Geometric Correction, Orthorectification, and Mosaicking

For: Janet Finlay
GISC9216- Digital Image Processing

John Bull
B.Sc Candidate
GIS-GM Candidate
3 Jasmin Crescent
St. Catharines, Ontario
# Table of Contents

1. Introduction ........................................................................................................................................ 1

2. Methodology ....................................................................................................................................... 2
   2.1. Polynomial Correction .................................................................................................................. 6
   2.2. Polynomial Model Mosaic .......................................................................................................... 13
   2.3. Orthorectification ....................................................................................................................... 17
   2.4. Orthorectification Mosaic .......................................................................................................... 22

3. Analysis .............................................................................................................................................. 23
   3.1. Polynomial Model Mosaic Results ............................................................................................. 23
   3.2. Orthorectification and Mosaic ................................................................................................... 27

Conclusions ............................................................................................................................................. 32

Bibliography .......................................................................................................................................... 33
Figure 1: Original air photo to be used as reference image ......................................................... 2
Figure 2: Photo 1 to be rectified .................................................................................................. 3
Figure 3: Photo 2 to be rectified .................................................................................................. 4
Figure 4: Photo 3 to be rectified .................................................................................................. 5
Figure 5: Control points button initiating geometric correction procedure .................................. 6
Figure 6: Example of ground control points .............................................................................. 7
Figure 7: Close look at placement of a ground control point ...................................................... 8
Figure 8: Fourth ground control point accuracy ........................................................................... 9
Figure 9: RMS error examples ..................................................................................................... 10
Figure 10: Prediction of eighth ground control point ................................................................. 11
Figure 11: Resample dialog box .................................................................................................. 12
Figure 12: Resampled photo overlaid on reference image ............................................................ 13
Figure 13: Mosaic Express ......................................................................................................... 14
Figure 14: Mosaic Express dialog box .......................................................................................... 14
Figure 15: Input area tab from mosaic wizard .............................................................................. 15
Figure 16: Colour corrections in mosaic ....................................................................................... 16
Figure 17: Mosaicked image of geometrically corrected photos using the polynomial model ...... 17
Figure 18: Camera model properties dialog box ......................................................................... 18
Figure 19: Fiducial placement and dialog box .............................................................................. 19
Figure 20: RMS errors in an orthorectified photo ........................................................................ 20
Figure 21: Resample dialog box for orthorectification ................................................................. 20
Figure 22: Resampled aerial photo using orthorectification ......................................................... 21
Figure 23: Orthorectified mosaic overlaid on reference image .................................................... 22
Figure 24: Misaligned roads in polynomial mosaic ..................................................................... 24
Figure 25: Colour changes and errors in mosaic result ................................................................. 25
Figure 26: Top half of polynomial mosaic result ......................................................................... 26
Figure 27: Road network misalignment and buildings displaced ............................................... 27
Figure 28: Orthorectification showing road networks lining up ................................................. 28
Figure 29: Comparison of elevation distortion between polynomial model and orthorectification ... 29
Figure 30: Slight difference in colour between mosaic and reference image............................ 30
Figure 31: Overlay of vector layers onto orthorectified mosaic .................................................. 31
Figure 32: Road networks lining up well with mosaic result ..................................................... 31
1. Introduction

Geometric correction and orthorectification are two possible ways of tying down remotely sensed imagery to an already geometrically corrected image or to geographic reference points. Conventional techniques of geometric correction such as polynomial transformation, which was used in this assignment, are based on general functions not directly related to any specific distortion or error sources (Intergraph Corporation, 2013). Orthorectification is a more accurate form of rectification that corrects for terrain displacement and can be used if there is a DEM of the study area available (Intergraph Corporation, 2013). Within this project the methodology of how a geometric correction using the polynomial model was performed as well as how an orthorectification was performed using ERDAS Imagine software. Three aerial photos were provided as well as an original reference image that the photos had to be rectified to. Using the previously mentioned techniques, the three photos were successfully rectified to the reference image and mosaicked together, with minimal error.
2. Methodology

The methodology section outlines how both the geometric correction as well as the orthorectification were performed in the ERDAS Imagine software. The original reference image can be seen below in Figure 1.

![Original air photo to be used as reference image](image.png)

Figure 1: Original air photo to be used as reference image
The aerial photos that are being rectified to Figure 1 can also be seen below in Figure 2, Figure 3, and Figure 4.
Figure 3: Photo 2 to be rectified
Figure 4: Photo 3 to be rectified
2.1. Polynomial Correction

Geometric correction was initially performed using the polynomial model and at least eight ground control points. To do this, the initial step is to assign the geometric model which is done by clicking on ‘Control Points’ in the ERDAS software Figure 5.

![Control points button initiating geometric correction procedure](image)

When the software prompts to select a geometric model, the polynomial model is chosen. Polynomial equations can be used to convert source file coordinates to rectified map coordinates, depending upon the distortion of the imagery, multiple-order polynomials can also be used (Intergraph Corporation, 2013). For the purpose of this image, only a first degree polynomial is necessary.

With the polynomial model chosen and the model properties correctly assigned it is now possible to start assigning ground control points to both images. Ground control points are specific pixels in an image for which the output map coordinates are known and consist of two X, Y pairs of coordinates, one from each image (Intergraph Corporation, 2013). Ground control points should be placed on the image to be rectified at places that are easily distinguishable on the reference image as well as at places that will be known to not have changed or moved after time. Some examples of good ground control point locations would be road intersections, building corners (though distortion can make this difficult), swimming pools, and any other easily distinguishable object with a specific corner. The ground control points should also try and cover the entire image as the more dispersed the ground control points are the more accurate the rectification will be (Intergraph Corporation, 2013).
Below, in Figure 6, is an example of the ground control points that have been used to rectify a photo, as you can see they are dispersed across the entire image to try and reduce the RMS error and increase the accuracy of the rectification.

Figure 6: Example of ground control points
The ground control points, as previously mentioned, should be placed at distinguishable locations such as corners, and an example of this is provided below in Figure 7.

It can be seen in Figure 7, that the ground control point was placed on the corner of a building’s roof. The second red circle above it shows a closer look that can be used for very precise placement of ground control points. The ground control points are placed on the corresponding locations in the reference image and are then used, along with a polynomial equation, to rectify the image to the reference image.

As you enter ground control points, the coordinates of the input layer, and the corresponding coordinates on the reference layer, are both stored in a table at the bottom of the display box. Along with these numbers is the X and Y residual, the RMS error, the error contribution by point, and a value indicating how precise the match was. The latter of these numbers are only displayed after at least three sets of ground control points have been assigned and if the ‘Automatic Transformation Calculation’ setting is on (otherwise they will appear once you click to solve the model). These numbers basically describe how well the model has matched the input photo to the reference photo. The X and Y residuals are simply the distances between the source and
retransformed coordinates, whereas the RMS error is the root-mean-square of the X and Y residuals added together; this gives a reasonable estimate of the overall error.

When the fourth ground control point is placed on the input image, the model automatically generates a corresponding ground control point on the reference image. In most cases this corresponding ground control point won’t be very accurate but should be in the vicinity of where it should be. Figure 8 below shows an example of a corresponding fourth ground control point, the red circle indicates as to where the ground control point should actually be placed.

As mentioned before, the prediction process for the ground control points will rarely be exact because the model’s inputs are always going to have a slight amount of error. Whether it be that the placement of the ground control points is slightly off, or that they are not placed in a way that gives a complete spatial coverage of the image, error will always exist in the inputs, and therefore the output will also always have error. The goal in this process is to minimize the error as much as possible.
Within this project, an RMS error of less than 0.1 was maintained to ensure an accurate rectification of the images. An example of the RMS error ranges that were encountered using the polynomial model can be seen below in Figure 9.

<table>
<thead>
<tr>
<th>Point</th>
<th>Point ID</th>
<th>X Input</th>
<th>Y Input</th>
<th>X Corrected</th>
<th>Y Corrected</th>
<th>Type</th>
<th>X Residual</th>
<th>Y Residual</th>
<th>RMS Error</th>
<th>Corners Matched</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GP1</td>
<td>22.940</td>
<td>13.785</td>
<td>26.091447495</td>
<td>40.364462473</td>
<td>Control</td>
<td>0.037</td>
<td>0.060</td>
<td>0.056</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>GP2</td>
<td>4.765</td>
<td>0.537</td>
<td>4.479223666</td>
<td>4.098830144</td>
<td>Control</td>
<td>0.016</td>
<td>0.005</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>GP3</td>
<td>0.039</td>
<td>32.371</td>
<td>24.6446.444</td>
<td>48.14034512</td>
<td>Control</td>
<td>0.004</td>
<td>0.040</td>
<td>0.056</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>GP4</td>
<td>19.774</td>
<td>23.192</td>
<td>25.022227208</td>
<td>40.14404434</td>
<td>Control</td>
<td>0.001</td>
<td>0.039</td>
<td>0.043</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>GP5</td>
<td>10.131</td>
<td>11.573</td>
<td>4.292727216</td>
<td>40.21021207</td>
<td>Control</td>
<td>0.025</td>
<td>0.059</td>
<td>0.091</td>
<td>0.079</td>
</tr>
<tr>
<td>6</td>
<td>GP6</td>
<td>16.771</td>
<td>0.639</td>
<td>24.97273699</td>
<td>40.06225507</td>
<td>Control</td>
<td>0.003</td>
<td>0.001</td>
<td>0.003</td>
<td>0.043</td>
</tr>
</tbody>
</table>

Figure 9: RMS error examples
The more ground control points that are entered, the better the prediction process will become, as long as the new ground control points are accurate. A total of eight ground control points were used for each photo; by the eighth ground control point, the prediction process is much more accurate as it has more inputs to work with. Error! Not a valid bookmark self-reference. below shows the prediction result of the eighth ground control point assigned.

The top-right corner of this house was chosen in the left image as the ground control point, and it can be seen in the right image that the prediction process was very accurate in placing the corresponding control point on the reference image, far more accurate than what was seen in Figure 8.
With the amount of error in the model drastically reduced, it is now possible to resample the image to a referenced image. The resample dialog box is shown below in Figure 11, and has multiple different options.

![Resample dialog box]

Figure 11: Resample dialog box

The resample method that was chosen for all of the resampling was nearest neighbor; this is the most simple and easiest to compute of the resample methods, but for this dataset it was appropriate. The nearest neighbor resampling method retransforms the rectified coordinates to the reference coordinate system and the pixel that is closest to the retransformed coordinate is the ‘nearest neighbour’ and assumes the data value of the rectified image (Intergraph Corporation, 2013).
With the resample method chosen and the output file selected, all other parameters were left as is. By pressing ‘OK’ the rectified image is resampled onto the reference image and results in what can be seen below in Figure 12.

![Figure 12: Resampled photo overlaid on reference image](image)

2.2. Polynomial Model Mosaic

Once all of the three photos went through the rectification process outlined previously, they were ready to be mosaicked together into one continuous image. The mosaic process can be easily
done in the ERDAS software using the Mosaic Express wizard which can be seen below in Figure 13.

![Mosaic Express](image1.png)

**Figure 13: Mosaic Express**

By clicking on the Mosaic Express button, the mosaic dialog box can be opened Figure 14.

![Mosaic Express dialog box](image2.png)

**Figure 14: Mosaic Express dialog box**

Within this dialog box, the parameters for the mosaic can be set and any colour manipulation or cropping can be done within the wizard. The three rectified air photos were loaded into the Input...
tab first, as can be seen in Figure 14. Secondly, the input area was adjusted so that the black area around the air photo, as well as the fiducial marks, would be eliminated from the mosaic image Figure 15.

The crop area was set to 18% after some trial and error in an attempt to cut out as little of the actual image as possible. With the cropping complete, colour corrections were also made since each of the air photos had a slightly different brightness value range.
Colour corrections were made in the mosaic wizard using histogram matching. This function attempts to match the histogram of the second and third aerial photo, to that of the first, based on intensity Figure 16.

With the colour correction settings set, the remaining tabs were left as the default parameters, and an output file was chosen before clicking finish.

Figure 16: Colour corrections in mosaic
The final mosaicked output can be seen below in Figure 17.

![Mosaicked Image of Geometrically Corrected Photos Using the Polynomial Model](image.png)

Figure 17: Mosaicked image of geometrically corrected photos using the polynomial model

2.3. Orthorectification

The second form of geometric correction that was performed on the aerial photos was orthorectification. Orthorectification is a form of rectification that corrects for distortion associated to terrain displacement and can be used if there is a digital elevation model of the
study area (Intergraph Corporation, 2013). A digital elevation model was provided within the project’s data and this was used along with provided parameters for the aerial sensor.

To begin the orthorectification process, the ‘Control Points’ button must once again be clicked to open up the geometric model dialog box. Instead of using the polynomial model, this time we will select ‘Camera’ as we have the associated parameters for the sensor used to take these photos. With ‘Camera’ selected as the geometric model, the ground control point selection screen once again opens along with the camera model properties. The camera model properties dialog box can be seen below in Figure 18.

![Camera Model Properties (ortho1.gms)](image)

The first step in the camera model properties box is to set the elevation source that will be used, which in this case is the previously mentioned digital elevation model. After navigating to the elevation model, we can fill out the rest of the parameters that were provided. The provided principal points were zero for both X and Y, while the focal length was 152.468mm; we were also told to use five iterations in the correction process. The next step is to navigate to the ‘Fiducials’ tab and identify the fiducials on the input photo so that the geometric model knows the location of the principle point in the aerial image. This is done in the same way as ground control points by placing a crosshair on the appropriate location. The aerial images that are being used have eight fiducials which were all marked, and the provided Film X and Film Y values were inputted (Figure 19).
The provided Film X and Film Y values can be seen in the right side of Figure 19, whereas the left side of the image shows a fiducial mark as well as the placement of a cross hair in the middle of it.

With the fiducial marks correctly placed, and all other parameters completed, ground control points are once again required to complete the orthorectification process. The orthorectification process is a much more accurate model than the polynomial model due to the accuracy of the parameters being inputted, as well as the usage of the digital elevation model, however, accurate ground control points still need to be used. Only four sets of ground control points are required for the orthorectification process as opposed to the eight needed for the geometric correction using the polynomial model. Unlike the polynomial model, once you reach the fourth ground control point, a corresponding, predicted, ground control point does not appear on the reference image; this control point must be manually placed. With the four ground control points placed, the ‘Solve Geometric Model’ button can be clicked and the residuals and errors will once again be visible.
Figure 20 below shows an example of the RMS errors in an orthorectified photo using only four ground control points.

<table>
<thead>
<tr>
<th>Point</th>
<th>X Ref.</th>
<th>Y Ref.</th>
<th>Z Ref.</th>
<th>Type</th>
<th>X Residual</th>
<th>Y Residual</th>
<th>RMS Error</th>
<th>Contrib</th>
<th>Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4811465.237</td>
<td>306.071</td>
<td>512.148</td>
<td>Control</td>
<td>0.001</td>
<td>-0.001</td>
<td>0.001</td>
<td>0.815</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4809348.108</td>
<td>302.241</td>
<td>512.148</td>
<td>Control</td>
<td>-0.002</td>
<td>0.002</td>
<td>0.002</td>
<td>1.197</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>4801463.146</td>
<td>302.241</td>
<td>512.148</td>
<td>Control</td>
<td>0.001</td>
<td>-0.001</td>
<td>0.001</td>
<td>1.015</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4801205.777</td>
<td>522.789</td>
<td></td>
<td>Control</td>
<td>0.001</td>
<td>-0.001</td>
<td>0.001</td>
<td>1.015</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 20: RMS errors in an orthorectified photo**

It can be seen that the RMS errors of 0.001 and 0.002 are far smaller than any of the RMS error values we hoped to get in the geometric correction using the polynomial model meaning that we are likely to get a far more accurate rectification.

With enough ground control points chosen, the photo is ready to be resampled to the reference image. The resample dialog box is once again shown below in Figure 21.

**Figure 21: Resample dialog box for orthorectification**

The previously described resampling method of nearest neighbor will once again be used in the resample, and the only other major difference in this dialog box is that the geometric model is set to ‘Camera’ and makes reference to an elevation source, whereas the polynomial model did not.
After pressing ‘OK’ the image is resampled and can be placed on top of the original reference image (Figure 22).

Figure 22: Resampled aerial photo using orthorectification
2.4. Orthorectification Mosaic

With the three photos rectified to the reference image using orthorectification, they can now be mosaicked together into one image using the same process as earlier described. The orthorectification mosaic used the exact same dialog parameters as the polynomial model regarding cropping, and colour corrections. The orthorectified mosaic can be seen below in Figure 23.

![Orthorectified mosaic overlaid on reference image](image-url)
3. Analysis

Once the geometric correction has been done to the aerial photos, once using a polynomial model, and another time using orthorectification, the photos must be visually analyzed to assess the quality of the rectification. The most common areas to look for errors are near the edges of the mosaic, where the photo edge meets the reference image edge. Linear features like roads and bridges are generally used as baselines for the amount of error that is seen in a rectification result. Other errors such as colour imbalances can also be seen through a visual inspection of the mosaic.

Another common way to check for errors is to overlap referenced vector data on top of the mosaic and to visually inspect how it lines up. For this project we were provided with a roads and buildings vector layer that will be used to compare the results of the rectifications.

3.1. Polynomial Model Mosaic Results

The rectification using the polynomial model and the following mosaic produced an average rectification result, with slight errors in distortion, but large errors in colour correction. The three rectified images all had slightly different pixel sizes, but the differences were extremely small and therefore would not have had a great effect on the rectification result. The pixel sizes can be seen below in Table 1.

<table>
<thead>
<tr>
<th>Photo 1</th>
<th>0.50125705</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo 2</td>
<td>0.50134817</td>
</tr>
<tr>
<td>Photo 3</td>
<td>0.50027489</td>
</tr>
</tbody>
</table>

Table 1: Polynomial model pixel sizes

The ever so slight change in pixel size comes during the rectification process. When the air photos are rectified they are distorted ever so slightly to adjust for the skew and distortion in the reference image; when this occurs the rectified image can be stretched or compressed causing the pixel sizes to slightly change.

The mosaic result, as mentioned earlier, came only with average accuracy. Like with all rectification processes, the distortion was far greater at the edges of the photos than in the middle. Figure 24 below shows an area where two sections of roads do not line up whatsoever, indicating areas of large error.
The two areas that are outlined in the red circles contain road segments that do not line up. Geometric errors similar to this can be seen at the edges of other photos as well but none are as severe as what is shown in Figure 24.

Aside from the geometric errors and distortion, there are also some problems with the colour correction, mostly in the bottom half of the image. Due to the large difference in brightness values between all three photos, even using the colour correction settings in the mosaic building wizard did not seem to be able to correct all of the colour differences. Figure 25 below shows an area that has a major colour change between the mosaic result and the underlying reference image.
Figure 25: Colour changes and errors in mosaic result

The top half of the image was rectified with a little more accuracy; however, small geometric and radiometric errors still occurred. Figure 26 below shows the top half of the mosaic result with some smaller errors outlined in red circles.
After visually inspecting the results, the roads and buildings vector layers were draped over the mosaic to compare how they line up to the mosaic results. For the most part, the vector layer corresponded with the mosaic result very well, with road networks lining up, but the buildings were slightly displaced, depending on which section of the mosaic you were looking in. The area of the mosaic where photo 2 was located had the most errors as can be seen below in Figure 27.
It can be seen in Figure 27 how the road network intersection does not align properly with the mosaic image intersection, and also the buildings in the mosaic image are in slightly different locations than those in the vector layer.

The distortion and errors that can be seen in the polynomial model are the results of the errors encountered when trying to rectify the image. As previously mentioned, because the polynomial model requires so much user input, that has the possibility for error, there is a very rare chance that you will get a perfect result. With that being said, this mosaic result is still only average when assessing the overall accuracy of the image. Having stricter ground control points, better placed ground control points, as well as more ground control points, are all factors that could potentially improve a rectification result. The addition of a 2\textsuperscript{nd} or 3\textsuperscript{rd} degree polynomial could also help to increase the accuracy of the rectification, however, a thorough knowledge of the study area and what trends it has within it, should be had before proceeding with this.

### 3.2. Orthorectification and Mosaic

The mosaic that was produced as a result of orthorectification was a lot more accurate when comparing to the original referenced image, than the polynomial model provided. It was expected that the orthorectification procedure would produce a more accurate result as it is a more accurate model to work with since the user-inputted parameters are subject to less error. Similarly to the polynomial model, each of the three rectified photos all had different pixel sizes due to the stretching and compressing necessary to rectify an image. The pixel sizes for each of the three photos can be seen below in Table 2.
Despite the orthorectified mosaic being the better of the two, it is still not perfect and has both geometric and radiometric errors within it. The geometric errors are far less distinct in the orthorectified mosaic, as the road networks line up much more neatly, even at the boundaries of the photos. Figure 28 below shows the same area as Figure 24, only this time the road networks have far less geometric error and therefore line up better.

Another area where the orthorectification process is superior, is areas where there is distortion caused by elevation changes, such as bridge overpasses. Since the orthorectification uses a digital elevation model it analyzes the rectified air photo pixel by pixel in comparison with the elevation in the digital elevation model, and therefore can account for distortion due to elevation far better than the polynomial model (Intergraph Corporation, 2013). Figure 29 below shows an example of this as the bridge in the orthorectified image appears to show some curvature whereas the bridge
in the polynomial model is still straight and therefore would lead to some distortion or error in geometric accuracy.

Figure 29: Comparison of elevation distortion between polynomial model and orthorectification

Radiometric errors were still present in the orthorectification, but for the most part they were less noticeable, with some areas having very little change. Figure 30 below shows an area where the colour matching is very close; a red line has been drawn on the image to indicate where the air photo boundary is.
Overlaying the vector data on top of the orthorectified mosaic also confirmed that the orthorectification result was far more accurate than the polynomial model. Figure 31 below shows the same area that can be seen in Figure 27, and despite the road network still being slightly off at the intersection, the buildings line up much better.
The road network at this location could also be simply an error in the vector layer, as the road network lined up near perfectly at every other location Figure 32.
It can be seen in this image that the road network at many other locations lines up near perfectly.

In all, the orthorectification result produced a far more accurate and reliable rectification result than the polynomial model. Geometric errors such as roads not lining up or other geometric distortions were visibly reduced when using orthorectification and the overlay of vector data also was aligned far more accurately.

**Conclusions**

The goal of this project was to create two new rectified and mosaicked images, using two different geometric models, in order to see which one produced a better result. Overall, it can definitely be said that the orthorectification gave a far more accurate and aesthetically pleasing result than the polynomial model did. Both geometric and radiometric distortion was reduced gradually when comparing the two different models to the reference image, as well as to referenced vector layers.

The reasoning behind this is that the orthorectification procedure uses more inputs, and more accurate inputs, to create its output. The polynomial model relies very heavily on the assignment of ground control points when it creates its rectified image, and therefore if the ground control points are not exact, or are not spread throughout the image, it is far easier to receive greater geometric errors. The orthorectification model uses an additional input, a digital elevation model, to increase the accuracy and reduce distortion caused by elevation changes. The inputs for the orthorectification model are also more concrete, in that the fiducials and camera parameters are set in stone and are not up for personal opinion as some ground control points may be.

Both geometric correction models worked successfully, allowing the three aerial photos to be rectified and mosaicked together, and then placed on top of the reference image with relative success but in the future the orthorectification model would be chosen as the superior model when dealing with this dataset.
Bibliography