REGISTRATION OF AIRBORNE SCANNER IMAGERY USING AKIMA LOCAL QUINTIC POLYNOMIAL INTERPOLATION*

RAFAEL WIEMKER

Universität Hamburg, II. Institut für Experimentalphysik
Mail: FB Informatik / KOGS, Vogt-Kölln-Str. 30, 22527 Hamburg, FRG
http://kogs-www.informatik.uni-hamburg.de/projects/censis/remotesens.html
E-mail: wiemker@informatik.uni-hamburg.de

ABSTRACT

Evaluation and analysis of most remotely sensed data requires careful image-to-image registration or ortho-rectification (geocoding). Photogrammetric practice has shown that polynomial transformation functions are useful for registration of aerial photographs. However, multi- and hyperspectral remotely sensed data are often recorded by airborne line scanners. Then ortho-rectification by conventional *global* coordinate transforms is not satisfactory, particularly due to the non-instantaneous image formation process. It is rather necessary to allow for *local* corrections of distortions.

We have implemented two interpolation techniques for the computation of the resampling coordinates, local AKIMA and HARDY multiquadric interpolation, and applied them to experimental image data. Comparison shows that resampling based on AKIMA interpolation is much faster than on HARDY multiquadric. Moreover, AKIMA interpolation in the limit corresponds to conventional second degree polynomial transformation. It is thus an appropriate instrument for local image registration utilizing ground control points.

1. INTRODUCTION

Image registration is essential for evaluation and analysis of remotely sensed data. For pure change detection purposes it can be sufficient to overlay various images of the same scene in order tp perform pixel-wise or segment-wise comparison. Most applications, however, demand an ortho-rectification where the imagery is not only rectified and corrected for flight path irregularities, terrain effects and sensor characteristics, but moreover is geocoded into map coordinates. Then the transformed imagery can be viewed and analyzed in the same reference system as that of a conventional map of the area.

Photogrammetry which deals with digitized photographic imagery can easily model the geometric image formation process. Photographs are taken with a short shutter time and a central perspective optics, and only one sensor position and attitude is needed for the mapping equations. When terrain effects are neglected, photographic aerial imagery is often geocoded using affine, bilinear and second degree polynomial transformation functions. A small number of ground control points (GCPs) is sufficient in order

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to determine the necessary number of coefficients; a higher number of GCPs can increase the registration accuracy.

In contrast, multispectral remotely sensed imagery is often recorded by line scanners which are mounted on airborne platforms. Thus the process of image formation is not instantaneous but depends on the flight path and the attitude of the instrument. Moreover, the mapping itself cannot be described by a lens camera imaging model. Therefore the ortho-rectification of scanner recorded images – especially aerial imagery from low flight altitudes with high spatial resolution – by conventional *global* coordinate transforms is not satisfactory. Ehlers (1994) has given illustrations that it is rather necessary to allow for *local* rectification, since flight position, altitude and velocity, as well as the aircraft's yaw, pitch and roll angles change during the recording.

A particular approach has been chosen by Zhang et al. (1994) for line scanner data. They use flight parameters which are logged during the image flight. In conjunction with a differential global positioning system (DGPS) the flight path can be reconstructed, so that sensor position and viewing angle are known for each recorded scan line. Then, with a given digital elevation model (DEM), one can geocode the imagery by determining the three dimensional map-coordinate position for each recorded pixel and place it accordingly in a resampled ortho-image. This approach (Zhang et al. 1994) can in principle do without any GCPs.

In digital image processing of remotely sensed data, however, we encounter a number of situations where the utilization of hand-set GCPs seems unevitable. This can occur

- When the imagery is taken from the archive and no flight parameter recordings are available.
- When several images are used for mosaic production and a forced fit is necessary in order to avoid spurious transition artifacts.
- When no digital elevation model is available for the given scene, or not to the required accuracy. In particular one might want to study man-made features which are recorded in high resolution imagery, but not represented in the DEM.
- When the operator demands more interactive control: the capability to manually add or delete GCPs for local corrections and pin-pointing certain features without changing the overall registration.

Hence local registration with GCPs, which can be set either by a human operator or by image processing modules, remains desirable. Corresponding GCPs are set within the original image (source image) recorded by the sensor as well as in a digitized map (target image). Instead of a map, the target image can of course also be another rectified sensor image or a photograph.

In order to provide a method of locally adaptive GCP registration, Ehlers (1994) suggested the application of an elastic registration method, namely the multiquadric interpolation of Hardy (1971). It has to be stressed that the multiquadric coordinate transformation function is still a single global one, but with rather locally governed behavior, due to radial weighting functions. Several radial weighting functions have been used, *e.g.* Ehlers (1994) used a distance function $u(r) = r$, and Bookstein (1989)'s thin plate spline interpolation uses $u(r) = r^2 \ln r$.

A global polynomial transformation determines a coordinate transformation function which maps the source GCPs as close as possible to the corresponding target GCPs while minimizing the sum of squared error. In contrast, elastic as well as local registration map the given GCPs exactly from source image to target image, whereas inter- respectively extrapolating the coordinates of all other pixel positions. In Ehlers (1994)'s two step approach, the elastic HARDY registration follows a preliminary conventional polynomial transformation.

2. BIVARIATE AKIMA INTERPOLATION

In this paper we investigate the use of a local interpolation for GCP image registration. We realized a one step registration for airborne scanner imagery which is fast compared with elastic methods and has several good-natured properties. We employ a well-known interpolation method introduced by Akima (1978) for bivariate interpolation of irregularly distributed points.

Our aim is to transform the coordinates (u, v) in the source image into the coordinates (x, y) of the target image. Using indirect resampling, we thus need transformation functions $u(x, y)$ and $v(x, y)$. This mapping $(x, y) \mapsto (u, v)$ can be established by *fitting* parameters of given functions (in particular bivariate polynomials in (x, y)) while minimizing the sum of squared deviation to the GCPs, or by *interpolating* between the GCPs. The transformation functions $u(x, y)$ and $v(x, y)$ are determined independently from each other.

In order to explain AKIMA's interpolation scheme, we substitute $u(x, y)$ and $v(x, y)$ for a bivariate surface function $z(x, y)$. The surface 'height' z is given at the locations of the GCPs, and shall be extra- and interpolated elsewhere. AKIMA first performs a triangulation of the given GCPs in the (x, y)-plane. The surface function $z(x, y)$ is considered as a collection of functions each valid within one triangle. Quintic polynomials in x and y are fitted locally within all triangles:

$$z(x, y) = \sum_{j=0}^{5} \sum_{k=0}^{5-j} q_{jk}\, x^j\, y^k \quad .$$

The 21 coefficients q_{jk} are determined by the following constraints:

- The bivariate function $z(x, y)$ and its first and second partial derivatives in x and y agree at all triangle vertices (GCPs).
- The partial derivative of the function differentiated in the direction perpendicular to each side of the triangle is a polynomial of degree three, at most, in the variable measured in the direction of the side of the triangle.

The AKIMA interpolation method has several desirable properties which let it appear suitable for image registration:

- The resulting interpolated surface $z(x, y)$ is continuous and smooth and does not exhibit erroneous undulations.
- The computation time of this piecewise method is much faster than for global elastic methods. It can thus be performed interactively by the operator.

- AKIMA's method will exactly inter- and extrapolate second degree polynomial bivariate functions. Hence, if the GCP coordinates in source and target image are related by affine, bilinear or second degree polynomial functions, the AKIMA based registration will give exact results and thus be in correspondence with conventionally used coordinate transformations.
- AKIMA *extra*polation is done with a polynomial of second degree in the distance from the polygon of GCPs and connects smoothly to the interpolated points within the polygon of GCPs.
- The transformation is invariant against rotation in the x-y-plane.
- The AKIMA method has no problems concerning computational stability or convergence.
- A local interpolation method may account better for the non instantaneous image formation process of a scanner than a global transformation method.

3. PANORAMA-RECTIFICATION AND RESAMPLING

The airborne DAEDALUS AADS 1268 sensor scans each line in $p_w = 716$ pixels, sweeping an angle from $\theta_{\min} = -43°$ to $\theta_{\max} = +43°$ in equal angular steps $\Delta\theta = 0.120112°$. The resulting panorama effect is corrected by conversion of the pixel coordinate p_u in the scan line into a ground normal coordinate u:

$$u = \tan\theta\ , \text{ where } \theta = 2\theta_{\max}\left[\frac{p_u}{p_w - 1} - \frac{1}{2}\right] \quad ,$$

while the other ground normal coordinate v is simply equal to the pixel coordinate $p_v = v$ along the flight track. The transformation is then computed with the source GCPs expressed in ground normal coordinates. When the resampling is performed and the gray value of a certain ground coordinate is required, this is retrieved after reconversion back into the original pixel coordinates.

We are using an indirect resampling technique, *i.e.* , for each pixel in the target image (map) the coordinate in the source image is determined from where the proper gray value is to be retrieved. As we deal here with multispectral imagery which is organized in spectral image layers, the transformation is computed only once, whereas the resampling is done for each spectral band. The coordinates in the source image are computed as float values. They are converted to integer addresses by a round-off, following a nearest neighbor resampling scheme. With multispectral imagery this method is preferable over interpolation, as the originally recorded spectra shall be preserved for later multispectral analysis. This may become prone to error by interpolation, and multispectral classification might be negatively effected (Richards 1993).

Several consecutive resampling steps (*e.g.* for panorama correction, prior polynomial transformation and final interpolation) are to be avoided, because it is costly, particularly for multispectral imagery, and prone to alias effects and loss of information. Therefore our resampling is organized as a one pass process, in that the computation of the resampling coordinates includes the line scanner panorama correction, and only after the resampling coordinates are determined, the actual resampling of the gray values takes place.

As pointed out above, the AKIMA interpolation implies a global second -degree polynomial transformation (thus including *e.g.* translation and rotation). In other words, a direct AKIMA registration yields just the same result as a prior polynomial transformation which is followed up by an AKIMA.

4. COMPARISON OF REGISTRATIONS ON EXPERIMENTAL IMAGERY

For comparison we have implemented three registration methods:
$\triangleright$ AKIMA's bivariate interpolation,
$\triangleright$ HARDY's multiquadric interpolation with a radial basis function of $u(r) = \sqrt{1 + r^2}$, and
$\triangleright$ second degree polynomial transformation.
All routines account for the scanner panorama effect, and were written in the PV-WAVE environment using mathematical library functions.

The registration methods were applied to image data recorded by a multispectral DAEDALUS AADS 1268 line scanner. The data were taken during a campaign in 1995 at a flight altitude of 1800 m over the city of Nürnberg, in cooperation with the German Aerospace Research Establishment (DLR). The line scanning was stabilized against aircraft rolling by a gyro subunit mounted on the sensor. Recording of the scene in Fig. 1 took 40 sec. Note in particular the distorted runway of the airport.

The image data was registrated with 91 GCPs to a digitized map of scale $1 : 25\,000$ (see Fig. 2). For this example of a 1400×1200 pixel target image, computation times on a Sun Sparc Station 20 were about one minute for global polynomial and AKIMA interpolation, and about one hour for HARDY multiquadric interpolation.

For comparison of the methods, the euclidean distance of the resampling coordinates (measured in pixels) is computed: $d(x, y) = \sqrt{(\Delta u)^2 + (\Delta v)^2}$, where Δu and Δv are the differences between two resampling coordinates for the position (x, y) in the target image using two different ways of transformation. Figs. 3 and 4 show displacement images where the euclidean distances between pixel resampling coordinates using AKIMA interpolation versus polynomial transformation and AKIMA's versus HARDY's interpolation are gray-value-coded. The GCPs are overplotted.

In this example, polynomial transformation does not suffice to registrate the imagery to the map. Note the different contours of the resampled area using global polynomials and AKIMA (Fig. 3). The displacement between both is not directly related to the position of the GCPs. The shifts occur in areas where the local corrections differ from the global fit.

Comparison of AKIMA's and HARDY's interpolation (Fig. 4) shows that – necessarily – the differences in the resampling coordinates vanish at the GCPs. Furthermore the differences are rather small in the *inter*polated area within the hull enclosing the given GCPs. The more significant differences occur only in the *extra*polated areas at some distance from the hull of the given GCPs. Note that the irregular contour of the HARDY registration is an erroneous result from extrapolating large resampling shift vectors between source and target image by pure elastic registration.

5. CONCLUSION

A number of situations requires geocoding using GCPs between raw image and digitized map. Global polynomial transformation is a reliable and widely used registration technique, but particularly airborne line scanner imagery may demand also local transformation in order to correct for flight path distortions, to account for missing DEM data or for forced fit mosaic production.

HARDY's elastic interpolation is not apt for large resampling shifts. It rather requires a prior polynomial transformation. In contrast to that, the AKIMA interpolation in the limit yields a perfect second degree polynomial transformation and is thus in very nice correspondence with the conventional transformation. It can thus be used as a one step transformation. Moreover, the computation time is more than one order of magnitude shorter for our example, with the gap widening with an increasing number of GCPs.

A common drawback of both methods certainly is that they do not account explicitly for the linewise scan characteristic of the sensor.

In summary, GCP image registration using AKIMA interpolation is a fast method and shows promising results where conventional global polynomial transformations in general do not suffice.

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direction of flight track →

Figure 1: The raw data (1000 $\times$ 716 pixels) as recorded by the line scanner during 40 sec from 1800 m altitude.

Figure 2: The geocoded image overlayed onto a map of scale $1:25\,000$, using AKIMA interpolation.

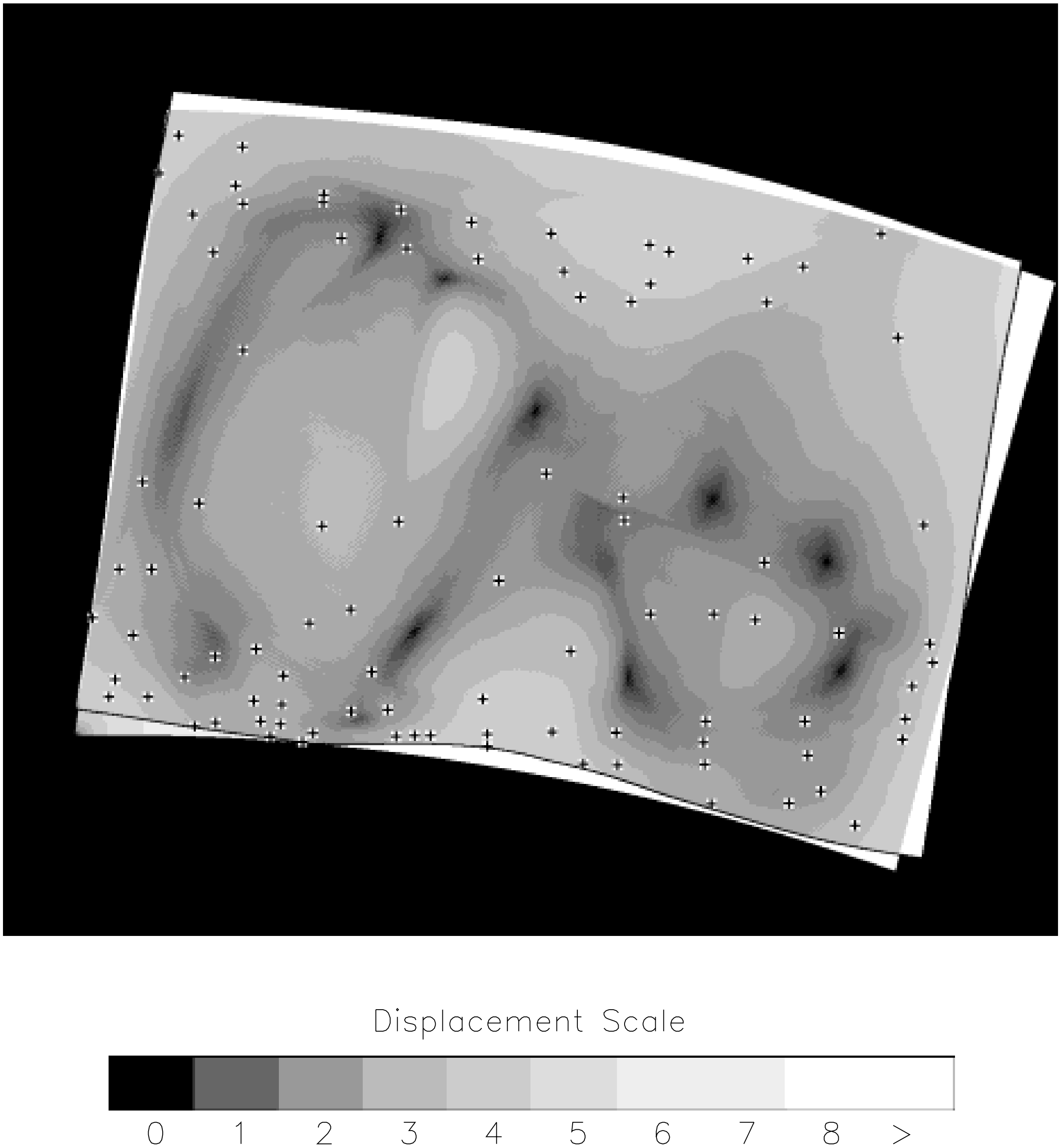

Figure 3: Displacement image between AKIMA interpolation and second degree polynomial transformation (black is vanishing, white is maximum euclidean distance in pixels).

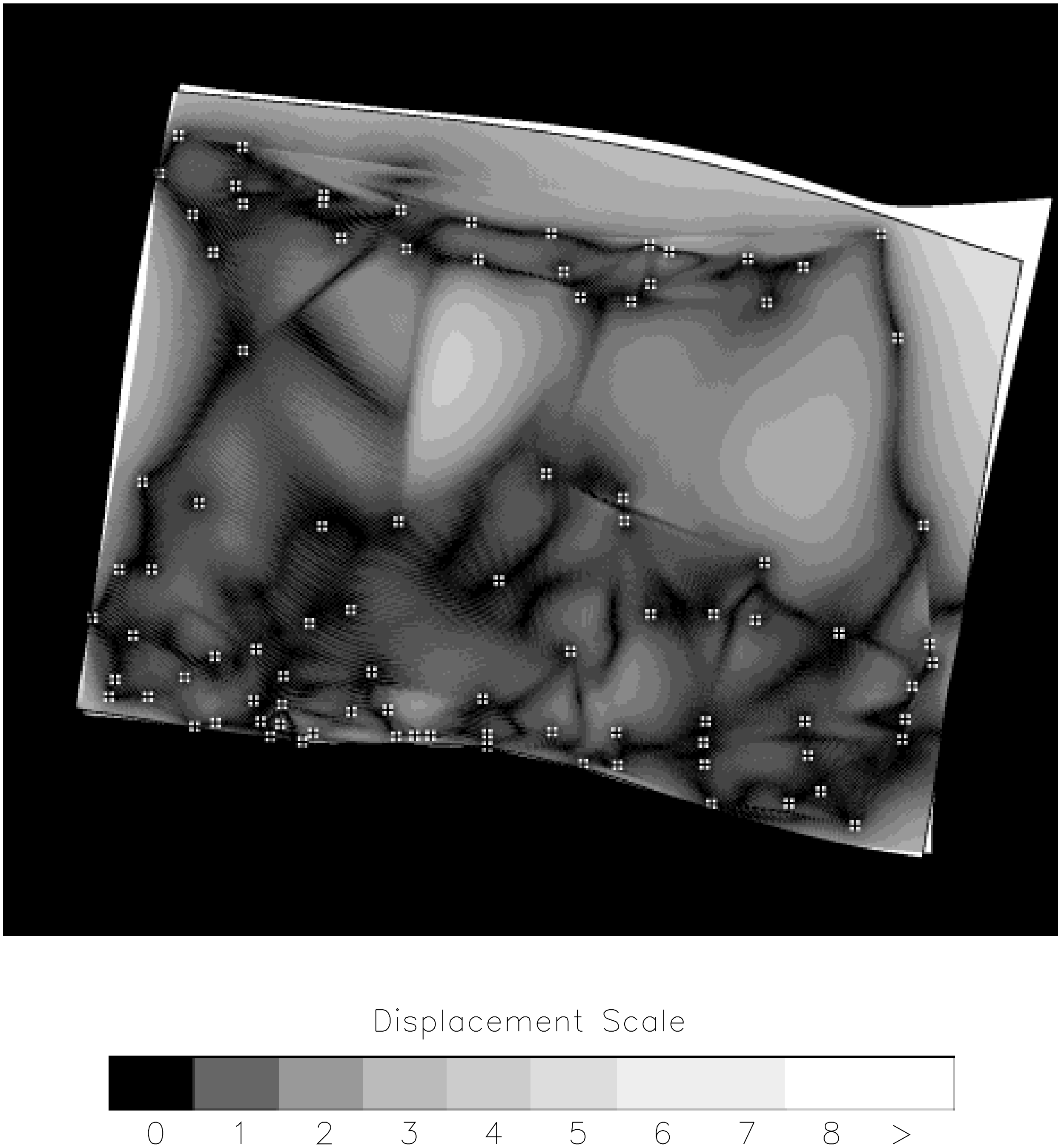

Figure 4: Displacement image between AKIMA interpolation and HARDY's multiquadric interpolation (black is vanishing, white is maximum euclidean distance in pixels).