AN IMPROVED METHOD FOR PRECISE AUTOMATIC CO-REGISTRATION OF MODERATE- AND HIGH-RESOLUTION SPACECRAFT IMAGERY

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ABSTRACT

Improvements to the automated co-registration and change detection software package, AFIDS (Automatic Fusion of Image Data System) has recently completed development for and validation by NGA/GIAT. The improvements involve the integration of the AFIDS ultra-fine gridding technique for horizontal displacement compensation with the recently evolved use of Rational Polynomial Functions/ Coefficients (RPFs/RPCs) for image raster pixel position to Latitude/Longitude indexing. Mapping and orthorectification (correction for elevation effects) of satellite imagery defies exact projective solutions because the data are not obtained from a single point (like a camera), but as a continuous process from the orbital path. Standard image processing techniques can apply approximate solutions, but advances in the state-of-the-art had to be made for precision change-detection and time-series applications where relief offsets become a controlling factor. The earlier AFIDS procedure required the availability of a camera model and knowledge of the satellite platform ephemeredes. The recent design advances connect the spacecraft sensor Rational Polynomial Function, a deductively developed model, with the AFIDS ultrafine grid, an inductively developed representation of the relationship raster pixel position to latitude /longitude. As a result, RPCs can be updated by AFIDS, a situation often necessary due to the accuracy limits of spacecraft navigation systems. An example of precision change detection will be presented from *Quickbird*.

BACKGROUND

Improvements to the automated co-registration and change detection software package, AFIDS (Automatic Fusion of Image Data System) has recently completed development for and validation by National Geospatial-Intelligence Agency / Geospatial Intelligence Advancement Testbed (NGA/GIAT). The improvements involve the integration of the AFIDS ultra-fine gridding technique for horizontal displacement compensation with the recently evolved use of Rational Polynomial Functions/ Coefficients (RPFs/RPCs) for image raster pixel position to Latitude/Longitude indexing. The earlier AFIDS procedure required the availability of a camera model and knowledge of the satellite platform ephemeredes. The recent design advances connect the spacecraft sensor Rational Polynomial Function, a deductively developed model, with the AFIDS ultrafine grid, an inductively developed representation of the relationship raster pixel position to latitude /longitude. As a result, RPCs can be updated by AFIDS, a situation often necessary due to the accuracy limits of spacecraft navigation systems.

OVERVIEW

The AFIDS software package provides an automated process for co-registering selected satellite images from a multi-date satellite dataset having overlapping coverage of the same region. The images should not contain massive differences such as cloud, seasonal, or time-displacement variations, but, otherwise, the assumptions are non-restrictive. For example, human selection of tiepoints is *not* required, and each image is resampled only once. Mapping and orthorectification (correction for elevation effects) of satellite imagery defies an exact projective solution because the data are not obtained from a single viewpoint (as with a framing camera), but as a continuous process along the orbital path. The basic technique we use first involves correlation and warping of raw satellite data points to the USGS Digital Orthophoto Quads (DOQ) or Controlled Image Base (CIB) (1 or 5m) databases to give an approximate mapping. The Rational Polynomial Coefficients (RPCs) associated with an image provide the initial mapping from pixel coordinates to georeferenced coordinates. Digital elevation models (DEMs) are then used to correct perspective shifts due to height and view-angle.

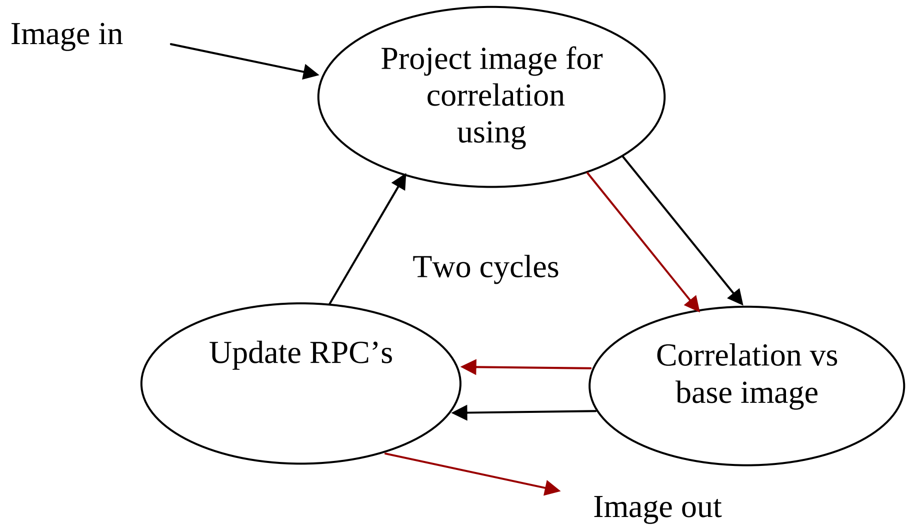

Figure 1. Use of RPC's for image registration. Two cycles are made first following the black arrows for one full cycle, then following the red arrows. The incoming image is projected to the coordinate system of the base (reference) image. Local correlations are performed to identify registration errors. These errors are then used to update the RPC's. Using the new intermediate RPC's, the process is repeated again leading to a set of final RPC's.

Ultra-Fine Grids

The registration process requires several sequential steps, each of which conceptually warps the dataset and involves resampling pixel values. However, to avoid degradation from multiple resampling, we represent each warp by an *ultra-fine grid* of tiepoints. When successive warps are required, the grids are composed mathematically into a single grid such that only one re-sampling occurs. Ultra-fine grids can currently be up to 2000 x 2000, or four million points.

The VICAR system has always used grids to specify warps and has had programs that performed the warp of an image using a grid. However, the grid was limited to about 30 x 30. Unfortunately, this size of grid does not allow for a very accurate warp unless the warp is particularly smooth. Using differential geometry, one can show that the error between grid points is approximated by the difference between a secant and an arc of a circle. The maximum of this difference decreases four-fold as the secant is halved. Thus, an ultra-fine grid of 1000 x 1000 will decrease this secant error by a factor greater than 1000 compared to an ordinary 32 x 32 grid. To achieve the full benefits, all relevant programs in the processing chain must produce and/or use ultra-fine grids. The relevant programs are:

1. The warping program.
2. The elevation correction program.
3. The 2-D FFT image correlation program.

In addition, another program is necessary to convert non-grids into ultra-fine grid format. For example, the output from correlation is rarely a grid, since bland areas may not correlate well resulting in gaps. This program needs at least two modalities for converting non-grids to grids: (a) polynomial fits and (b) piece-wise linear fits.

The final key to the ultra-fine grid approach is a program that can compose two initial ultra-fine grids into a single ultra-fine grid. Repeated applications of this program can then compose all of the image processing steps, each of which has its own grid, into a single grid. The *Composed Gridding* approach avoids problems that arise in the classical image processing techniques of piecewise transformation or polynomial-based geometric correction algorithms, which are known to introduce horizontal position errors in even the flattest terrain. The Composed Gridding approach also does not reduce digital elevation models to triangular irregular networks (TINs) commonly used in digital photogrammetry to lower ray-tracing computation. Rather, it employs a new algorithm for image-to-image tiepoint generation that can efficiently accept up to four million points, or a 2000x2000 matrix. The procedure allows multiple steps to be performed by a toolbox of routines, each outputting an ultra-fine grid. The grids from the steps are mathematically combined into a composed ultra-fine grid. While every sensor is a unique case, the toolkit of routines can address each type of systematic and erratic component associated with horizontal adjustments. Since the grids are floating point numbers, they do not contribute to a resampling type error as the composition process takes place. However, care must be taken so that the earlier transformations do not introduce errors that cannot be removed by later transformations.

Processing Steps Using Ultrafine Grids

The processing becomes a cycle or iteration through the steps that are necessary to produce the final image. For example, image correlation might be a third step. The first two steps are performed, the first two resulting ultra-fine grids are composed, and the resulting grid is used to warp the input into a partially corrected output. This output then becomes an input into correlation. The output from correlation is turned into a new ultra-fine grid, which can be used with the previous two ultra-fine grids to produce a third stage partially corrected output. The last cycle of this cyclic process produces the final output. Some stages might not need the actual image, for example, the elevation correction works on the grid only.

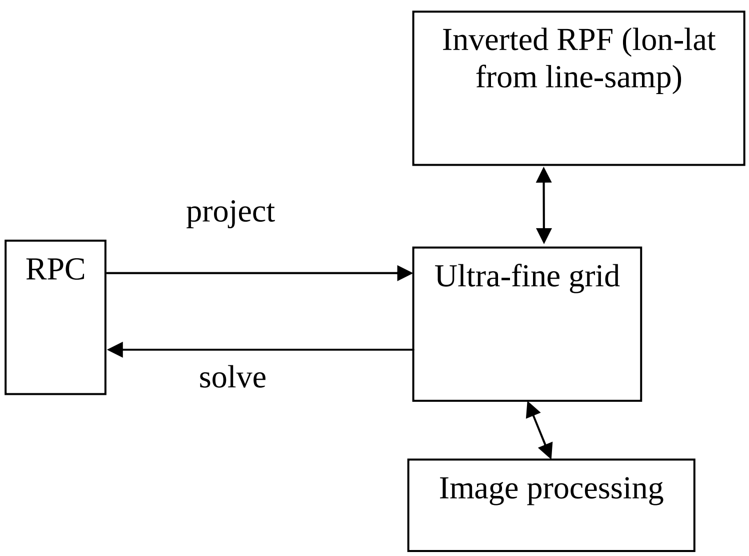

Figure 2. Use of ultra-fine grids with RPC’s.

Image Registration Steps

Below is a checklist of the steps involved in image registration.

1. √ **Select two (or more) multi-date satellite images** (of the same sensor type). Choose one image/date to be the "Master," to which the "Secondary" image(s) will be co-registered. Output image products can be generated in UTM or Platte Carree map projections, or matched to an external GeoTIFF’s projection.

2. √ **AOI - Gather Lat/Long coordinates describing your image Area of Interest**. Compare the satellite image with a map (or use a commercial image display program) to obtain Latitude and Longitude coordinates completely surrounding your imagery's geographic area. Also note your particular subarea AOI coordinates (if different from the whole image). You will need to expand the whole-image coordinates for specifying the DEM, and DOQ/CIB mosaic dimensions.
3. √ **DOQ/CIB - Obtain Orthorectified DOQ/CIB compressed image data that completely covers your image`s geographic area**. AFIDS requires either a Landsat or DOQ/CIB "image base" to impart map projection characteristics during the co-registration process.
4.√ **DEM - Obtain Digital Elevation Model (DEM) completely covering the image area.** DEM data is used to correct for topographic relief displacement during the co-registration process. If an image's geographic area crosses a DEM boundary, the data from both files will be needed. Both USGS DEMS and DTED Level 1 and Level 2 are supported. Up to 30 DEM cells can be mosaicked at a time.

Registration Example

Figure 3 shows registration of a *QuickBird* image of Iraq with CIB-5**.** Note the curvature along the left edge of the cyan image. This curvature is due to a steep bluff along the lower edge of the river. In Figure 4 one can "see" the river bluff from the projection of the RPC's to an ultra-fine grid. Figure 5 shows the inverted ultra-fine grid that is used to resample the *QuickBird* image.

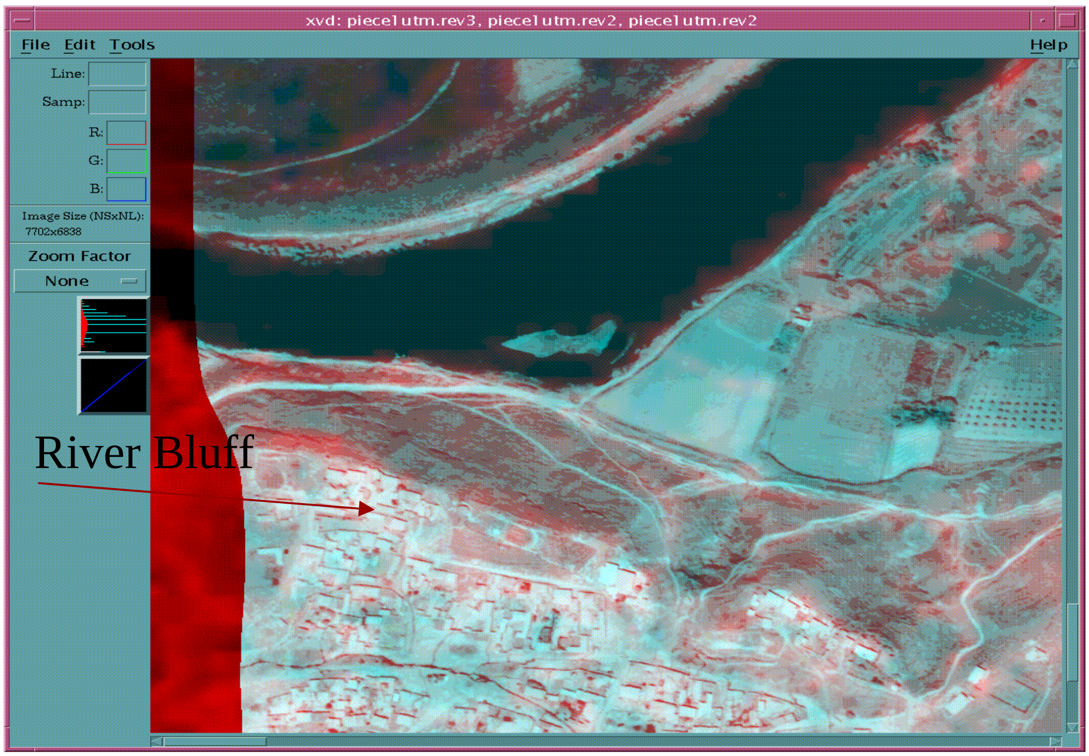

Figure 3. Registration of portion of *QuickBird* image with CIB-5.

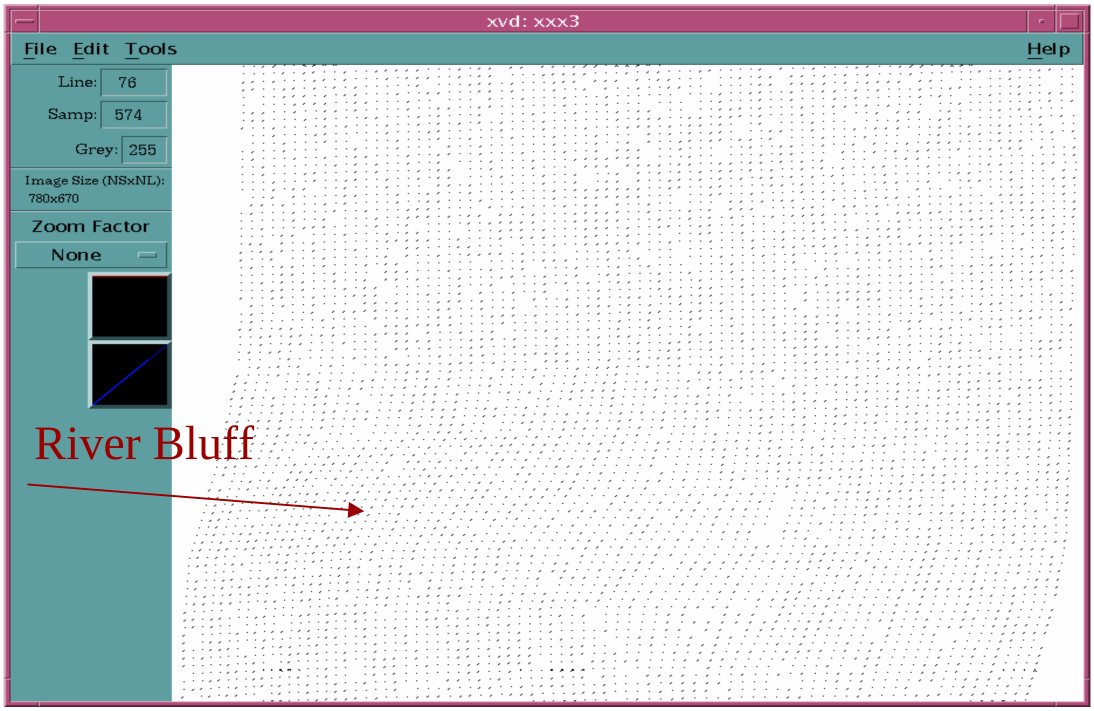

Figure 4. Projection of RPC to ultra-fine grid for portion of *QuickBird* image.

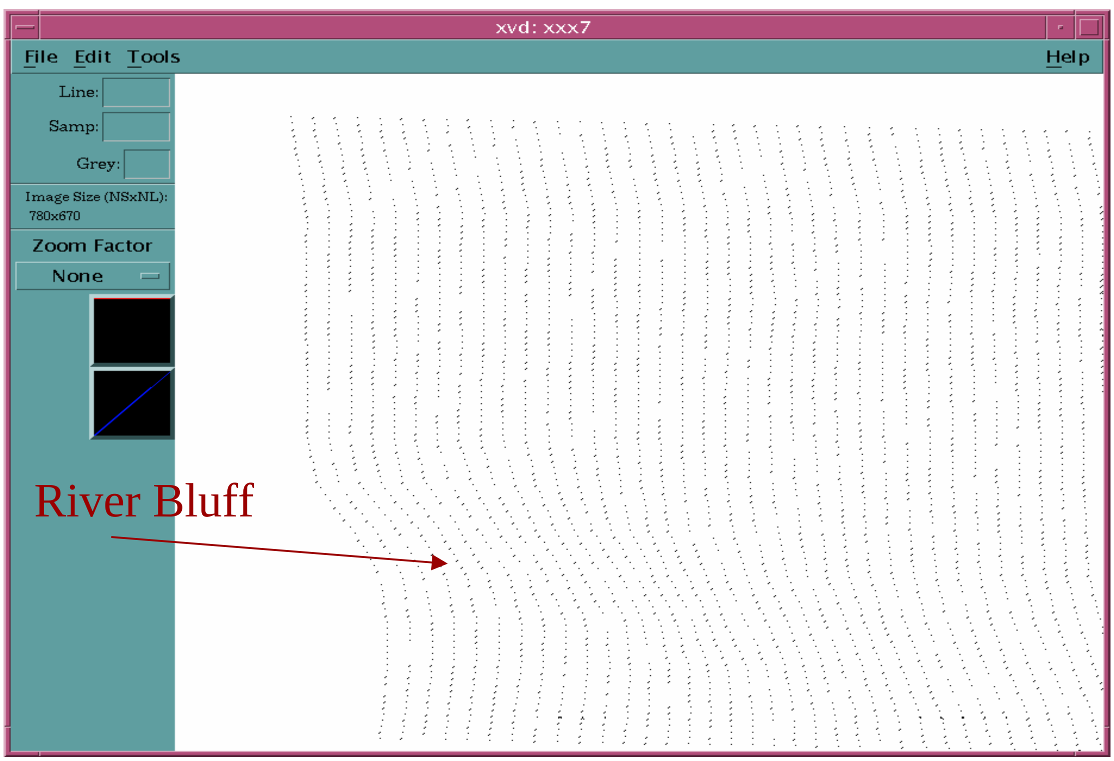

Figure 5. Inverted ultra-fine grid for portion of *QuickBird* image

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