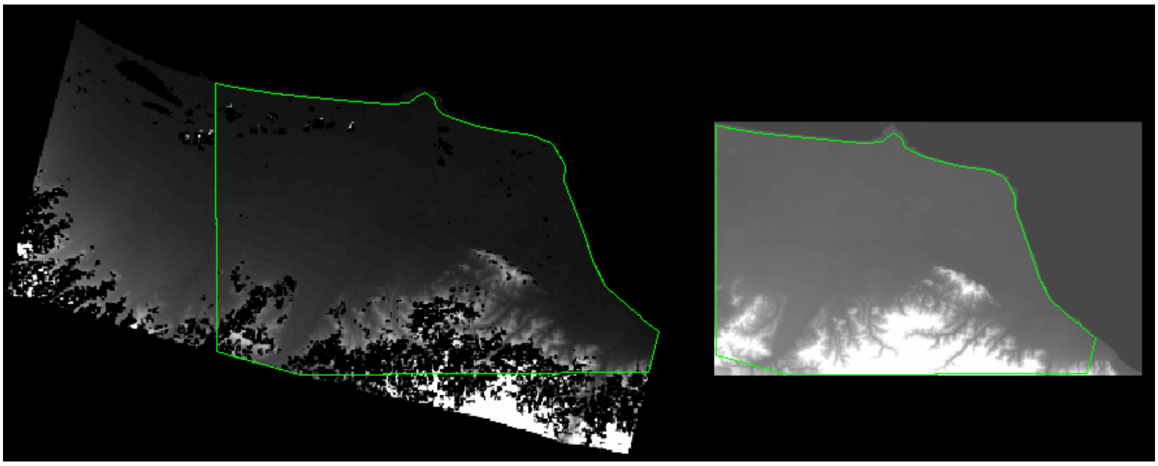

Figure 8. The left image is the DTM from automatic process and the right one is from digital maps.
The green line shows the region for accuracy evaluation

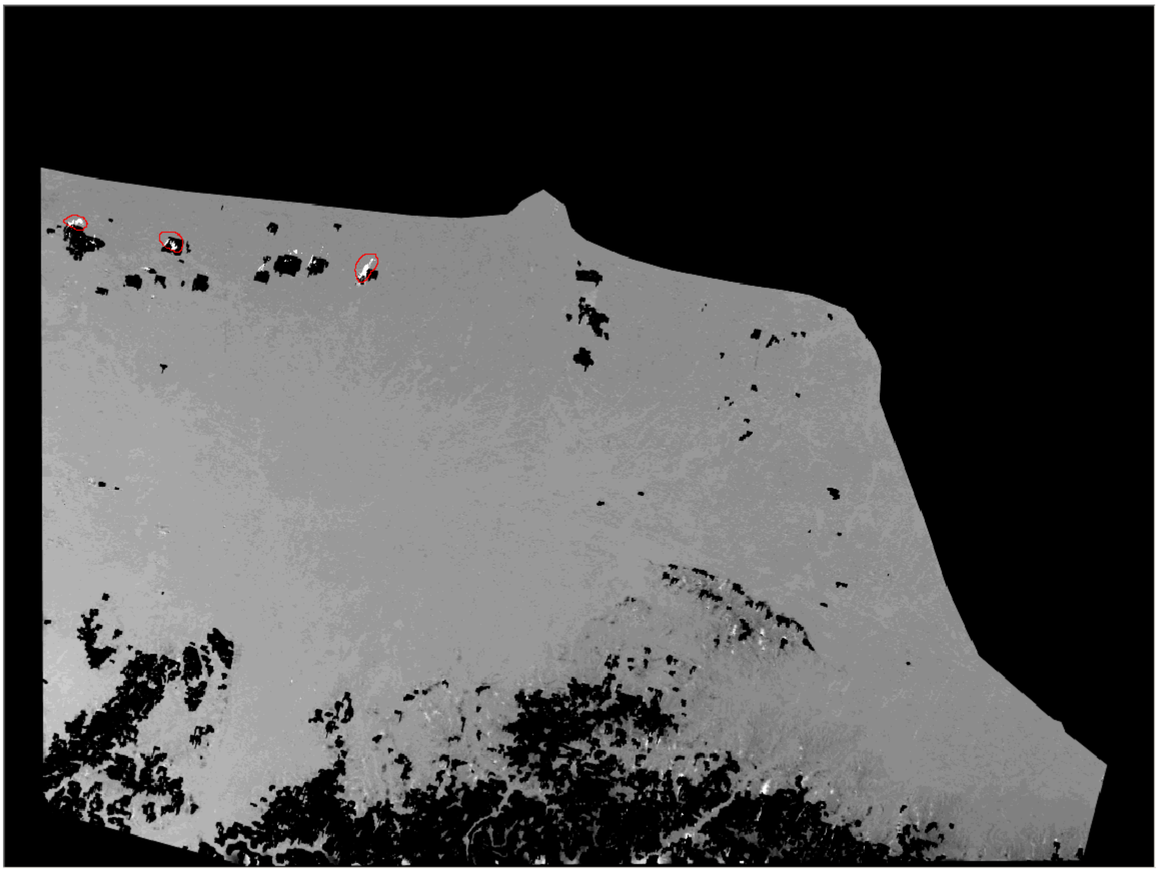

Figure 9. The difference image between automatic DTM and original DTM.
The red lines show some of the gross error regions.

3. ERDAS IMAGINE

The ERDAS IMAGINE is an image processing package for processing spatial data. It has many different kinds of tools which enable the user to process, manipulate and analyze the data in both raster and vector formats. This software consists of different modules. The module which handles the orthorectification and automatic DTM extraction is OrthobasePro. It is capable for different kinds of sensors like Aerial imagery, close range imagery and optical satellite imagery (IRS, SPOT, IKONOS and QuickBird). This research is for evaluating the capability of the software in handling SPOT 5 stereo imagery for automatic DTM generation.

In this study both ERDAS IMAGINE v8.6 and v8.7 are evaluated. Section 3.1 describes the process and the result for v8.6 and section 3.2 describes the process and the result for v8.7.

3.1 OrthobasePro v8.6

In use of the OrthobasePro, there are some stages that should be followed. In the following, the steps will be described.

3.1.1 Model definition

The first step is to define the kind of model for OrthobasePro, which is shown in Figure 10.

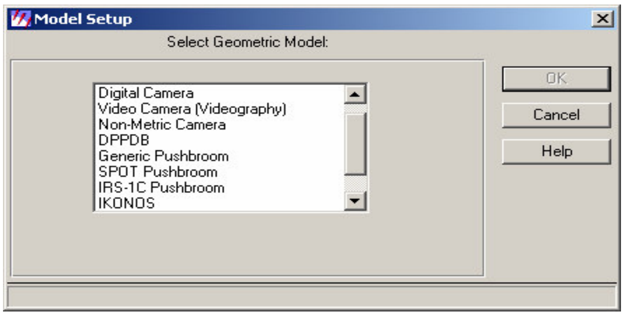

Figure 10. Model definition in Orthobase Pro v8.6

The SPOT Pushbroom model is selected. In OrthobasePro v8.6, this model is designed for SPOT1-4, but it has the capability to be modified for SPOT 5. The SPOT model in ERDAS uses the bundle adjustment and it uses polynomial order for orbit modeling.

3.1.2 Data Input

The images imported into the software with Import/Export module. The user can use TIFF format for import because in ERDAS Imagine v8.6, there is no option to read the data and the header of the data directly as SPOT 5 image. After importing, the images are added to the OrthobasePro.

3.1.3 Interior Orientation (Frame Editor)

In this stage, the interior orientation parameters for SPOT 5 will be modified, e.g. the user will give the focal length, number of pixels in each line and the incidence angle. As the OrthobasePro uses polynomial for orbit modeling, user should specify the polynomial order for the orbital parameters such as X, Y, Z, Omega, Phi, Kappa.

3.1.4 Point Measurement

The next step is to select Ground Control Points, Check Points and Tie Points. For Rasht region, with using the provided digital maps, the 17 GCPs and CPs (Full Control Point) are selected. These points are in accuracy of 1:25000 maps. The selected points are the same as the points selected for PCI software. Figure 2, Figure 3, and Figure 4 show the distribution of the GCPs and CPs. The digital maps do not cover the whole imagery area and they cover about 60%-75% of the whole images. In GCPs selection, it was tried to distribute them in the entire image. As a result, this kind of coverage makes the error to be distributed in the entire image homogenously and doesn't let extrapolation happen in the image.

The ERDAS Imagine also has the ability to extract the tie points automatically. Because it is tried the conditions to be similar for both software, again 13 automatic tie points selected. But the tie points are not the same as they are dependent to the software algorithm to find and extract them.

3.1.5 Triangulation

After doing point measurement process, the bundle adjustment (triangulation calculation) will be done. The test has been done with changing the GCPs to CPs and vice versa and also removing Tie points or contributing them in the calculations. The result of these tests is:

1- The role of tie points in the calculations is important.
2- The minimum number of GCPs for solving model is dependent to the polynomial order selected by the user for the orbit parameters. The polynomial order for each parameter that is selected for this study is: X order 2, Y order 2, Z order 2, Omega order 0, Phi order 0 and Kappa order 2. Based on that, the minimum number of GCPs selected is 6 points for each image (or 6 common GCPs).

The result of the bundle adjustment for 6 GCPs for each image and 13 tie points is shown in Table 3.

	GCP	CP
Ground X (m)	0.001	16.118
Ground Y (m)	0.016	20.219
Ground Z (m)	0.000	38.564
Image x (pixel)	3.246	3.563
Image y (pixel)	1.922	1.764

Table 3. The RMSE of the Orthobase v8.6 bundle adjustment There are 6 GCPs per image, 5 common CPs, and 13 tie points

Please see the Appendix I for more information about the used points.

3.1.6 Automatic DTM Extraction

After solving orbit modeling parameters, the software can start processing for automatic DTM extraction. This software uses Correlation function for image matching.

3.1.7 The DTM result

Table 4 shows the error analysis on GCPs and CPs in the DTM.

ID	Calculated Elevation (m)	GCP/CP Elevation (m)	Difference (m)
1	-28.225	-25.814	-2.411
2	No matching		
3	No matching		
4	No matching		
5	-100.011	5.418	-105.43
6	No matching		
7	418.863	499.656	-80.793
8	203.786	218.974	-15.188
9	115.024	11.932	103.09
10	-31.894	-22.514	-9.38
11	118.47	-22.267	140.74
12	9.925	1.576	8.349
13	111.034	49.411	61.623
14	-69.504	-22.076	-47.428
15	-28.559	-21.47	-7.089
16	231.363	474.2	-242.84
17	29.424	-11.028	40.452

Table 4. The error analysis on GCPs and CPs in the generated DTM by OrthobasePro v8.6

The result of Table 4 could be summarized as:
RMS Error : 94.1256 m
Average Error: -12.02 m

Figure 11 shows the general view of the generated DTM. The black areas inside the image are the places that matching process was unsuccessful.

For evaluating the DTM, the generated DTM subtracted from the provided DTM of the Area. The provided DTM as it was mentioned previously doesn't cover the entire images and the coverage is about 60-75%. Therefore, the evaluation has been done on the common area. Because of the non stability in the coastal line, the area for the comparison is selected as Figure 8. The difference image is shown in Figure 12.

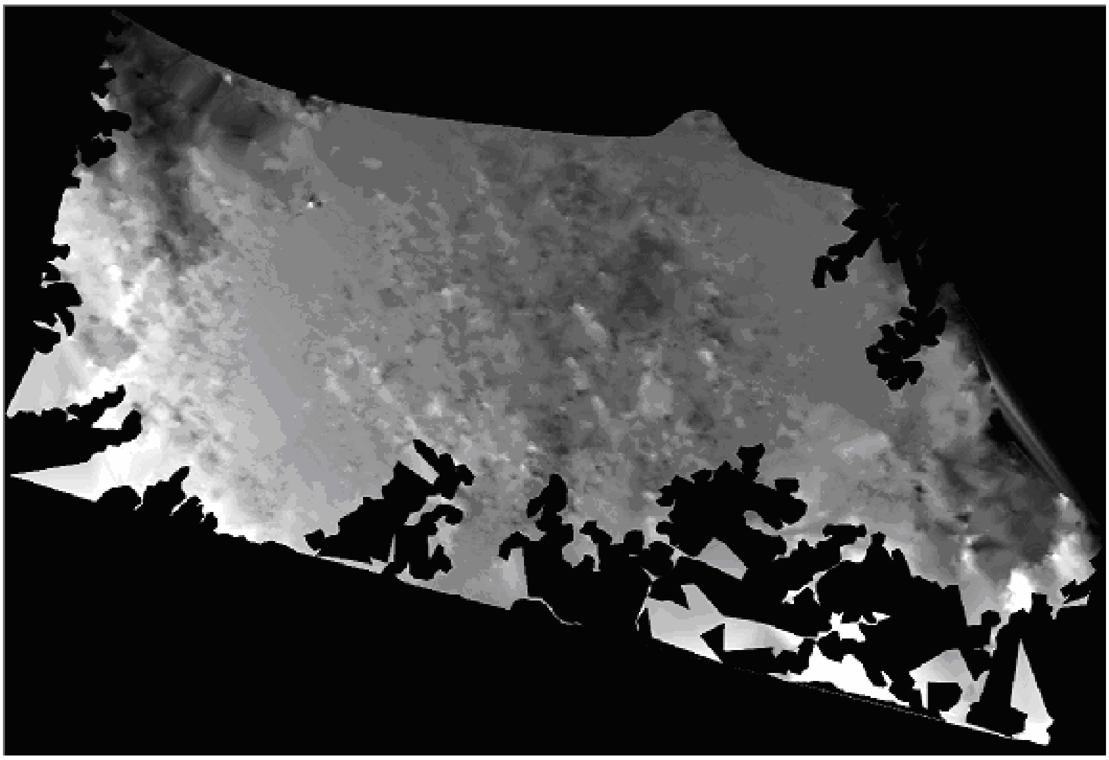

Figure 11. The automatic DTM generated by OrthobasePro v8.6

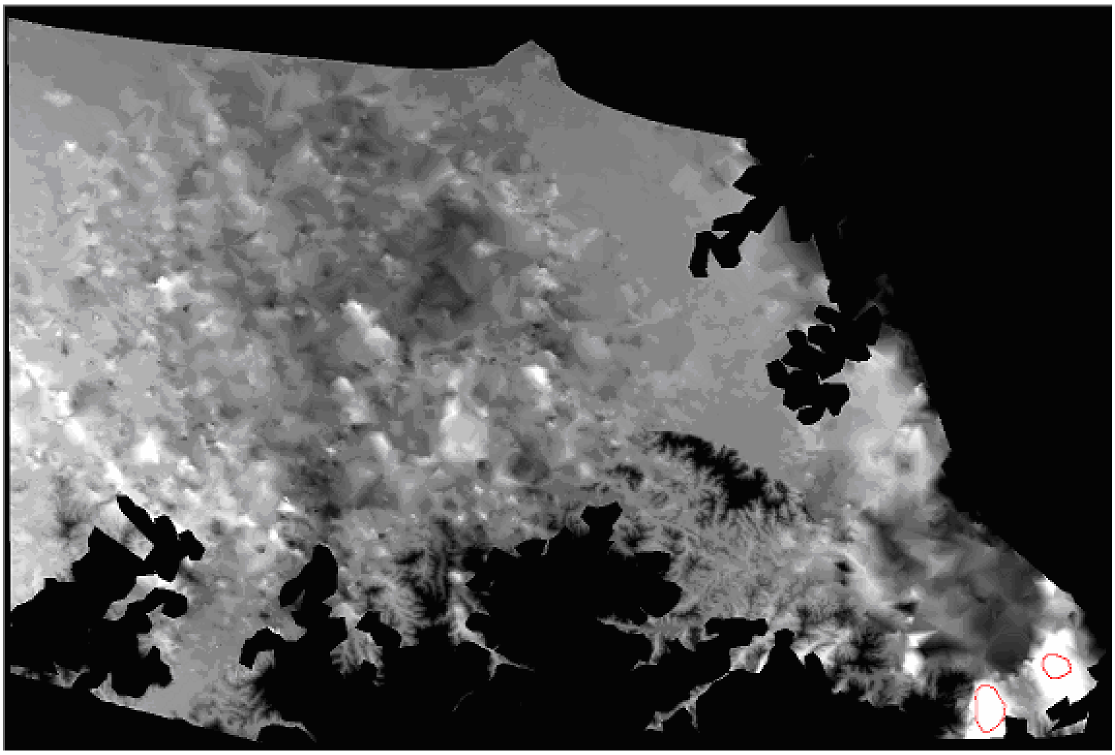

Figure 12. The difference image between original DTM and automatic DTM by OrthobasePro v8.6
The red lines show the gross error regions.

In some areas, there are some gross errors to the mismatching. It means that the software has accepted two points as a pair but in the reality they are not. It is different form the regions that the software declares them as not matched place. In Figure 12, some of them are indicated by the red color.

The result of the difference, which is shown in Figure 12, is:

-Median = -14.1 m
-Mean = -13.5 m
-Standard Deviation = 112.6 m

3.2 OrthobasePro v8.7

The OrthobasePro V8.7 has the ability to handle SPOT 5 data. All the steps and the process are like the OrthobasePro v8.6, but the differences are the model definition and direct read of SPOT 5 data format.

3.2.1 Model definition

The first step is to define the kind of model for OrthobasePro v8.7, which is shown in Figure 13.

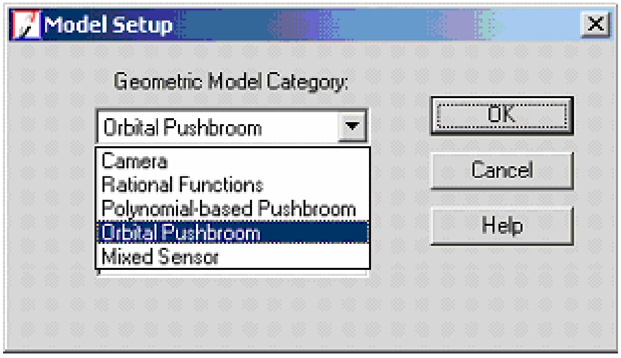

Figure 13. Model definition in OrthobasePro v8.7

OrthobasePro v8.7 uses a model for SPOT 5 called as Orbital Pushbroom.

3.2.2 Data Input

The OrthobasePro v8.7 software has the capability to read the DIMAP (tiff) format, which SPOT IMAGE distributes the data in that format, directly.

3.2.3 Interior Orientation (Frame Editor)

In this stage, the interior orientation parameters for SPOT 5 could be modified. As the OrthobasePro uses polynomial for orbit modeling, user should specify the polynomial order for the orbital parameters such as X, Y, Z, Omega, Phi, Kappa.

3.2.4 Point Measurement

The next step is to select Ground Control Points, Check Points and Tie Points. For Rasht region, with using the provided digital maps, the 17 GCPs and CPs (Full Control Point) are selected. These points are in accuracy of 1:25000 maps. The selected points are the same as the points selected for PCI software and OrthobasePro v8.6. Figure 2, Figure 3, and Figure 4 show the distribution of the GCPs and CPs. The digital maps do not cover the whole imagery area and they cover about 60%-75% of the whole images.

Like version 8.6, the ERDAS Imagine also has the ability to extract the tie points automatically. Because it is tried the conditions to be similar like the other, again 13 automatic tie points selected. But the tie points are not the same as they are dependent to the software algorithm to find and extract them.

3.2.5 Triangulation

After doing point measurement process, the bundle adjustment (triangulation calculation) will be done. To make the condition the same for OrthobasePro v8.6 and v8.7, the same points are used. The result of these tests is:

The result of the bundle adjustment for 6 GCPs for each image and 13 tie points is shown in Table 5.

	GCP	CP
Ground X (m)	3.967	4.976
Ground Y (m)	4.390	6.513
Ground Z (m)	8.042	10.833
Image x (pixel)	0.001	0.215
Image y (pixel)	0.002	0.004

Table 5. The RMSE of the Orthobase v8.7 bundle adjustment
There are 6 GCPs per image, 5 common CPs, and 13 tie points

Please see the Appendix I for more information about the used points.

3.2.6 Automatic DTM Extraction

After solving orbit modeling parameters, the software can start processing for automatic DTM extraction. This software uses Correlation function for image matching.

3.2.7 The DTM result

Table 6 shows the error analysis on GCPs and CPs in the DTM.

ID	Calculated Elevation (m)	GCP/CP Elevation (m)	Difference (m)
1	-18.5493	-25.814	7.2647
2	No matching		
3	No matching		
4	-43.1196	-22.191	-20.9286
5	-6.6655	5.418	-12.0835
6	134.9967	157.167	-22.1703
7	478.7794	499.656	-20.8766
8	211.0184	218.974	-7.9556
9	14.4012	11.932	2.4692
10	-40.6903	-22.514	-18.1763
11	-34.9393	-22.267	-12.6723
12	-10.0288	1.576	-11.6048
13	45.3006	49.411	-4.1104
14	-25.8908	-22.076	-3.8148
15	-46.4238	-21.47	-24.9538
16	479.3013	474.2	5.1013
17	-8.8323	-11.028	2.1957

Table 6. The error analysis on GCPs and CPs in the generated DTM by OrthobasePro v8.7

The result of Table 6 could be summarized as:

Total number of check points used: 5
Minimum, Maximum Error: -24.9538 m, 5.1013 m
Mean Error: -8.7875 m
Mean Absolute Error: 11.7063 m
Root Mean Square Error: 15.2444 m

Total number of GCPs used: 10
Minimum, Maximum Error: -20.9286 m, 7.2647 m
Mean Error: -9.8379 m
Mean Absolute Error: 11.7846 m
Root Mean Square Error: 13.3499 m

Figure 14. The automatic DTM generated by OrthobasePro v8.7

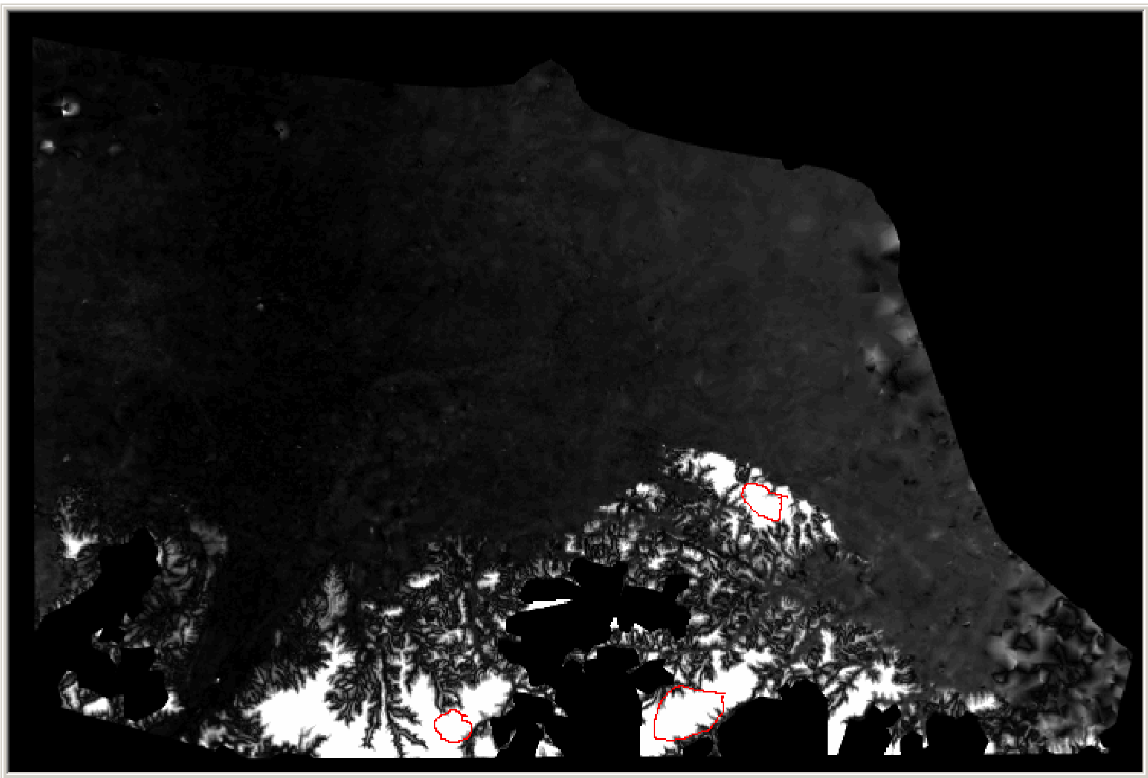

Figure 15. The difference image between original DTM and automatic DTM by OrthobasePro v8.7

Figure 14 shows the general view of the generated DTM. The black areas inside the image are the places that matching process was unsuccessful.

The report of the general mass point quality, used for DTM creation, is:

Excellent % (1-0.85): 77.2222 %
Good % (0.85-0.70): 8.0818 %
Fair % (0.70-0.5): 0.0000 %
Isolated %: 0.0000 %
Suspicious %: 14.6960 %

The number in the parenthesis shows the cross correlation coefficient.

For evaluating the DTM, the generated DTM subtracted from the provided DTM of the Area. The provided DTM as it was mentioned previously doesn't cover the entire images and the coverage is about 60-75%. Therefore, the evaluation has been done on the common area. Because of the non stability in the coastal line, the area for the comparison is selected as Figure 8. The difference image is shown in Figure 15.

In some areas, there are some gross errors to the mismatching. It means that the software has accepted two points as a pair but in the reality they are not. It is different form the regions that the software declares them as not matched place. In Figure 15, some of them are indicated by the red color.

The result of the difference is:

-Median = -9.8 m
-Mean = -21.0 m
-Standard Deviation = 57.4 m

The OrthobasePro v8.7 has the ability of the evaluation of the generated DTM with a reference DTM. The result of this evaluation is:

Total number of DEM Points Used for Checking Vertical Accuracy: 1249240

Minimum, Maximum Error: -788.4983 m, 333.8307 m
Mean Error: -21.2591 m
Mean Absolute Error: 25.7627 m
Root Mean Square Error: 63.8070 m

4. CONCLUSION

The region of study has a high elevation difference, urban areas, water, and low relief, which make it useful for the scientific purposes for automatic DTM extraction evaluation. The result of this study could be summarized as follows:

1- Both softwares had problems in high mountain areas as the changes in relief were very high.
2- In a low relief and low mountains, both softwares acted well.
3- The minimum number of GCPs recommended is 6 per image or 6 common GCPs.
4- Tie points should be selected in both softwares, as they increase the accuracy of the orbital modeling.
5- The modification of OrthobasePro v8.6 model for SPOT 5 was not so successful. The given model in OrthobasePro v8.7 for SPOT 5 works well.
6- Both generated DTMs by PCI OrthoEngine v8.2.3 and ERDAS Imagine – OrthobasePro v8.7 have approximately the same accuracy. However, it seems that PCI strategy in automatic image matching acts better.
7- The DTM refinement and editing by user is a very important task after the job is done. The reliability of the automatic generated DTM is not high.
8- As the images are taken in a short time difference and the look angle for stereoscopy is very appropriate, the stereo imaging geometry of SPOT 5 data have a high capability for height information extraction. Manual DTM extraction will have a high reliability.

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APPENDIX I

In this appendix the coordinates of GCPs, CPs and Tie points are given. Table A-1 gives the image coordinates of the tie points, which are used in PCI. Table A-2 gives the image coordinates of the tie points, which are used in ERDAS. Table A-3 gives the image and ground coordinates of the ground control points and Check points, which are used in both softwares.

ID	Image 1 x (pixel)	Image 1 y (pixel)	Image2 x (pixel)	Image2 y (pixel)
AT0001	8351.5	1298.5	8422.5	1221.1
AT0002	1155.5	2998.5	1228.5	3081.5
AT0003	6035.5	3136.5	6107.4	3092.2
AT0004	1295.5	4938.5	1368.5	5013.5
AT0005	3479.5	4931.5	3552.4	4944.2
AT0006	6060.5	4991.5	6132.6	4942
AT0007	1181.5	6862.5	1255.4	6932.5
AT0008	3481.5	6906.5	3554.6	6913.1
AT0009	6093.5	7031.5	6165.8	6975.3
AT0010	10794.5	7078.5	10865.5	6963.5
AT0011	1128.5	8943.5	1202.2	8994.2
AT0012	3550.5	8881.5	3623.5	8878.5
AT0013	1307.5	10794.5	1380.5	10817.5

Table A-1. The image coordinates of the tie points used in PCI

ID	Image 1 x (pixel)	Image 1 y (pixel)	Image2 x (pixel)	Image2 y (pixel)
18	7981.0812	1521.5083	8057.627	1446.6207
19	4559.0702	1861.6845	4625.7352	1857.5047
20	2045.1481	2296.4619	2124.6203	2350.5714
21	9562.9853	4407.4044	9639.9255	4307.7669
22	7217.227	4546.3645	7279.5502	4482.6171
23	1705.4913	4660.2865	1789.0174	4718.1817
24	4319.8174	7355.0785	4384.7155	7340.8119
25	10253.924	7493.6821	10338.7181	7373.299
26	1613.0052	7518.3053	1697.6769	7565.7741
27	6255.3087	9431.4391	6321.6722	9359.1327
28	9034.7072	9454.9573	9113.0584	9310.198
29	1707.2829	10206.7762	1790.0971	10232.9992
30	4662.4378	10340.3363	4729.9712	10285.113

Table A-2. The image coordinates of the tie points used in ERDAS

ID	Image 1 x (pixel)	Image 1 y (pixel)	Image2 x (pixel)	Image2 y (pixel)	Xg (m)	Yg (m)	Zg (m)
G0001	3191.063	2439.813	3263.469	2466.094	370043.3	4146742	-25.814
G0002	4210.2	11612.54	4282.938	11496.06	368207.2	4100067	566.881
G0003	11720.54	8401.98	11791.47	8237.406	444762.2	4096607	258.618
G0004	8475.43	2139.39	8546.469	2059.594	421512.2	4135015	-22.191
G0005	7319.33	6602.97	7391.594	6526.344	404622.9	4116308	5.418
G0006	7749.594	7729.406	7821.594	7620.469	407351.8	4109842	157.167
G0007	8837.438	9877.563	8908.563	9692.438	415130	4096878	499.656
G0008	5942.438	11480.44	6014.438	11384.44	385071.4	4096248	218.974
G0009	3933.969	6980.969	4007.016	6973.953	371415	4122935	11.932
G0010	7376.531	2095.531	7447.469	2031.531	410957.4	4137988	-22.514
G0011	9735.484	5330.453	9807.492	5231.43	429583.6	4116396	-22.267
G0012	6967.508	6299.508	7039.492	6231.492	401610.5	4118664	1.576
G0013	5637.438	9017.438	5709.563	8961.438	385266.8	4108856	49.411
G0014	5049.5	1858.5	5121.516	1839.547	388759.7	4144934	-22.076
G0015	8225.484	4793.984	8297.531	4712.031	415695.6	4122793	-21.47
G0016	7292.477	10834.46	7363.508	10673.46	398975.3	4096096	474.2
G0017	4913.453	4365.484	4985.484	4342.484	384239.3	4133164	-11.028

Table A-3. The image and ground coordinates of the ground control points and Check points