

# A NEW AUTOMATED AEROTRIANGULATION PRODUCT

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## ABSTRACT

Image Processing Software, Inc. has developed a new easy-to-use automated aerotriangulation product called **IPS-Match™**. The product will automatically find conjugate points in overlapping areas of images and uses a very fast bundle adjustment to determine the exterior orientation of the images. Poor matches are automatically eliminated resulting in RMS residuals from the bundle adjustment ranging from 0.3 to 0.5 pixels. The results of the bundle adjustment can be graphically displayed so the user can assess the strength of the solution. Project setup is made easy, using a setup Wizard that guides the user through the setup process. Existing orthophotos can be used to allow easier project setup and also as a substitute for ground control for historical film applications. **IPS-Match™** currently also creates orthophotos and orthophoto mosaics of the project imagery. The program works with or without GPS/INS as well as with film or digital cameras. Fiducial marks are automatically measured for file imagery. **IPS-Match™** works well with any number of images, only limited by storage and/or computer memory. The program can generate vertical oriented images which are ideal for stereo interpretation. The next version of **IPS-Match™** will include the generation of Digital Elevation Maps. This product is specifically designed for the small to medium sized digital camera photogrammetric projects, but will work equally well with traditional film based camera projects. The unique features of **IPS-Match™** allow it to be a cost effective tool for use in historical film applications, emerging UAV applications, and traditional photogrammetric applications.

**KEYWORDS:** automated aerotriangulation, orthophotos, DEM generation

## INTRODUCTION

There are a large number of different types of cameras which can be used for mapping purposes. The only common denominator is that orientation parameters need to be derived from the imagery from these cameras in order to create an orthophoto, map features, or create a Digital Elevation Model (DEM). Image Processing Software, Inc. (IPS) has developed a product, **IPS-Match™**, which can be used with most of these cameras to automatically determine orientation parameters, create both orthophotos and in the near future DEMs. **IPS-Match™** uses matching technologies to find common points between adjacent images and then uses a bundle adjustment to calculate the orientation parameters. Once the orientation parameters have been determined, orthophoto mosaics of the project area can be created. The next version of **IPS-Match™** will be able to generate a point cloud of elevation points which can be used to create a Digital Elevation Map of the project area. The orientation parameters can also be exported for use by other mapping software to accomplish additional mapping tasks.

## PRODUCT FEATURES

**IPS-Match™** is designed to work well with traditional film cameras as well as large and small format digital cameras. For a film project, the fiducial marks only need to be measured on one of the images and then the program will use matching technologies to determine the interior orientation for all of the imagery in the project. For film projects without camera calibration information, built-in technology allows for the calculation of reasonable results.

The use of GPS and INS for mapping projects is becoming very common. **IPS-Match™** will use available GPS/INS to guide the matching process. It is not necessary to use highly accurate GPS/INS information as a first approximation to the orientation parameters. This feature allows the use of lower quality GPS/INS systems such as that used in an UAV application. If GPS/INS is not available, **IPS-Match™** will determine a first approximation to the orientation parameters from user entered control points and then the final orientation parameters from matching technologies.

The matching technology uses multi-ray techniques to allow better determination of the conjugate points. Matched points are only saved if they are matched on all overlapping images. The bundle adjustment then is used to automatically eliminate poor and ambiguous matches. The multi-image matching is very efficient and can take as few as 3 seconds per image.

### Project Examples

The first project discussed is 15 digital images from a Vexcel UltraCamD camera. This is a relatively small format mapping camera with 7500 rows and 11500 columns of 16-bit data. **IPS-Match™** worked well with this data and accomplished the matching as well as the bundle adjustment in about 3 seconds per image (using a laptop computer). The orientation parameters were derived from 457 matched points. Figure 1 summarizes the statistics derived from this project.

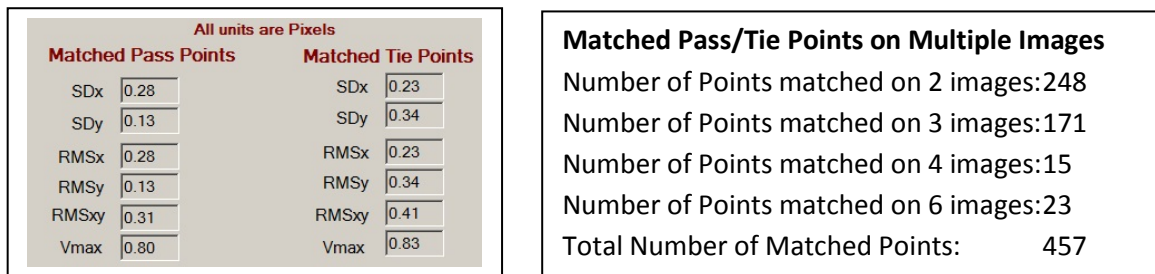


Figure 1. The statistics from a bundle adjustment for a Vexcel UltraCamD project which contained three strips of 5 images each. Both GPS and INS were measured at time of flight. The flight direction was along the columns.

**IPS-Match™** attempts to match a large number of points within a strip (pass points) and between strips (tie points). The bundle adjustment automatically eliminates poor points and the statistics in Figure 1 represent the points saved in the final bundle adjustment. In order to visualize the strength of the solution, **IPS-Match™** can display a diagram with each of the matched points connected to the image centers. In Figure 2, the pass point rays are displayed in white and the tie points are displayed in orange.

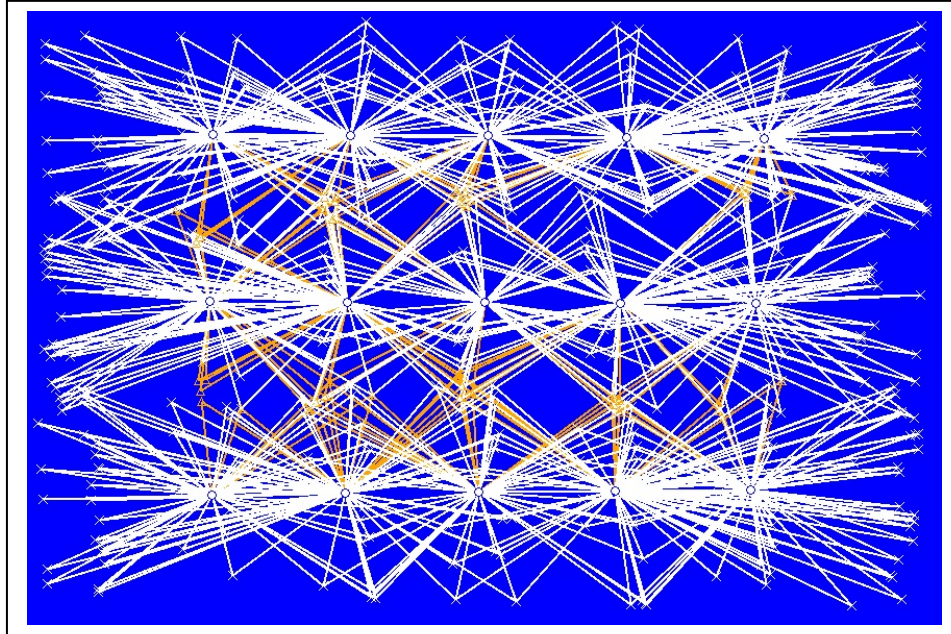


Figure 2. Diagram which plots the matched pass points as white X and matched tie points as orange X. The white and orange lines connect the matched pass/tie points to the image centers on which they are located.

There are numerous options for the user to optimize the matching process. Figure 3 shows a display of the most important options. The Down Strip and Between Strip matching window sizes and search distances can be chosen. Matching is accomplished at up to 4 different resolutions. In Figure 3, L0 represents the window sizes and search distances for the full resolution pyramid level of the image. L2 represents the window sizes and search distances for the  $\frac{1}{4}$  resolution pyramid level. L3 and L4 represent the  $\frac{1}{8}$  and  $\frac{1}{16}$  resolution pyramid levels respectively. The choice of the number of points IPS-Match will attempt to match in each 20% of the image along a center line is shown in the upper right of Figure 3. The user can choose up to 10 points in each zone.

DS Win Size		DS Search Distance		Match Points per Zone	
		X	Y		
L0	19	L0	10	L0	10
L2	11	L2	20	L2	20
L3	11	L3	25	L3	25
L4	11	L4	25	L4	25
BS Win Size		BS Search Distance		Matching Band(s)	
L0	19	L0	11	L0	11
L2	11	L2	30	L2	30
L3	11	L3	30	L3	30
L4	11	L4	30	L4	30
Min Correlation x100		Max Missing Rays		Display Band Order	
L0	85	L0	0	<input checked="" type="radio"/> Band 1 <input type="radio"/> Band 2 <input type="radio"/> Band 3 <input type="radio"/> All	
L2	85	L2	0	<input checked="" type="radio"/> RGB Order <input type="radio"/> BGR Order	
L3	85	L3	0		
L4	85	HF	0		
2-Way Matching		Match Odd Strips		Save Options	
<input type="radio"/> Off <input checked="" type="radio"/> On		<input type="radio"/> Yes <input checked="" type="radio"/> No			

Figure 3. The matching options chosen for the Vexcel 15 Image Project.

After the orientation parameters have been determined, an orthophoto mosaic of the project images can be created. Figure 4 is a representation of the orthophoto created for this project.

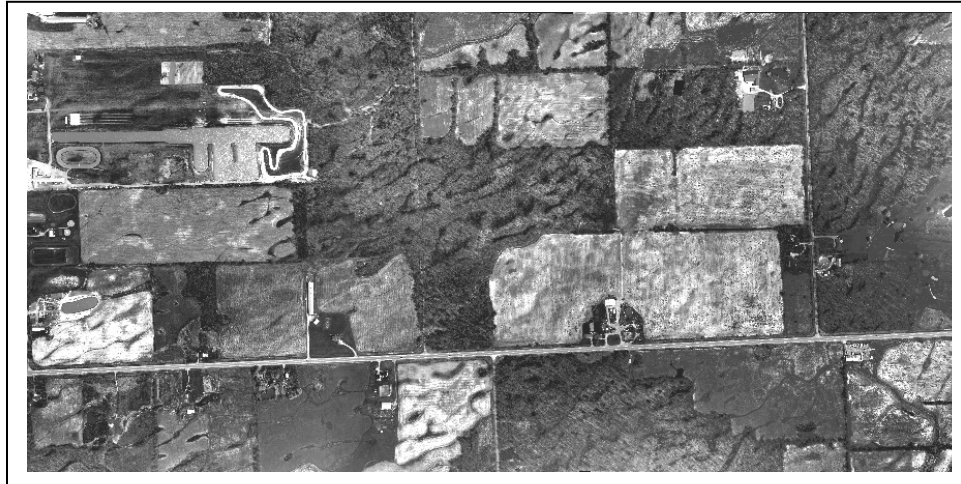


Figure 4. 15 Image orthophoto mosaic created using the 15 ImageVexcel Project Imagery.

IPS-Match works well with medium sized projects. A project was created using 374 images from the Vexcel UltraCam D. The imagery was flown as 6 strips of 62 or 63 images per strip. The matching options chosen for this project can be found below in Figure 5. Note for this project, the tie points were only derived from matching odd strips (2,4, and 6). If not enough tie points were matched, one could choose to match additional tie points using strips 1,3, and 5. The matching time for the 6 down strip matching and tie points using strips 2,4, and 6 was 1552 seconds (~26 minutes). This is about 4 seconds for the matching per image. The final bundle adjustment took an additional 2.7 minutes.

Matching Options		Units and Block Options	
<b>Down Strip Search Distance</b>			
<b>DS Win Size</b>	<b>X</b>	<b>Y</b>	<b>Match Points per Zone</b>
L0 19	L0 10	L0 10	BS Zone 1 6
L2 11	L2 20	L2 20	DS Zone 1,2 3
L3 11	L3 20	L3 20	DS Zone 3 3
L4 11	L4 20	L4 20	DS Zone 4,5 3
			BS Zone 5 6
<b>BS Win Size</b>		<b>Between Strip Search Distance</b>	
L0 19	L0 10	L0 10	
L2 11	L2 25	L2 25	
L3 11	L3 25	L3 25	
L4 11	L4 20	L4 20	
<b>Min Correlation x100</b>	<b>Max Missing Rays</b>		
L0 82	L0 0		
L2 82	L2 0		
L3 82	L3 0		
L4 82	HF 0		
<b>Matching Band(s)</b>			
<input checked="" type="radio"/> Band 1 <input type="radio"/> Band 2 <input type="radio"/> Band 3 <input type="radio"/> All			
<b>Display Band Order</b>			
<input checked="" type="radio"/> RGB Order <input type="radio"/> BGR Order			
<b>2-Way Matching</b>		<b>Match Odd Strips</b>	
<input type="radio"/> Off <input checked="" type="radio"/> On		<input checked="" type="radio"/> Yes <input type="radio"/> No	
<b>Save Options</b>			

Figure 5. Matching Options chosen for the 374 Image Vexcel Project.



All units are Pixels			
Matched Pass Points		Matched Tie Points	
SDx	0.29	SDx	0.18
SDy	0.18	SDy	0.20
RMSx	0.29	RMSx	0.18
RMSy	0.18	RMSy	0.20
RMSxy	0.34	RMSxy	0.27
Vmax	1.12	Vmax	1.97

<b>Matched Points on Multiple Images</b>
Points matched on 2 Images: 337
Points matched on 3 Images: 375
Points matched on 4 Images: 400
Points matched on 5 Images: 7053
Points matched on 6 Images: 1437
Number of Matched Points: 9602

Figure 6. The statistics from this bundle adjustment for the 375 image project:

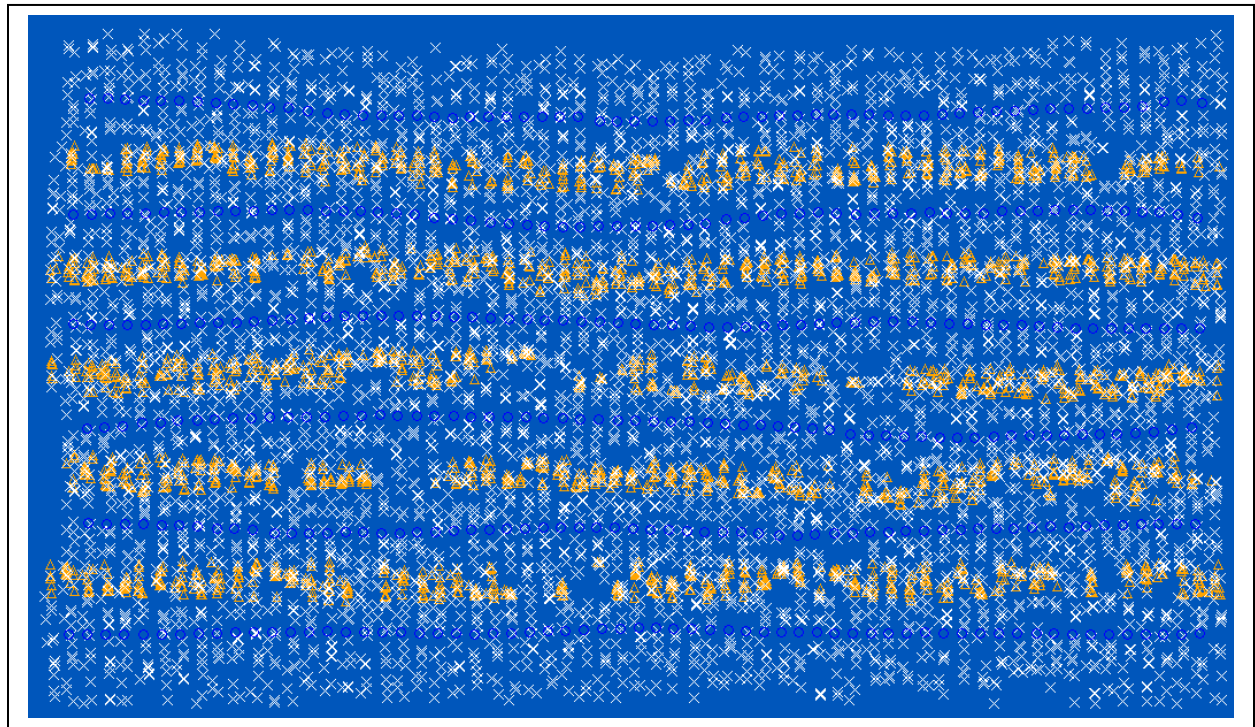


Figure 7. Graphical representation of the matched points for the 375 Image Vexcel Project. The white X's represent the pass points and orange X's represent the tie points.

In general, matching technology works best using 16-bit images (or at least 12-bit information). Described below is a 2 strip, 12 image (8-bit, 3-band) film project. This project did not include GPS/INS information, but did include 6 control points. The next picture shows the matching points (white X's), Tie rays in orange, control point rays in red and manually entered pass points in green. There were 254 matched points and the bundle adjustment yielded an  $RMS_{xy} < 0.4$  pixels.

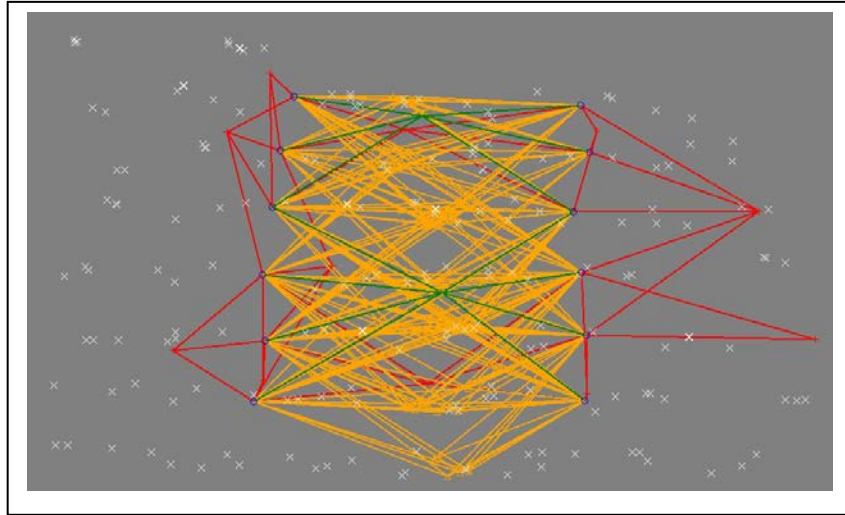


Figure 8. Graphical representation of the matched points (white X's), tie rays (orange), control points and rays (red) and manually entered pass points (green) for the 12 photo film project.

This is a complicated urban area containing dense residential areas as well as tall buildings. IPS-Match was able to accomplish very good results using matching technology. The orthophoto produced appears to be very good and is depicted in Figure 9.

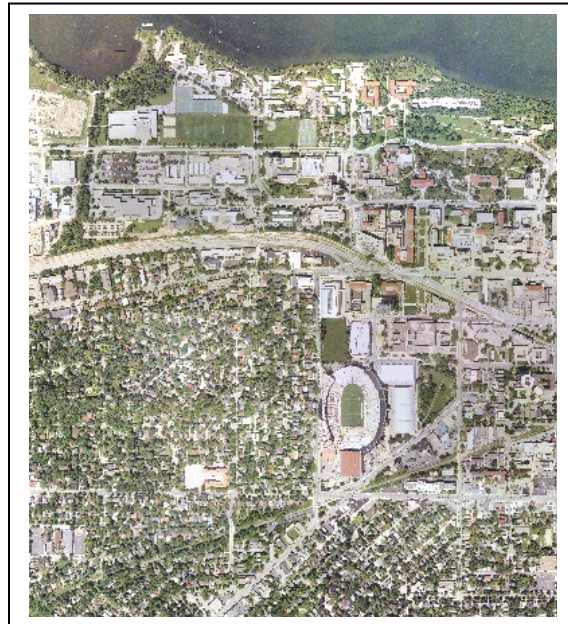


Figure 9. The 12 Image Mosaic of the 12 photo film project.

### Using Existing Orthophotos as Approximate Control

**IPS-Match™** has a unique feature that allows the use of existing orthophotos to help in project setup, locating control points for measurements and adding the orthophoto coordinates as control if needed. If the project does not include GPS measured in the aircraft, first approximations of the centers of each image are required by IPS-Match.

This information can be manually entered, but using an orthophoto to choose one point on every fourth image is a very easy method of determining the image center.



Figure 10. One of the images in a project and the reference orthophoto are displayed next to each other for the user to select a common point. This selection is used to determine an approximate image center. The reference orthophoto can also be used for easy entry of control points. After clicking on a few common points between the reference orthophoto and project images, the image centers and all of the control points are plotted for easy measurement of the control.

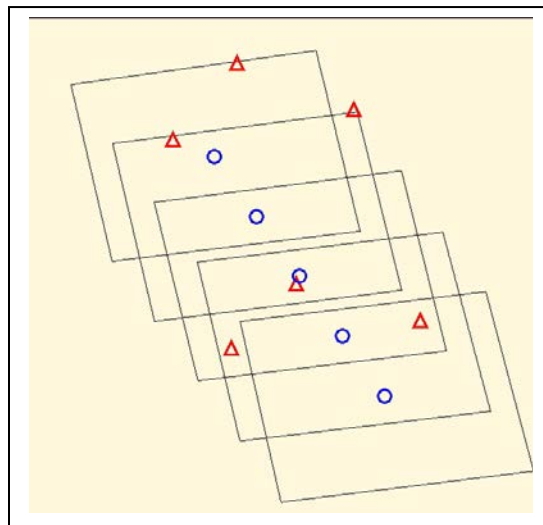


Figure 11. A graphical plot of the image centers, image extent, and coordinates of the control points for a 5-photo film project.

A click on any of the red triangles (designating the control points) will display the images on which this control point is located. The control point should be evident on the images.



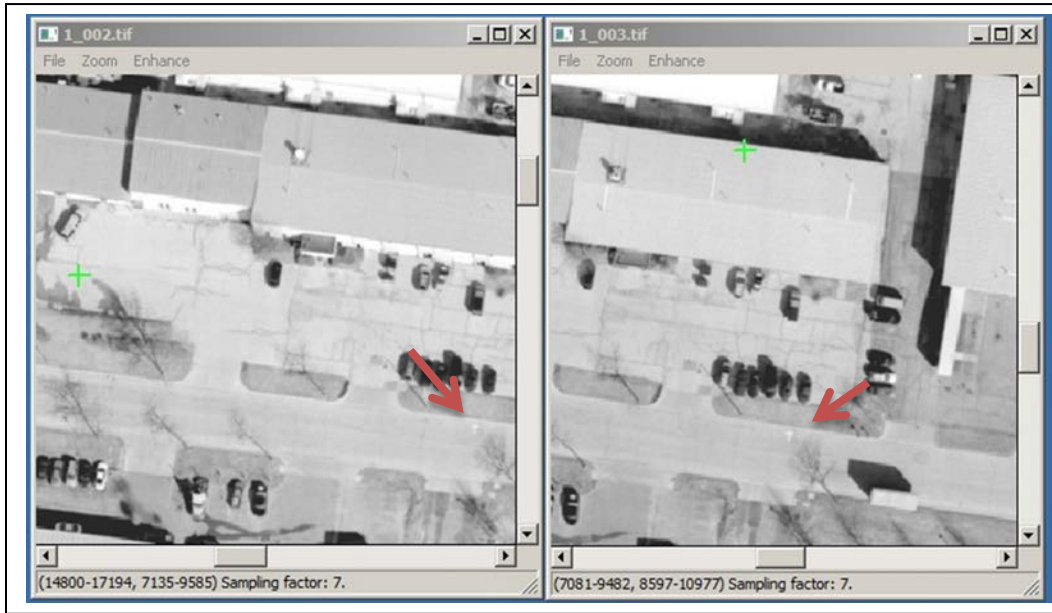


Figure 12. The images displayed after clicking on one of the red triangles in the control plot for the 5 photo film project. The red arrows were added to identify the location of the control point on these images.

The user is expected to zoom in and click at the location of the control point on each of the images.

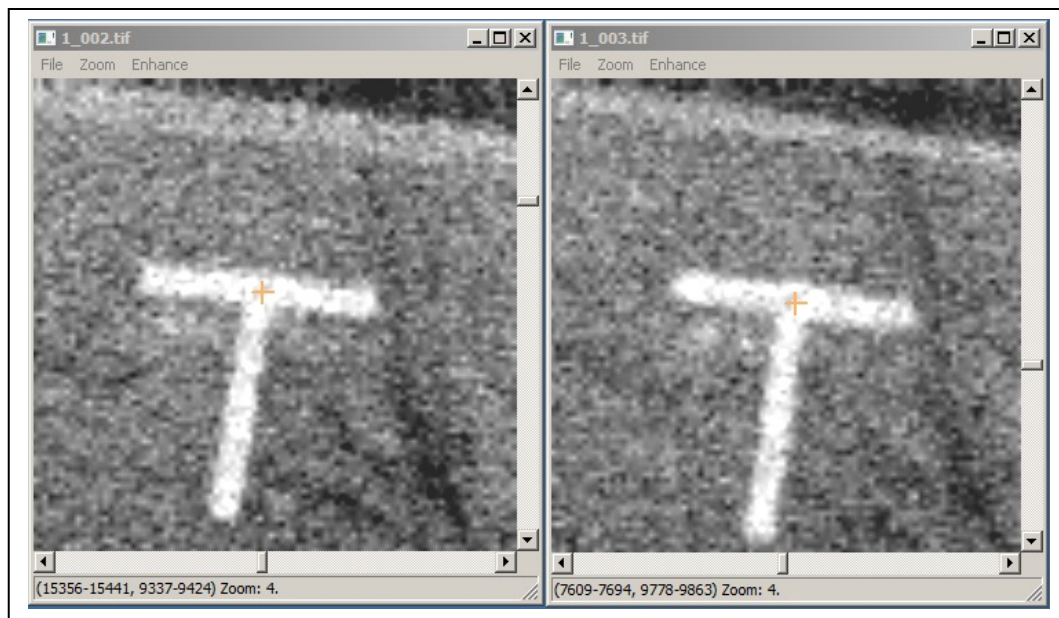


Figure 13. After zooming in on the display of the control point, the coordinate of the control point is measured by a left mouse click on each of the images for the 5-photo film project. For this example, the control point is measured with a precision of 1/8 pixels (about 1.5 microns on the film).



## Automatic DEM Generation

With the release of Version 3 of IPS-Match (summer of 2014), the creation and editing DEM will be added to **IPS-Match™**. A number of innovative techniques are used to quickly find conjugate points in the overlap area between adjacent imagery. Multi-image matching is implemented to assure that only good matches are saved in the point cloud of elevation points and then used in the creation of the TIN. In order to speed up the matching time, matching is accomplished in parallel – up to 15 processes simultaneously. IPS-Match will automatically select the number of parallel processes depending on the number of processor cores available. The editing tools will include innovative point cloud editing techniques, smoothing and fill functions. The user will be able to generate bare earth elevation maps as well true elevation maps. All users who subscribe to support services will receive all updates to **IPS-Match™** at no additional charge.

Figure 14 shows the progress bars for a matching process which used 7 simultaneous threads for matching on a laptop computer. At the top right of the figure is the unedited DEM created from the elevation point cloud of matched points. Below that is a portion of a 10m USGS DEM.

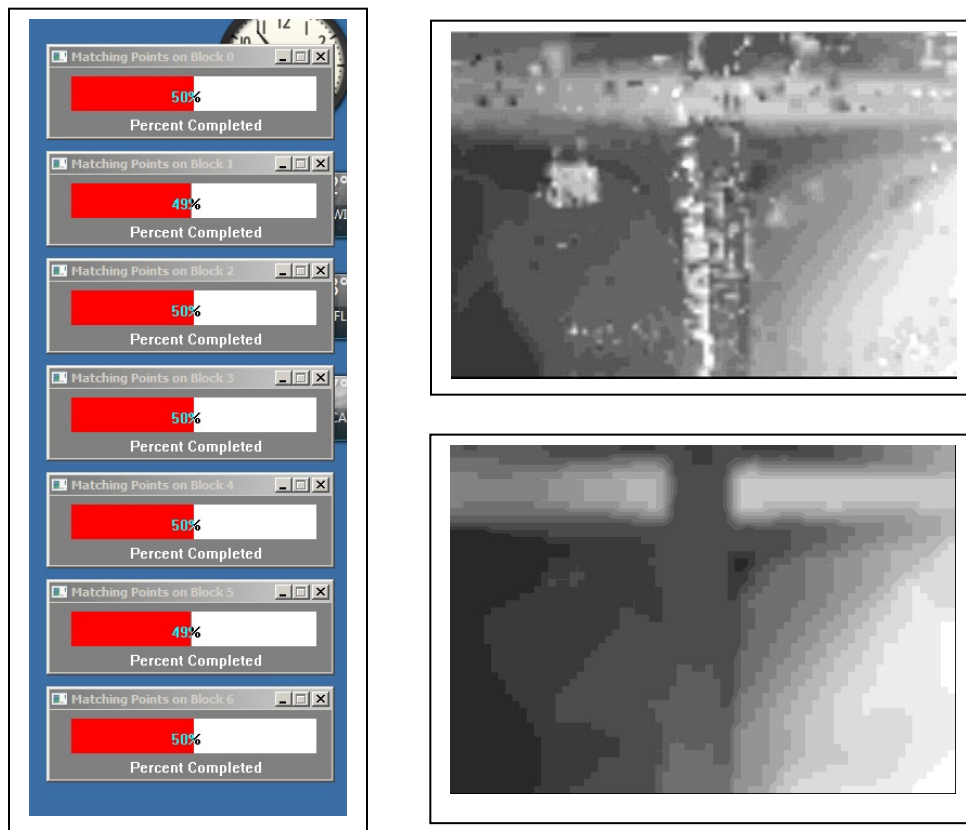


Figure 14. Example of progress bars for multi-threaded matching. At the top right side of the figure is part of a DEM generated from the 5 photo film project discussed above. The bottom right side of the figure are the elevations in a 10m USGS DEM.

The DEM created by **IPS-Match™** has more detail, but is in general agreement with the USGS 10m DEM. Note that the elevation of the horizontal overpass is correct on the **IPS-Match™** generated DEM. Orthophotos created using the **IPS-Match™** generated DEM may allow generation of a true orthophoto more closely than those using a bare earth DEM.

## CONCLUSIONS

We believe we have developed a cost-effective product for almost any photogrammetric project that requires aerotriangulation and the creation of orthophotos. **IPS-Match™** works well with traditional photogrammetric film camera projects. Even though the scanned film is only 8-bit data (or perhaps 8-bit color data) the matching technologies work very well. The use of **IPS-Match™** for automatically determining and matching pass points will prove to be a very cost effective tool. The automated measurement of the Fiducial Marks can also prove to be a time saver. **IPS-Match™** features the use of existing orthophotos to add control for historical photography using the technologies developed in our other product, **OrthoMapper™**. Existing orthophotos also allow easy project setup.

Digital cameras are clearly the future platform for acquisition of photogrammetric data. **IPS-Match™** is specifically designed to process the data acquired from the small and medium format digital cameras. The only practical solutions to determining the exterior orientation parameters for a large number of images are the use of very accurate GPS/INS or a product like **IPS-Match™** which can also do this task. We believe that **IPS-Match™** is a much more cost-effective solution for determining the exterior orientation parameters for projects with large numbers of images.

**IPS-Match™** works well with or without GPS/INS first approximations. It could be especially useful for projects where imagery is acquired with low accuracy INS such as imagery acquired from a UAV. For more information and examples see our web page at [www.orthomapper.com](http://www.orthomapper.com).