Automated HRSI georegistration using orthoimage and SRTM: Focusing KOMPSAT-2 imagery

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Conventional manual georegistration has been labor-intensive and time-consuming to process globally acquired high-resolution satellite imagery (HRSI) including the Korea Multi-Purpose Satellite-2 (KOMPSAT-2). While an image-to-image matching-based method can provide an automated procedure, geometric and pixel value differences such as the apparent leaning of the terrain limits an accurate georegistration. This study utilizes the projection of orthoimages into the HRSI space using external elevation data to reduce the geometric difference, and an edge matching is applied to overcome the pixel value differences. Either rigorous or replacement sensor modeling is then carried out for georegistration with robust outlier removal. An experiment for a KOMPSAT-2 strip using Digital Orthophoto Quadrangles and the Shuttle Radar Topography Mission improved the horizontal positional accuracy from 70 to only a few meters for the test data set.

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1. Introduction

High-resolution satellite imagery (HRSI) has been a primary data source in base maps for wide-spread geospatial and location information, such as in Google Maps and 3D geospatial information acquisition. As many countries have made an effort to operate high-performance satellites (Stoney, 2008), the Korea Multi-Purpose Satellite-2 (KOMPSAT-2) has been operating to collect 1-m resolution images with a 15 km swath width from a pushbroom sensor-based camera (Seo et al., 2008).

An important KOMPSAT-2 processing is precise georegistration, which conventionally requires well-distributed ground control points (GCPs) over the image. KOMPSAT-2 level 1R data includes ephemeris data providing the satellite position, velocity, and attitude angles for direct georegistration as well as rational polynomial coefficients (RPC) for a replacement sensor model. Note that most other HRSI are provided with RPC, e.g., IKONOS, GeoEye, Quickbird, WorldView, OrbView, Cartosat. Without any GCPs, the horizontal positional accuracy of KOMPSAT-2 imagery is about 80 m (90%) after processing the precise orbit and attitude (Seo et al., 2008), which is definitely not accurate enough for large-scale applications. GCP acquisition is usually made through GPS survey, but is also time consuming and labor intensive. Moreover, such a survey is not feasible in remote and inaccessible areas. This GCP requirement leads to inefficiency, and makes the process a critical path in the geospatial information production.

Therefore, it is desirable to increase the georegistration efficiency by reducing the number of required GCPs in the adjustment (Rottensteiner et al., 2009) and by utilizing automated GCP acquisition from a reference image such as an orthoimage and others (Wong and Clausi, 2007; Yu et al., 2008; Rottensteiner et al., 2009; Oh et al., 2011). Note that many countries have made the effort to build national geospatial image data. Well-known examples are Digital Orthophoto Quadrangles (DOQ) and the Shuttle Radar Topography Mission (SRTM). A DOQ is a geometrically corrected aerial image, due to terrain relief and camera viewing angles, produced by the U.S. Geological Survey (USGS). A DOQ covers 3.75 × 3.75 or 7.5 × 7.5 min, with a one-meter spatial resolution, and its accuracy meets the National Map Accuracy Standards at a 1:12,000 scale for 3.75 min quadrangles (6 m at 90% of points). For details, refer to the USGS fact sheet (USGS, 2001). SRTM is near-global elevation data that was generated by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA) in 2000. The absolute height error of SRTM at 90% confidence level is 9 m for North America when compared to kinematic GPS (Rodriguez et al., 2005). The accuracy does not seem high enough
for an accurate georegistration of high-resolution satellite imagery, but free SRTM should be cost-effective and useful external elevation data because of its near-global coverage.

Conventional methods matching a 2D image to another 2D image focusing on medium resolution geospatial imagery have a limitation for high resolution satellite images requiring accurate 3D ground controls. Therefore, this study proposes a different approach to overcome this limitation. First, this approach performs image-projection of orthoimages into the KOMPSAT-2 image space using external ground elevation data, so that each pixel of the projected orthoimage is coordinated with the KOMPSAT-2 image space. The image projection minimizes the effect from these geometric differences such as relief displacement in KOMPSAT-2 image space, not in orthoimages. Since ephemeris data or RPC is used for the projection, the resulted projected orthoimage represents inaccuracy of the data in the KOMPSAT-2 image space.

The basic idea of the second step is that finding the correct image location by matching the projected orthoimage to KOMPSAT-2 image can determine the georegistration error over the entire KOMPSAT-2 image. For this, a simple but robust approach to overcome this limitation. First, this approach performs image-projection of orthoimages into the KOMPSAT-2 image space using external ground elevation data, so that each pixel of the projected orthoimage is coordinated with the KOMPSAT-2 image space. The image projection minimizes the effect from these geometric differences such as relief displacement in KOMPSAT-2 image space, not in orthoimages. Since ephemeris data or RPC is used for the projection, the resulted projected orthoimage represents inaccuracy of the data in the KOMPSAT-2 image space.

The proposed matching scheme produces a number of GCPs over KOMPSAT-2 imagery and enables a final adjustment for georegistration. In the georegistration step, well-known RPC correction (Fraser and Hanley, 2005) or rigorous sensor modeling (Kratky, 1989; Rottensteiner et al., 2009) can be performed depending on the ancillary data availability. A KOMPSAT-2 image strip is usually delivered after being subset into a regular sized scene (15,500 × 15,000 pixels), and each includes its ephemeris data and RPC for georegistration. Experiments were carried out for a long strip of KOMPSAT-2 imagery corresponding to 13 regular scenes. DOQ and SRTM were taken as reference data. Following DOQ image projection into the KOMPSAT-2 domain, the projected DOQ (representing inaccuracy in ancillary data) were matched to seven KOMPSAT-2 scenes for GCP. Three strategies were tested for georegistration: RPC correction per scene, rigorous modeling per scene, rigorous modeling for the whole image strip.

This paper is structured as follows: in Section 2, the proposed method is explained assuming that DOQ and SRTM are used. Experimental results for a long KOMPSAT-2 image strip are presented in Section 3. Finally, a summary and some concluding remarks follow in Section 4.

2. Automated georegistration

2.1. KOMPSAT-2 rigorous pushbroom sensor model

KOMPSAT-2 is modeled using the collinearity equation for the generic pushbroom model (KARI, 2008), expressed as Eq. (1), which is in a non-linear form of projection from a given ground point in an earth centered earth fixed (ECEF) coordinate frame to a point in the sensor coordinate frame. Note that KOMPSAT-2 level 1R data include epimetric data and the exterior orientation parameters (EOPs) can be computed through interpolation given an instant time. For more detail and a figure of sensor coordinate frames, refer to KARI (2008).

\[
\begin{bmatrix}
X \\
y \\
z
\end{bmatrix} = M_{\text{Body}} \cdot k_{\text{Sensor}} \cdot M_{\text{Body}} \cdot M_{\text{ECEF}} \cdot \begin{bmatrix}
X - X_1 \\
y - Y_1 \\
z - Z_1
\end{bmatrix}
\]

(1)

where \(x, y, z\) are the coordinates in the sensor coordinate frame (\(y\) is the flight direction, and \(z\) is direction to the surface of the earth), \([X Y Z]^T\) is the ground point in the ECEF coordinate frame, \([X_1 Y_1 Z_1]^T\) is the satellite position in the ECEF coordinate frame, \(M_{\text{ECEF}}\) is the time-dependent rotation matrix from the ECEF coordinate frame to the orbit coordinate frame, \(M_{\text{Body}}\) is the time-dependent rotation matrix from the orbit coordinate frame to the body coordinate frame, \(M_{\text{Sensor}}\) is the rotation matrix from the body coordinate frame to the sensor coordinate frame, and \(k\) is the scale factor.

When ground control information is available, georegistration is carried out by correcting the bias and drift in the ephemeris. Since the trajectory of a spaceborne is smooth and there is a high correlation between the position and attitude angles, the correction can be made by estimating the bias and drift in attitude angles as in Eq. (2) (Kratky, 1989). To this end, the collinearity equation, Eq.(1), is linearized with respect to the attitude correction terms, \(d\phi_0, d\phi_1, d\phi_2, d\kappa_0, d\kappa_1, \) to form the Gauss Markov model, and the model is solved using the least square.

\[
\begin{align*}
\omega & = \omega^{\text{eph}} + d\phi_0 + d\phi_1 + L \\
\phi & = \phi^{\text{eph}} + d\phi_0 + d\phi_1 + L \\
k & = k^{\text{eph}} + d\kappa_0 + d\kappa_1 + L \\
\end{align*}
\]

(2)

where \(\omega, \phi, \) and \(k\) are the roll, pitch, and yaw angle, respectively; superscript ‘eph’ means the ephemeris data; and \(L\) is the image line number.

2.2. Replacement sensor model

The rational function model (RFM) is the most popular replacement sensor model, which is also in a non-linear form with 80 unknowns (or 78 unknowns) used to compute an image coordinate, \((s, l)^T\), from a given ground coordinate, \((x, y, z)^T\). It is known that there is little difference in the projection accuracy between the RFM and the rigorous model for a given elevation range (Grodecki, 2001). An RPC correction is made when the RPC is erroneous. In this case, the georegistration is rather simple, because the georegistration problem is simplified into a two-dimensional image domain. The well-known affine model can be used as in Eq. (3) for RPC correction (Fraser and Hanley, 2005).

\[
s' = a_1 + a_2 s + a_3 l, \quad l = b_1 + b_2 s + b_3 l
\]

(3)

where \(s, l\) are the input image coordinates of the conjugate points (sample and line), and \(s', l'\) are the georegistered coordinates of the conjugate points.

2.3. Automated ground control extraction from DOQ and SRTM

The proposed automated ground control extraction from DOQ and SRTM is depicted in Fig. 1. The method begins with the projection of DOQ pixel values into the KOMPSAT-2 domain using SRTM elevation based on the provided RPC or ephemeris data, which are often erroneous and should be corrected. One reason of the DOQ projection is that it reduces the scale difference between the orthoimage and KOMPSAT-2 image. Though the same spatial resolution data, i.e., DOQ and KOMPSAT-2, are used for the experiment in this paper, this approach is useful when orthoimages of different spatial resolution are utilized. Another reason is that the projection reduces geometric difference due to terrain relief displacement. Note that DOQ is relief-corrected but KOMPSAT-2 is not, thus the geometric difference will be prominent for high terrain relief areas. The projected DOQ image will have better similarity to KOMPSAT-2.

Note that a DOQ image only has horizontal ground coordinates with pixel values. With the help of SRTM providing height