PARAMETRIC GEOCODING OF AVIRIS DATA USING A GROUND CONTROL POINT DERIVED FLIGHTPATH

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1. INTRODUCTION

The position of scanning airborne systems (e.g. of the AVIRIS instrument [Vane et al. 1988]) never is as stable as the behaviour of sensors on spaceborne platforms. Thus, geometric distortions occur due to variations of the flightpath as well as of the attitude (given by roll, pitch and heading angles) of the plane. These distortions can not be corrected by ground control point based traditional georeferencing procedures easily, since the movements can not be approximated satisfyingly by polynomial transformations of the image. A linewise calculation has to be performed instead, to consider the behaviour of the plane.

Various projects have been carried out at the RSL, which require an exact localization of ground truth measurement or need the information from a digital elevation model (DEM) fitting to the scanner data (e.g. in-flight calibration of the DAIS sensor [Schaepman et al., 1997], limnological investigations on Swiss lakes (in progress), or water vapor retrieval over complex terrain, using the digital elevation model [Schläpfer et al., 1997]). The geocoding issue therefore had to be addressed, resulting in the presented algorithm and application. The described georeferencing procedure is based on a parametric approach and theoretically allows sub-pixel accuracy even in steep terrain. A predecessor of the algorithm was developed by Meyer [Meyer et al., 1993 and Meyer, 1994].

To achieve accurate results, all auxiliary data have to be provided at highest accuracy possible. Since these requirements seem to be very hard to fulfill, a ground control point based procedure has been developed to recalibrate the offsets of the attitude angles as well as to reconstruct the flightpath. It was possible to geolocate AVIRIS data in mountainous terrain at accuracies of 1-2 pixels, using this GCP based PARGE algorithm (PARametric GEocoding).

2. THE PARGE ALGORITHM

2.1 Features

The described package supports the following features:

- consideration of the exact navigation data by line or by pixel
- exact correction of roll, pitch and true heading (no small angle approximations)
- consistent data structure for various airborne imaging instruments
- ground control point based algorithms for auxiliary data offsets estimation and flightpath reconstruction
- output to desired DEM geometry
- two implemented geocoding algorithms for different accuracy requirements:

1st: sub-pixel accuracy achieved by a DEM-oversampling algorithm (considering the cornerpoints of each pixel)
2nd: pixel accuracy using a pixel centre based triangulation algorithm

- nearest neighbor techniques after triangulation prevent data modifications
- fully IDL (Interactive Data Language, RSI Inc.) based and therefore portable application with window based user interface and on-line help system

2.2 Input Data

For an exact geometric rectification a variety of input data is required. Often some parts of this data are not known exactly and must be estimated or interpolated from external sources. This can occur even in generally well documented test sites, which were flown with high performance sensors. The three categories of input data are:

a) Navigation data, consisting of location (longitude, latitude, height) and engineering data (roll, pitch and true heading). This data should be resampled exactly per line or per pixel of the scanner image.

b) The Digital Elevation Model has to be in the same coordinate system as the airplane data. The resolution has to be based on the image nominal pixel size. The DEM initiates the final geometry of the geocoded image.

c) Image general information consists of exact information on FOV (field of view) and IFOV (instantaneous field of view), scanning frequency, starting time, coordinates of first nadir point, missing lines, and dimensions of the image.

2.3 Geometric Algorithm

The parametric processor starts with an estimate of the 'theoretic look angle vector' (L), oriented from a horizontal plane faced to direction north. This vector has to be turned in three dimensions to get the 'effective look angle vector' (L_t):

$$L_t = [R] \cdot [P] \cdot [H] \cdot L, \qquad (1)$$

where $[R]$, $[P]$ and $[H]$ are the coordinate transformation matrices for roll, pitch and true heading respectively. The calculation order is of interest, since matrix multiplications are not commutative. The order of equation (1) is based on the measurement order of the gyros. The sensor is virtually turned from a north looking flight to the actual position (see Denker [1996]).

The following steps are performed during the main processing algorithm:

- *Calculate the current observation geometry (see Figure 1):* The theoretic look angle vector (L) is calculated between the airplane position and a supposed 'flat' DEM, using the instruments FOV and the pixel position information. This vector is transformed to the effective look angle vector (L_t) afterwards using equation (1).

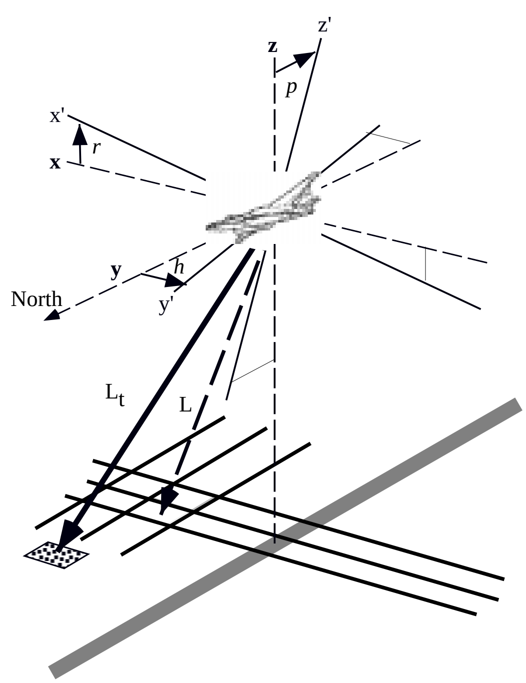

Figure 1: Transformation of the theoretical look angle vector L to the effective look angle vector L_t. *r, p* and *h* denote roll, pitch and true heading angles respectively [modified after Meyer, 1994].

- *Find the intersection point on the surface:* There are various possibilities to intersect a vector with an irregular plane (as the DEM is). Meyer [1994] used a minimizing procedure of the angle between L_t and a number of surrounding test vectors. The intersection procedure used in the PARGE algorithm calculates a height profile along the footprint of L_t and searches for a point of equal height on L_t.

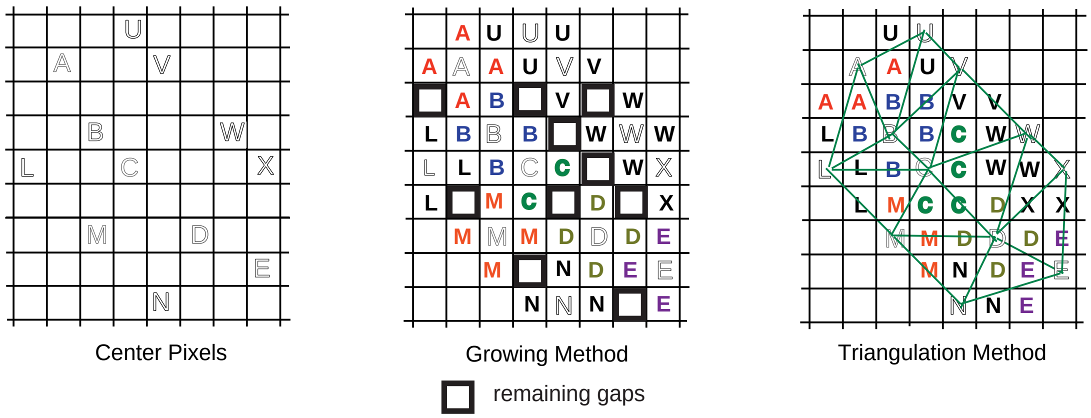

Figure 2: Gap filling methods for slightly oversampled output images. Residual gaps may occur with the fast growing method, whereas the triangulation method covers the area completely.

- *Map the image coordinates:* The image pixel and line coordinates are written to the intersection point position in the DEM geometry. The result of this procedure is a ‘remapping array’, consisting of the indices of the raw image coordinates, mapped on the DEM.

- *Gap filling:* In order not to lose too much information of the raw image, the resolution of the final DEM (and image) has to be taken slightly higher than of the original image data. It is not possible to avoid, that some of the image data will be repeatedly mapped, while that some other parts will be lost because of the aircraft motion. If the instabilities are relatively high, there will be a high number of pixels of the final image with no information from the scanner. These gaps have to be filled by image processing techniques in order to get an area dependent representation of the image data. Three methods to resolve this problem were tested:

i) The Oversampling Method was proposed by Meyer [1994] and uses a temporary DEM, with up to 16 times the original pixel number. At this high resolution, it is possible to calculate the position of all four corners of each pixel and to fill this area with the correct pixel position. Afterwards the DEM is resampled to final geometry using a modus filter procedure.

ii) The Growing Method (see Figure 2) is a simple technique, which expands each final pixel by a surrounding cross. If an adjacent pixel is already occupied, no replacing will occur. This technique is fast, and yields satisfying results, if no high accuracy is required and the DEM-pixels are about the size of the original image.

iii) Our favored procedure is the Triangulation Method. The center pixel locations are triangulated to remap the missing pixels, based on a gridding procedure (see Figure 2). It guarantees a true nearest neighbor technique while filling all occurring gaps between the center pixels. Another advantage of this method is its independence of final product resolution. The produced TIN (Triangular Irregular Network) can be used to achieve whatever image final resolution is required.

- *Final processing:* The result of the main processor is an array with the indices of the original image pixels on each mapped DEM pixel. This array can be applied as an index directly to the original image data to perform the final geocoding. This step is applied band by band, which makes the processing of a band sequential raw data cube very fast.

3. IMPLEMENTATION OF THE ALGORITHM

The algorithm was implemented based on the requirements for ‘real world’ hyperspectral sensors as AVIRIS or DAIS [Oertel, 1994]. It was a main goal, to create an interactively usable application with all main features between raw input data and image output. A consistent data format was created, containing image and DEM description as well as all sets of the auxiliary data. The format helps to reconstruct the processing steps and to store intermediate

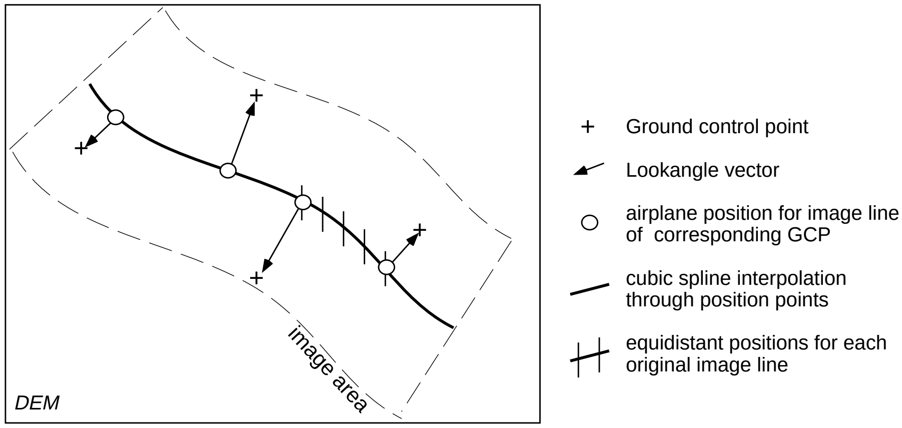

Figure 3: The ground control points based flightpath reconstruction procedure

status reports. Some minor viewing and analysis capabilities for the DEM and the image data were introduced too, but are not a key part of the package.

3.1 Ground Control Points Module

A ground control point (GCP) based offsets estimation tool was developed for the PARGE application. The inversion of the geocoding algorithm allows one to calculate the position of the airplane for each GCP. The differences of this estimated positions to the real navigation data are analyzed to obtain the offsets statistically. The auxiliary data offsets can be calculated for roll, pitch, heading, x-navigation, y-navigation, height and/or FOV. Each of these offsets potentially depend on each other. Thus, iterations may be done between them; e.g. the heading offset is iterated together with the pitch offset over sloped terrain.

The flightpath normally is provided with a data set. If none is available, a flightpath reconstruction procedure is applied based on a number of GCPs: The x-y position of the plane is determined for each GCP and an average flight height is derived from the statistics of additional GCPs. The position (and height) then is calculated using a cubic spline interpolation between the aircraft position points (see Figure 3). Errors may be introduced into this procedure if the height is not constant during the overflight and if the GCP accuracy is lower than the resolution of the resulting image. The procedure needs approximately one or two GCP for 100 image lines for flightpath calculation and another GCP for the offsets determination within the same area.

3.2 Processing Timeframe

The whole processing (work and computing) can take from a few hours up to a week per scene, depending on the quality of the auxiliary data available. A typical schedule for an image of 512 x 614 pixels may look as follows:

1. Get all data, including image, DEM, navigation data and airplane attitude data. Convert them to physical units (radian/meters) test all data by a quick preview (1h - 6h of work).
2. Check the flightpath and introduce a number (5-20) of ground control points. Eventually reconstruct the flightpath (1h - 8h of work).
3. Calculate or test the attitude values offsets, using your ground control points, exclude bad GCPs (2h - 4h of work).
4. Run the center pixel geocoding on a subset of the image and check the position on the DEM (15 - 30 min.).
5. Run the main geocoding processor on the whole image (30 min. - 2h runtime, depending on the computing speed).
6. Remap single bands and afterwards the whole cube (10 - 50 min. runtime).

Based on the above numbers, a fast processing would be possible within about 5 hours of work and 1-2 hours of runtime. This time increases proportionally with the required quality of the geocoding and the number of lines to be processed.

4. RESULTS.

4.1 Geocoding of AVIRIS ‘95 Data

The new algorithm was applied to AVIRIS 1995 data over complex terrain in Camarillo, California. (The results for a 1991 AVIRIS dataset, which were obtained with a predecessor of the algorithm were already described by Meyer et al. [1993].)

The internal navigation system of the airplane provided poor resolution at low absolute accuracy, since there was no differential GPS system mounted during the 1995 AVIRIS campaign. Therefore it was necessary to reconstruct the flightpath from the image data, using the described procedure. The roll angle was set to zero because AVIRIS roll compensation was switched on. These two restrictions lead to a lower accuracy of the geocoding than potentially possible.

The fast pixel centre based algorithm could be used for the required final USGS DEM resolution of 30m. The processing of the standard AVIRIS image (614x512 pixels) was performed within half an hour on a Sun SPARC 20 workstation. This time would increase by about a factor 4 if e.g. 15m end resolution would be chosen. The geocoded image is shown in Figure 4 in comparison with a DEM shadow view image.

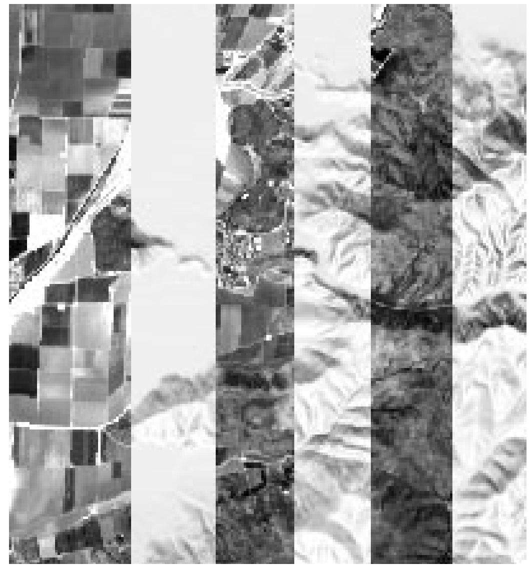

Figure 4: The geocoded AVIRIS image of Camarillo (CA) in comparison with the USGS DEM shadow view image.

4.2 Quality Assessment

The quality of geocoding results is difficult to quantify. Possible methods are:

- calculate the location residuals of ground control points, which were not used for the prior offsets or flight line calculation
- compare with the DEM along terrain lines or in specific mountainous areas (see Figure 4)
- overlay digital linegraphs (see Figure 5)
- correlation analysis with digital maps (if such are available)

For the described scene location residuals of 10-20m were found for independent GCPs. This difference is within the accuracy of GCP determination. Ridge lines of the mountains fit within one pixel shift (Figure 4) and the roads are located on the image within the same 1-2 pixel accuracy.

The quality of the procedure was found to be within the validity of the input data. The accuracy of the GCPs remains the main limitation as long as the flightpath has to be reconstructed, but also insufficient gyro calibration can cause problems for this kind of processing.

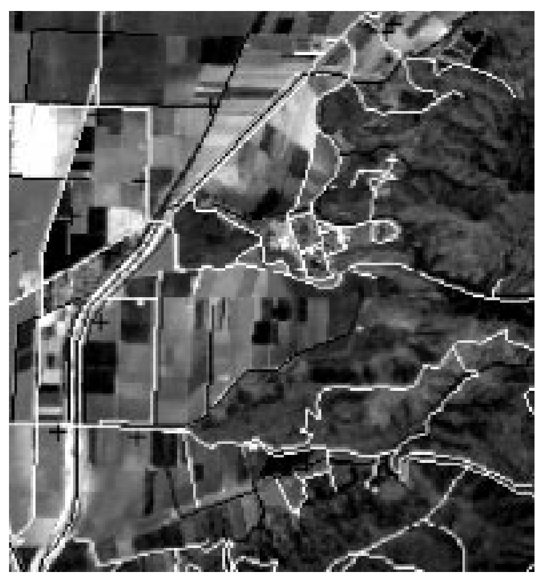

Figure 5: Comparison of a subset of the geocoded AVIRIS image with USGS digital linegraphs of roads (white) and water (black)

5. CONCLUSIONS

A new geocoding processor was implemented using a parametric approach. It allows to correct for attitude and flightpath dependent distortion even for unstable sensor platforms such as for low level airplanes. The algorithm is now in a test status for hyperspectral sensors. The final tests are to be performed in the winter 1997/1998, and the package is planned to be operational by spring 1998. Currently, the sensors DAIS and AVIRIS are supported, further airborne systems might be introduced later.

AVIRIS geocoding leads to satisfying results using USGS DEMs. Higher resolved DEMs could increase the accuracy of the geocoding at high spatial resolution. Further work could be done on accurate residual roll determination on roll compensated AVIRIS images. The accuracy of AVIRIS pitch and true heading calibration was not examined by the authors neither. Another main issue is the introduction of DGPS based flightpath determination for airborne scanners in general. The presented GCP flightpath determination only is a rough aid for missing or insufficient navigation data; the accuracy is significantly decreased compared to a geocoding with known exact flightpath. Nevertheless, the results are still better than those achieved with traditional georeferencing methods applied to images of unstable platforms, flown over rugged terrain.

The IDL based package will be made available to selected users for well defined purposes and to testing customers in a first release. It is not suited for fully operational use yet, since it still requires some expertise for accurate data preparation and processing decisions. After testing of the application our focus will be on a higher automatization level and faster processing time to obtain a real operational system. The latter might be achieved with upcoming faster computers. Another effort has to be done on quality assessment, to allow a calculation of the accuracy values for each geocoded image.

6. ACKNOWLEDGMENTS

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