Simultaneous Relative Geometric Orientation and Pseudo DEM Generation from Uncorrected Satellite Images

Ban S. and Kim T. *
Department of Geoinformatic Engineering, Inha University, Republic of Korea
*tezid@inha.ac.kr

1. Introduction

Recently, satellite images have become a vast source of big data for various applications, including urban planning, land monitoring and change detection. Uncorrected satellite images, either geometrically and orthometrically, present difficulties in utilization due to positional errors and relief displacements. To correct satellite images, ground control points(GCPs) and terrain model such as digital elevation model(DEM) are required (Son *et al*, 2021). However, obtaining high-precision GCPs is typically challenging in the practical utilization of satellite images due to time constraints (Cabo *et al*, 2021). Therefore, it is crucial to develop techniques that can quickly resolve positional errors between satellite images and extract three-dimensional spatial information without any external data sources. Although a DEM is crucial for generating orthorectified images, accurate and up-to-date DEMs are often unavailable. In this study, we propose a method of simultaneously estimating relative geometric orientation from uncorrected satellite images and generating a pseudo DEM by extracting three-dimensional spatial coordinates of dense tie points. For experiments, we used 29 KOMPSAT-3/3A satellite images of the Seoul in South Korea. To verify the proposed method, bundle adjustment was performed on all 29 satellite images. Additionally, orthorectified result images was created from the generated pseudo DEM.

2. Proposed Methods

The satellite image relative orientation estimation and pseudo DEM generation proposed in this study proceed in the following order: tie point extraction, relative geometric orientation and ground coordinates estimation through bundle adjustment, re-estimation of all tie point ground coordinates, pseudo DEM generation through ground coordinates interpolation, and finally, generation of orthorectified result images. In this study, ground control points are not used, and they are replaced by tie points between input satellite images. For tie point extraction, we use the SIFT (Scale-Invariant Feature Transform) algorithm. The SIFT algorithm is well-suited for satellite images that require a substantial number of feature points. The extracted tie points can establish observation equations between ground coordinates and image coordinates through the RPCs (Rational Polynomial Coefficients) associated with each image. To estimate the relative geometric orientation and ground coordinates, the residuals of the observation equation must be minimized. To achieve this, we apply the concept of bundle adjustment method for handling multiple satellite images (Grodecki and Dial, 2003). In cases where highly accurate GCPs are available, the estimated parameters can be constrained to geometric orientation. However, since this study uses only tie points, the estimated parameters are expanded beyond the orientation to include ground coordinates. We apply an affine correction model for the relative geometric orientation estimation of each image. Accordingly, estimated parameters through bundle adjustment include six correction model parameters per image and the ground coordinates (longitude, latitude and height) for each tie point. We recursively re-estimate the weights of the observations using the residual covariance matrix of the observation equations, ensuring a more precise adjustment (Ban and Kim, 2024). After bundle adjustment, the correction model is applied to re-estimate the ground coordinates of tie points through forward intersection. Subsequently, interpolation is applied to the estimated ground coordinates to generate a pseudo DEM for orthorectification. Finally, the relative geometric orientation is represented by the RPCs and the correction model. The pseudo DEM is then combined with there to assist in orthorectification process, and image resampling method is used to generate the orthorectified result images.

3. Test Result

For experiment, we used 29 KOMPSAT-3/3A (Korea Multi-Purpose Satellite 3/3A) images of Seoul, South Korea, taken between 2014 and 2019. The satellite images used in the experiment were at processing level 1R, where only radiometric and sensor correction were applied without geometric correction and orthorectification. The initial ground coordinates of tie points were assigned as average values through the initial RPCs, and the positional error was calculated as reprojection error when estimated ground coordinates were projected back onto the image. The calculated initial relative positional error between the satellite images was 18.63 pixels. A total of 230,000 tie points were extracted from the 29 images. Due to the rapid increase in computational load with larger number of images and tie points, approximately 500 tie points per image were selectively chosen based on their distribution. Finally, a total 13.500 tie points were then used for bundle adjustment. As a result of the bundle adjustment, the high reprojection error of 18.63 pixels was significantly reduced to 1.45 pixels. Figure 1 shows image overlapping result before and after applying the proposed method to the 29 satellite images. As shown in Figure 1, the overlap of uncorrected satellite images exhibits significant positional errors, making the result appear blurry .

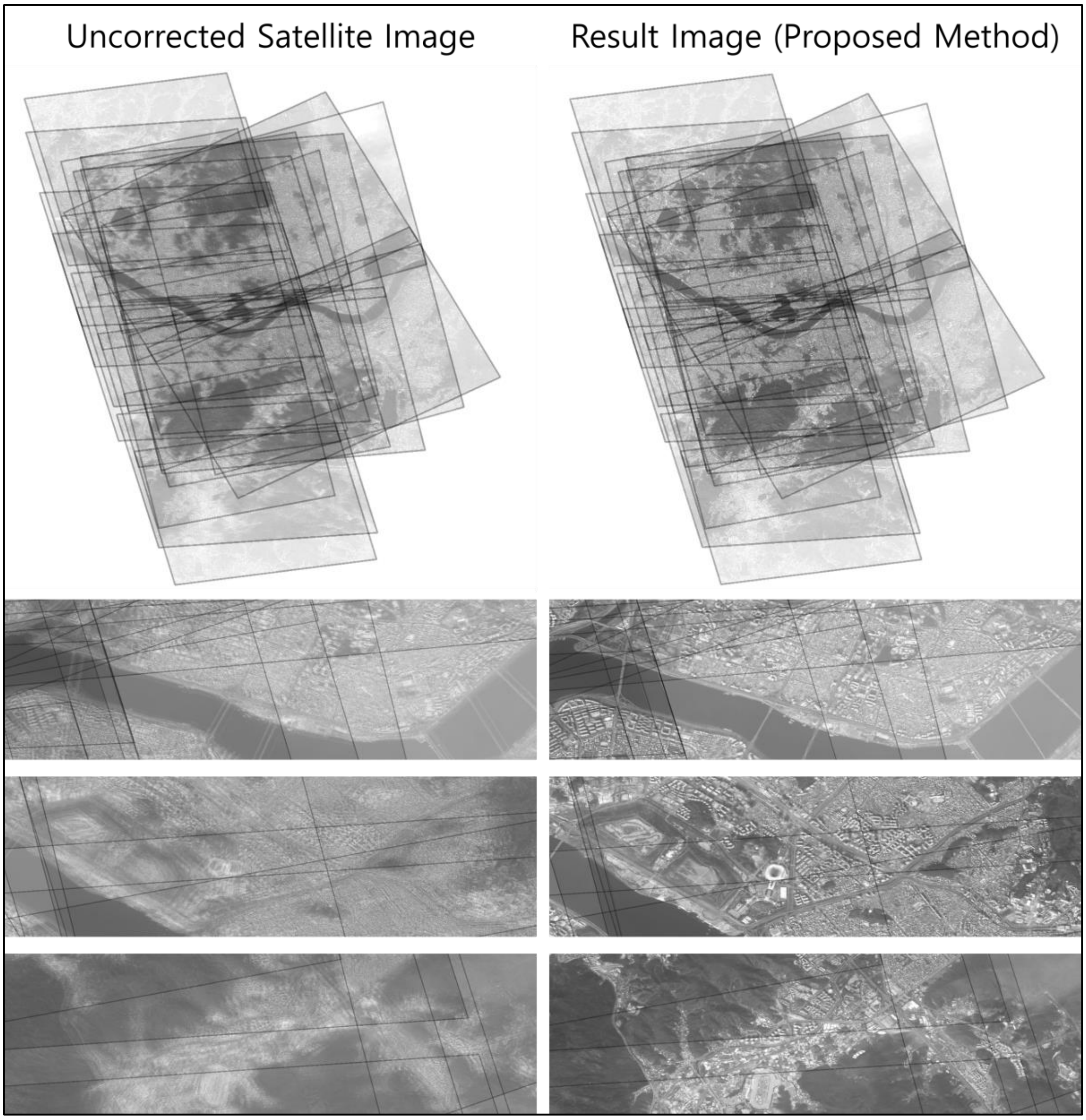

Figure 1: Satellite images overlap result (left : uncorrected, right : proposed method).

The result images overlap result shows that the blurriness caused by positional errors had been effectively resolved. Figure 2 is 3D map that overlays the pseudo DEM, generated by applying interpolation to the estimated ground coordinates, with result images. The map shows that areas with high elevation, such as mountains and buildings, exhibits higher elevation values compared to the surrounding areas.

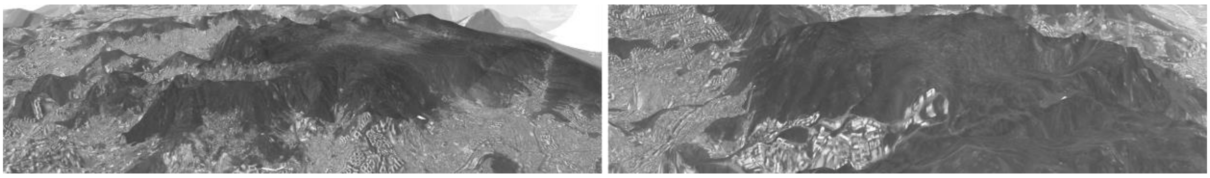

Figure 2: 3D view of result image with pseudo DEM.

Figure 3 shows the reprojection error of the ground coordinates of the tie points, confirming that the model was stably estimated with an error of less than 2 pixels for all extracted tie points.

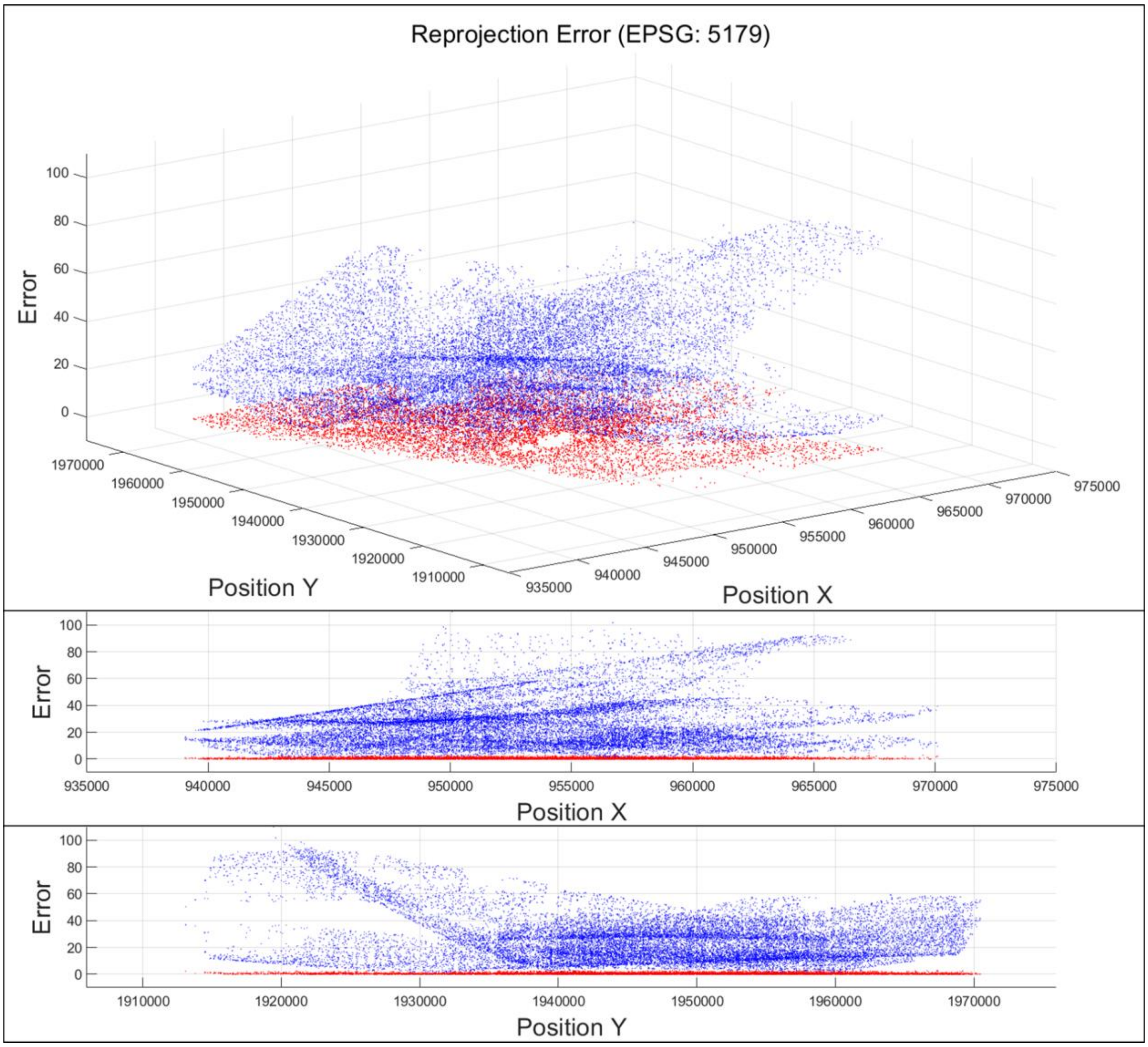

Figure 3: Reprojection error (blue dots : initial, red dots : result).

4. Conclusion

This study proposes method for estimating relative geometric orientation and generating a pseudo DEM from uncorrected satellite images using only tie points without a need for GCPs. The proposed method successfully estimated the relative orientation for multiple satellite images using bundle adjustment. Additionally, the orthorectified result images created from the pseudo DEM resolved relief displacement errors. In conclusion, the feasibility of simultaneous relative orientation and ground coordinates estimation using multiple satellite images without ground control points was confirmed.

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