QUALITY STUDY OF ASTER DATA GEOMETRY BY DIGITIZE CONTOUR LINES IN ILWIS

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Abstract

There are requirements in many fields of the earth science for the accurate knowledge of terrain topography. Nowadays, ASTER data provides valuable data sources for this field. ASTER stereo imagery is now being acquired and it is hoped that, throughout its 5 years mission, most of the earth’s land surface will be imaged in stereo (since, there are the stereo bands in its products). It provides a major data source for generating high resolution DEMs for most parts of the world at a relatively low cost using push broom scanning. In push broom scanner each image line has its own nadir point. When the viewing is in a vertical plane, the nadir point is in the image line. Also here relief displacement is radial with respect to the nadir point, thus it is only within the line, away from the nadir point. When the viewing plane of the sensor is not vertical (e.g. backward view) the nadir point may be far away from the image line. In this case all vertical structures lean the same way in flight direction. This is in addition to the sideways leaning effect shown explained above that it causes consistence shift in the satellite images. In this approach the geometry of 1A and 1B level products of ASTER images at several parts of the globe are studied to digitize accurate contour lines in ILWIS software because of its availability for many users (user friendly and suitable cost). ILWIS is GIS software, which can also makes stereo pairs for viewing satellite images and aerial photographs in stereo. This can be used for digitizing lines of constant parallax (in row-parallax on the screen, i.e. \( \Delta \text{col} = 0 \)). So, several epipolar stereo pairs from some parts of the earth generated to find out the relation between height and column-parallax (using ground control points). This relation used to digitise contour line in ILWIS. The comparison between the digitized and existing contour lines showed the shift in the image caused by the effect of side look angle. Thus, the mathematical formulation defined to calculate the shift and used to correct it.

ASTER DATA

ASTER is an advanced multispectral imager, which is flying on Terra polar orbiting spacecraft with other 4 sensors under international cooperation. ASTER stands for the Advanced Space borne Thermal Emission and Reflection radiometer. The Terra spacecraft is operated in a circular, near polar orbit at an altitude of 705 km. The orbit is sun-synchronous that cross the equator at 10:30 a.m local time. The repeat cycle is 16 days. Thus, the orbit parameters are the same as Landsat except for the local time. The instrument covers a wide spectral region from the visible to the thermal infrared by 14 spectral bands.
each with high spatial, spectral and radiometric resolutions (Earth Remote Sensing Data Analysis Center, 2001b).

In order to cover the wide spectral range of the ASTER instrument, the components have been separated into three subsystems, visible and near infrared radiometer (VNIR) subsystem, short wave infrared radiometer (SWIR) subsystem and thermal infrared radiometer (TIR). The VNIR subsystem has two telescopes, a nadir looking telescope and a backward looking telescope. The two telescopes enable a stereoscopic view with a base-to-height ratio of 0.6 in the along-track direction with minimum mass resource (Earth Remote Sensing Data Analysis Center, 2001c).

STEREOSCOPY IN ASTER DATA

Stereo imagery is collected by the VNIR subsystem. The relation between B/H ratio and \( \alpha \) is \( B/H = \tan \alpha \), where \( \alpha \) is the angle between the nadir and backward direction at an observing point on the earth surface. The angle \( \alpha \) that corresponds to B/H ratio of 0.6 is 30.96 degree. By considering the curvature of the earth surface, the setting angle between the nadir and the backward telescope is designed to be 27.60. ASTER stereo bands 3N (Nadir) and 3B (Backward) have spectral bandwidths in the NIR (0.76- 0.86 \( \mu \)m). The VNIR images have a nominal pixel resolution of 15 m (Earth Remote Sensing Data Analysis Center, 2001b). The geometry of 3N and 3B will be focused by this research.

EPIPOLAR STEREO PAIRS GENERATION IN ILWIS

As the final goal, stereo pairs should be Y-parallax-free (i.e. same row number for corresponding points). X-parallax (i.e. difference of column number) as function of height differences, the ground track should be left to right in the image. For this reason average direction of the western and eastern edges of each image was turned into row differences. This was done as follows:

When producing a stereo pair ILWIS uses a “pivot point” and a “transferred pivot point” in each image. The “transferred pivot point” should be the same terrain detail as the “pivot point” of the other image. Each image is then rotated such that those four points are in the same row (Partovi, 2003).

This procedure gave a good stereo impression. The ground control points were used to find out the relation between the height differences and X_parallax (column in image) in Y_parallax (row in image) free situation. So, ground control points as point map were superimposed on the nadir image. Then for each such point the position of the same terrain detail in the backward view was measured to calculate the differences in row and column number and also in X and Y_coordinates for each point. The Table 1 shows the results of this process for northeast of Iran (the small part of Binaloud mountain). The Table 1 shows that the stereo pair is Row_parallax free. It means, a truly epipolar stereo pair is generated by resampling as described above. The relation between height and X-parallaxes is shown in Figure 1. It is very precisely a linear relation, the parallax changes by 0.04 pixel per meter height differences, thus a parallax change of one pixel corresponds to 25 m height difference.
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Table 1: The result of parallax measuring.

<table>
<thead>
<tr>
<th>Height</th>
<th>Dif.Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>1700</td>
</tr>
<tr>
<td>2200</td>
<td>2700</td>
</tr>
<tr>
<td>3200</td>
<td>3700</td>
</tr>
</tbody>
</table>

Figure 1: The relation between height differences and column parallax.
DIGITIZING OF CONTOUR LINES IN ILWIS

The stereo viewing can be done by stereoscope or anaglyph viewer in ILWIS. In the stereoscope viewing the nadir and backward images are displayed as left and right images respectively in separate windows. This mode was used to measure corresponding points in the nadir view and the backward view to compute the parallaxes. In the anaglyph viewer coordinate of both images cannot be obtained so easily. The anaglyph viewer visualizes the nadir and backward images on top of each other in one window, the left image in red and the right image in blue or green. To digitize contour lines, the stereo pairs were visualized as anaglyph. In this case, the terrain appears in stereo such that the high places appear outside of screen’s surface and low parts seem inside of it. The cursor is seen by both eyes and thus appears stereoscopically exactly in the screen’s surface. The right image can be shifted (left-right) by using the Pixel Shift Spinner in the “Display Options- Stereo pair As Anaglyph” window, which changes the height of the terrain at which the cursor appears. The terrain will appear further inside or outside the screen depending on this setting. A shift of one pixel changes the height by the pixel size divided by the “base-height ratio” thus:

\[
15 \text{ m} / 0.6 = 25 \text{ m}
\]

The cursor appears at a fixed terrain height. By moving it stereoscopically along the terrain the contour line for this particular height can be digitized.

If the height of the pivot point on the nadir image is known, this helps the user to know the height value belonging to each pixel shift on the anaglyph viewer (Partovi, 2003).

For this reason as pivot point in one of the ground control points with 2200 m height was selected. It means, without any pixel shift (pixel shift= 0) the cursor appears at 2200 m height. Therefore, contour line can be digitized on the screen with this value. Each 4 pixels shift shows 100 meters height difference based on relation between height and column-parallax. Thus, the contour lines are digitized with 100 meters interval in separate files. The digitized contour lines are shown by Figure 2.

![Figure 2: Digitized contour lines in ILWIS using pixel shift.](image)
THE COMPARISON OF DIGITIZED CONTOUR LINES AND EXISTING CONTOUR LINE

We compared the digitized contour lines in the ASTER image pair with the digital 1/25000 topographic map and with ground control points of study area from N.C.C. (National Cartography Centre of Iran) to evaluate the accuracy of it. Furthermore, the aerial photographs that show position of each ground control point are used to find out the same points both on the aerial photograph and ASTER image. The result of comparison shows a consistent shift in georeference of digitized contour map with respect to the existing contour map and ground control points that can be caused by the effect of side ward looking angle or by errors in ASTER georeference (Figure 3).

![Figure 3: The comparison of existing contour lines and digitized contour lines.](image)

THE SHIFTING CORRECTION

The coordinates digitized in ILWIS are (within the accuracy of the georeference of the ASTER images) correct for points on the ellipsoid. For points which are clearly higher (or lower) than the ellipsoid they are shifted according to the"Line of sight vector” (The viewing line from satellite scanner to observed points) for this point.

This Line of sight vector varies from the left edge to right edge of the image and depends on the “Pointing Angle” of ASTER. (To be able to cover the entire earth and to achieve a higher repetition cycle if necessary the ASTER instrument can be pointed sideward). These data are seen in a HDF file (Earth Remote Sensing Data Analysis Center, 2001a).
When digitizing contour lines in an ILWIS stereo pair the coordinates are taken from the nadir view, the backward view is only used to create the stereo effect. Due to the sideward viewing all points on the ellipsoid digitized points are shifted side wards (with respect to their correct position) for an amount, which depends on the position in the image and on the height of the point above the ellipsoid (Partovi, 2003).

To facilitate the calculation of this displacement in the UTM-coordinates directly a spreadsheet was made, which carries out the following steps:

1. Requires input of X,Y coordinates of 4 points, preferably corner points of the image or lattice points surrounding the area of interest such, that the sides of the quadrangle are parallel to the edges of the image;
2. Requires input of the y-component of the line of sight vector for each of the 4 points given above;
3. Finds the parameters for a bilinear transformation from the X,Y-coordinate to “across” and “forward”-components such, that the coordinates of the 4 points mentioned above become (-1,-1), (+1,-1), (-1,+1) and (+1,+1) respectively;
4. Finds affine transformations between (changes of) X,Y coordinates and (changes of) the “across” and “forward”-components in meters from the above transformation.
5. A list of points (X,Y,h - coordinates) can be entered. For each point it
   a. Calculates the “across”- and “forward”-position,
   b. Uses bilinear interpolation to find the sideward look angle for this place
   c. Calculates the sideward shift (in meters) from the look angle and the height,
   d. Transforms the sideward shift to shifts in X and Y-direction,
   e. Adds this shift to the input coordinates to obtain corrected coordinates (for the case that digitized coordinates are entered),
   f. Also subtracts these shifts from the input coordinates (for the case, that true coordinates are entered and shifted coordinates should be obtained for use as control point in the georeferencing without removing the effect of height.)
   g. For a backward look it performs the same calculation, but adds a “forward”-shift using 0.6 for the tangent of the backward inclination.

There are separate worksheets for:

- Input of the 4 points and their sideward look angle
- Calculation for a Nadir view image,
- Calculation for a Backward view image.

So, the coordinates of the points of the digitized contour lines with unique height value separately were used as input data to calculate the shifts in X and Y direction based on height and position on the image. Separate point maps are generated from each digitized contour line by segment to point option in ILWIS.

Then the spreadsheet was applied to calculate the shift for these points. The coordinates of four corners of image and their sideward look angle used to transform X and Y coordinate to U and V coordinate. And the X and Y coordinate and height value of the digitized
The above process (using the Nadir calculation sheet), results in corrected coordinates. The corrected coordinates were converted to point map separately to compare with existing contour lines as shown in Figure 4.

![Figure 4: The comparison of existing contour lines and digitized contour lines.](image)

**RESULTS AND DISCUSSIONS**

There is significant correlation between height and difference of column numbers, vector length and azimuth. The relation between difference of column numbers and height shows 25 m height differences for one pixel shift in column. The coefficient of the height and vector length equation is equal to the base to height ratio (base/height=0.6) as should be expected (Partovi, 2003).

Such research was also carried out for several parts of the globe (different latitude and longitude), to confirm above relations. But lack of accurate ground truth (in WGS84) data didn’t allow getting precisely the same results.

As Figure 4 shows, the corrected contour lines keep their similarity with the digitized ones, but fit very well to the existing contour lines. Small deviations between them can be caused by:

- Limited accuracy of the contour digitizing influenced by the quality of the images (low contrast, no texture in some parts, like in shadow areas) and by normal measuring errors.
- Limited accuracy of the existing contour lines. (Their accuracy is not known, but probably much better than the digitised ones.)
Datum shift: The shift belonging to pixel shift zero was chosen using an uncorrected ground control point, thus can be wrong. This was however checked at a very much different height in a very flat part, so that a possible positional error has no effect there. These two determinations of the relation pixel shift–terrain height agreed perfectly. Thus, there should be no considerable datum shift error.

Considering these sources of error, it is obvious that there is no visible georeferencing error in ASTER image and the error in the digitized contours is caused mainly by the shift resulting from the side looking angle effect (Partovi, 2003). It means the corrected images are:

- Nadir image has orthophoto geometry in flight direction.
- Backward image has across the flight direction the same geometry as the nadir image.
- Backward image has in flight direction the geometry of a stereo mate.
- Also, the relation between heights differences and X-parallaxes shows the highest accuracy because, the height changes 25 m per one pixel shift. It means, the accuracy is equal one pixel. So, the ground control points cannot influence to improve the accuracy of this research.

REFERENCES

Earth Remote Sensing Data Analysis Center, 2001a: ASTER level 1 data products specification (GDS version).