TOTAL BUILDING AREA EXTRACTION AND ORTHORECTIFICATION FROM HIGH RESOLUTION SATELLITE IMAGES WITH BUILDING DATABASE

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ABSTRACT: Research on orthorectification of satellite images is important for generating precise image maps, which are used in various studies such as change detection. Uncorrected relief displacements reduce positional accuracy of orthoimages. They are often caused by a height difference of man-made features. To remove them, we need height reference data for man-made objects such as digital surface model as well as digital terrain elevation models. It is inefficient to constantly update a digital surface model for man-made structures on frequently changing urban region. Unlike a digital surface model, a building database is updated during a construction process of individual buildings. Therefore, in this paper, orthorectification including building relief correction is conducted using a building database. Firstly, we detect building roofs and façades visible within high resolution images, which we refer to as total building area. In this process, we used the coordinates of building corners from the building database to calculate corresponding image points and define polygons for a total building area for each building. Next, we blank out the total building areas from original images and we generate orthoimages without building relief displacements. Next, we map the image patches of building roofs onto the orthoimages generated. Remaining blank areas in the orthoimages are from the occluded region due to height relief. These occluded areas are inpainted by neighbouring pixel values assuming. In this way, we generate orthorectified images with true building locations. We applied the proposed method to Kompsat-3A images with ground sampling distance of 55cm. We compared orthorectified rooftops from our method with a digital topographic map. In some buildings, errors occurred due to inaccurate height values within the building database used. However, when we adjusted the building heights with errors to true heights, errors were removed. Additionally, the inpainted areas appeared similar to building boundary regions in the original image. In this paper, we showed the feasibility of automated true orthorectification with correct building localization and occlusion inpainting. Based on this, it is possible to extract the building and rooftop area and use it to create a realistic image. Furthermore, our method could identify erroneous buildings within a building database and provide a mean to update them.

1. INTRODUCTION

For urban areas with many artificial features such as buildings, high resolution satellite images are required to generate image maps and to perform change detection and classification (Piero *et al*, 2004). Satellite images with higher ground sampling distance (GSD) require more precise positional accuracy and geometric correction accuracy. However, satellites indicate relief displacement due to many elevated objects including topographic and artificial features. The displacements in urban images occurred by buildings are often severe and difficult to correct. They also create occluded areas, which makes it impossible to acquire actual digital number (DN) values on the occluded area. As a result, it is very difficult to generate an orthorectified image that removes the relief displacement of artificial features as well as topographic features.

In general, a digital terrain model (DTM) which is height information about the ground surface is required to perform orthorectification on topography. In contrast, in order to perform orthorectification for artificial structures existing in urban areas, a digital surface model (DSM) containing the height of the artificial structures is required. These height information are in raster type. Because of this, the resolution of data used affects a quality of generated orthoimages.

Orthorectification research using a digital building model (DBM), which contains the height of artificial features as vector data, is currently being conducted. Vector data less affected by GSD. Recently, orthorectification research using DBM is being conducted. Previous research using a DBM was tested on aerial photographs (Amhar *et al*, 1998; Qin *et al*, 2003.) or for the purpose of creating 3D models with orthoimage (Zhou *et al*, 2022). These studies require stereo or multi-images to obtain information about occluded areas and facades (Chen *et al*, 2007). When obtaining DN values from different images, corrected occlusion area may still be detected as a change due to differences in radiometric resolution. For this, a separate process such as relative radiometric correction is required. There is a need for ortho-rectification research for satellite images using a DBM and with a monocular approach.

In Korea, a building height database (DB) for the Korean Peninsula is being built. Digital elevation models (DEMs) are also being updated at regular intervals. It is possible to secure use data for orthorectification without separate surveying. If automatic orthoimage generation is performed using the building DB and DEMs available, efficient automatic orthorectification system can be established.

Therefore, in this study, orthorectification including terrain and building relief correction is conducted using a building database–and DEMs. Firstly, the image positions and orthorectified positions of artificial features are automatically calculated using the height information. Then we detect building roofs and façades visible within high resolution images, which we refer to as total building area. Based on this, the image patch on each building roof is extracted for later use. Next, we blank out the total building areas from original images and we generate orthoimages without building relief displacements. We map the image patches of building roofs onto the orthoimages generated. Remaining blank areas in the orthoimages are from the occluded region due to height relief. These occluded areas are inpainted by neighbouring pixel values assuming. By overlapping the inpainted image and the ortho layer, a final orthoimage with orthorectification of the building is created. In this way, we generate orthorectified images with true building locations. We applied the proposed method to Kompsat-3A images with ground sampling distance of 55cm. We compared orthorectified rooftops from our method with a digital topographic map for accuracy test. As a results, the possibility of automatically generating true orthoimage from high-resolution satellite images was confirmed.

2. METHODS

To detect building roofs and façades from high resolution satellite images, we follow the workflow in Figure 1. First, we extract ground coordinates of building roofs and footprints, using a DEM and building DB. The ground coordinates are projected onto the image space using image geometric models such as the RFM (Rational function model). The projected image points are used to define total building areas and a total building area mask. Image patches corresponding to building roof are also extracted. Ortho coordinates corresponding the image coordinates is also calculated. An ortho image is created by inputting a DN(Digital number) of the projected image coordinates onto orthogonal position from which relief displacement has been removed. Orthorectified roof areas of the building are mapped by the image patches on building roofs extracted earlier. Finally, a final orthoimage is created by overlapping the terrain orthoimage, the total building area mask, and the building ortho layer.

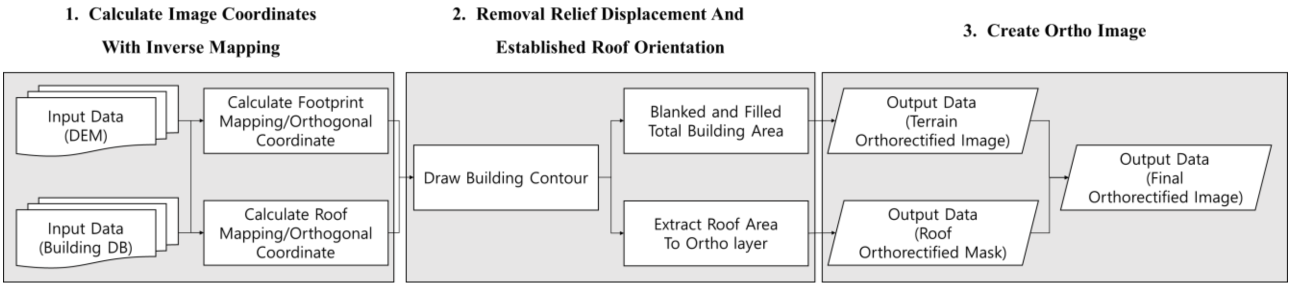


Figure 1. Flowchart of this study.

In this study, ground coordinates is converted to image coordinates using a transformation relationship between ground and image coordinates by the RFM shown in equation (1). The RFM consists of four high-order polynomials of a form as equation (2). One high-order polynomial has 20 RPC coefficients, and a total of 80 initial RPC coefficients are provided from satellite images. We map image coordinates using RPC coefficients with geometric correction completed through precision sensor model.

$$x_i = \frac{P_1(X_i,Y_i,Z_i)}{P_2(X_i,Y_i,Z_i)},\ y_i = \frac{P_3(X_i,Y_i,Z_i)}{P_4(X_i,Y_i,Z_i)} \tag{1}$$

where x_i, y_i = image coordinates
X, Y, Z = ground coordinates
a_0~ a_{19} = RPC Coefficient

$$\begin{aligned} P_1(X_i,\ Y_i,\ Z_i) = \ & a_0 + a_1X + a_2Y + a_3Z + a_4XY + a_5XZ + a_6YZ \\ & + a_7X^2 + a_8Y^2 + a_9Z^2 + a_{10}XYZ + a_{11}X^2Y + a_{12}X^2Z + a_{13}Y^2X + a_{14}Y^2Z \\ & + a_{15}Z^2X + a_{16}Z^2Y + a_{17}X^3 + a_{18}Y^3 + a_{19}Z^3 \end{aligned} \tag{2}$$

Once we define an extent and a GSD of an orthoimage, the coordinates of an orthoimage point can be calculated by Equation (3).

$$
\begin{aligned}
c_{ortho} &= (X - X_{TL}) / GSD_X \\
r_{ortho} &= (Y - Y_{TL}) / GSD_Y
\end{aligned} \tag{3}
$$

where c_{ortho}, r_{ortho} = ortho image coordinates
X_{TL}, Y_{TL} = top left ground coordinates
GSD_X, GSD_Y = ground sample distance of ground coordinates

To calculate mapping coordinates, a height value of a ground feature is required. The elevation value of the terrain is extracted from the DEM. Footprints of buildings are assumed to have the same height as the terrain elevation. A height of building's roof is calculated by adding a height of the building to the height of footprint. Height data of the same size and resolution as the satellite image is generated and used for convenience of calculation.

The roof of an artificial feature that appears in the image exists as a single polygon. To classify the roof into object units, roof mapping points of the same building are grouped into one contour. A closed polygon created using the points of contour is assumed to be the roof. The roof of the same building is supposed to be flat and have the same elevation value. Therefore, to estimate image points, the average Z value of the building roof points is inputted to the pixels included in the roof polygon.

We define a total building area to eliminate a relief displacement of buildings. A structure of a building is mainly divided into three parts: a roof, façades, and a footprint. Among these, excluding a footprint, the roof and façades of the building are referred to as a total building area. The footprint is necessary for calculating the total building area and to construct façades. A façade is rectangles consisting of two pairs of rooftop and ground points. The footprint and the façade are also composed of a single contour such as roof contour. A total building area extracted is entered a value of 0 to make it blank. Afterwards, the area is created as a mask layer. Figure 2 shows contours that make up a building in an image and with the total building area blanked out.

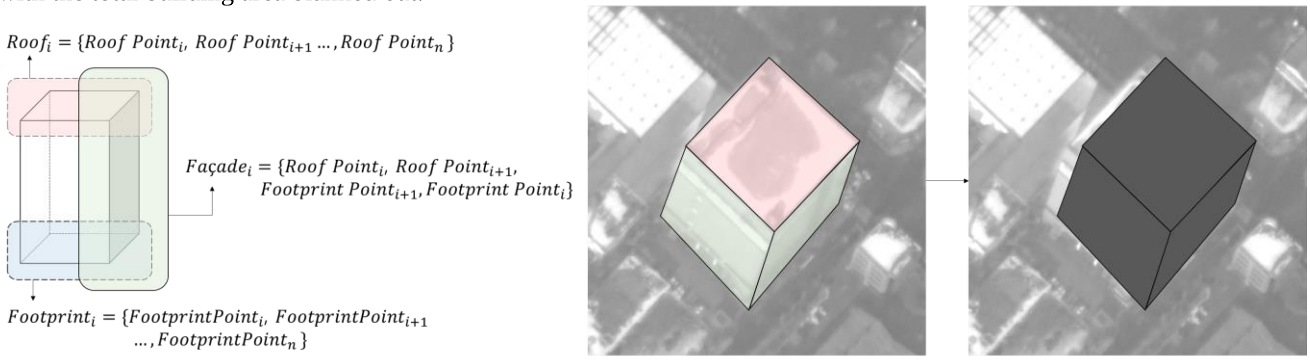


Figure 2. Example of building structures and mapped appearance.

Elevation data is also used in the process of entering DN values in the blanked area for inpainting. A 3 x 3 window was created. We calculated the DN of the middle pixel by reprojection using the height values of eight nearby pixels. If there were 0 values in these other eight pixels, they were excluded from the calculation. Inpainting was performed using only the DN value of the original image. By entering values into blank pixels, an orthoimage of the terrain was created.

A separate roof ortho layer is created during the orthoimage creation process. The roof is moved to the location captured by orthographic projection. For this, the mapping and orthogonal coordinates of the ground points calculated previously are used. In the ortho layer, a DN value of the mapping coordinates is entered in orthogonal coordinates. As a result, the rooftop area is moved to footprint position. Figure 3 shows how the building's ground point is mapped to the original satellite image and orthoimage.

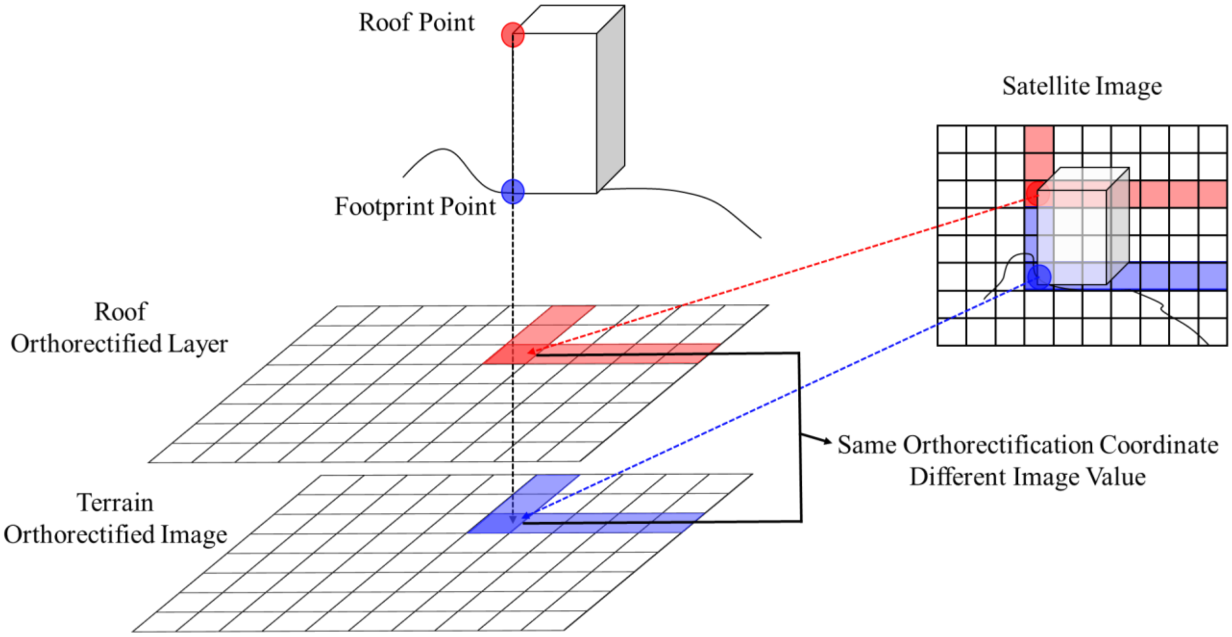


Figure 3. Mapping and orthogonal coordinates using height data.

Generating an orthoimage using the terrain orthorectified image and ortho layer is as follows. First, the building area in the original image is blanked out using the extracted building area. Then the blank areas are filled with other pixels in the image to create a terrain orthorectified image. The terrain orthorectified image and the ortho layer are overlapped. If the DN value of the ortho layer is not 0, the value is input into the orthoimage. The value of the original image is taken when the DN value is 0. Finally, we create final orthoimages used the ortho layer in which building areas are blanked out and the roof is orthorectified.

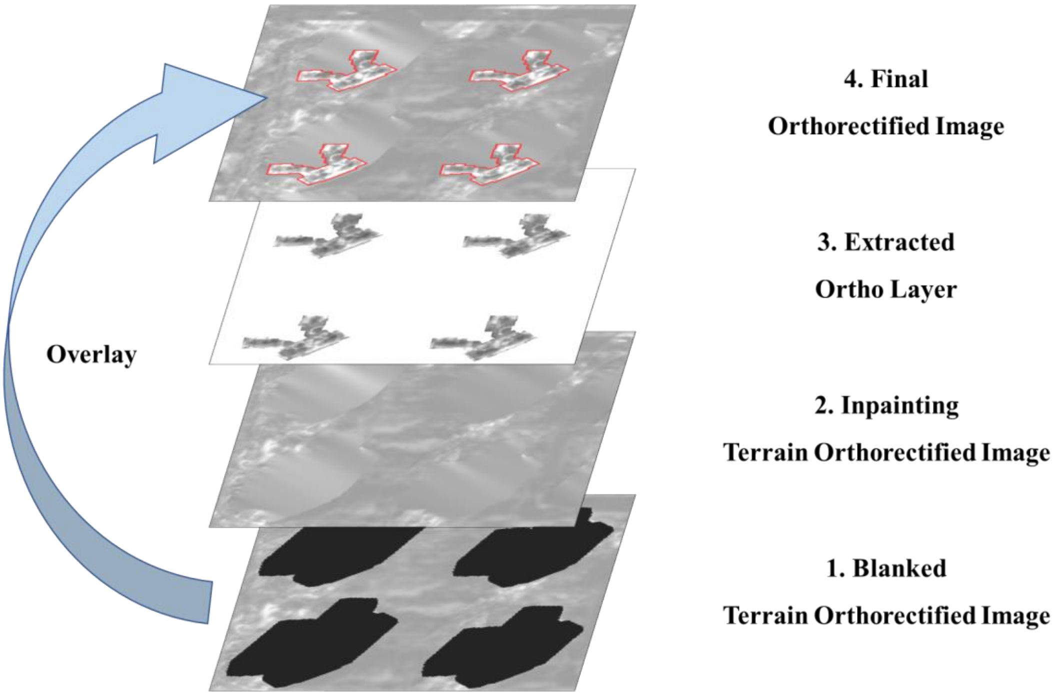


Figure 4. Order of creating final orthoimage by ortho layer and terrain orthoimage overlapping.

3. DATA USED

We used two high-resolution K3A satellite images in our experiments. High-resolution satellite images make it easy to identify objects at the building level, making it possible to confirm whether orthorectification has been established. We used images with relief displacement in different directions to check whether orthorectification was performed at various shooting angles. The images and regions used in the experiment are shown in Figure 5.

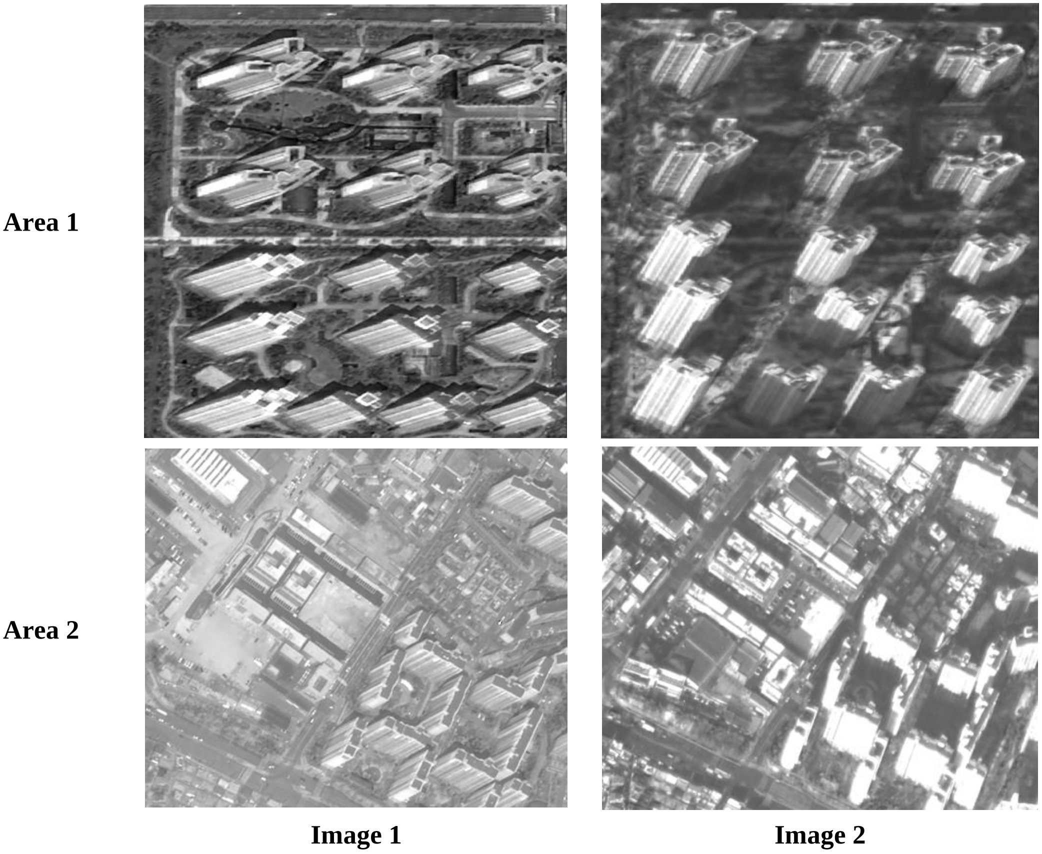
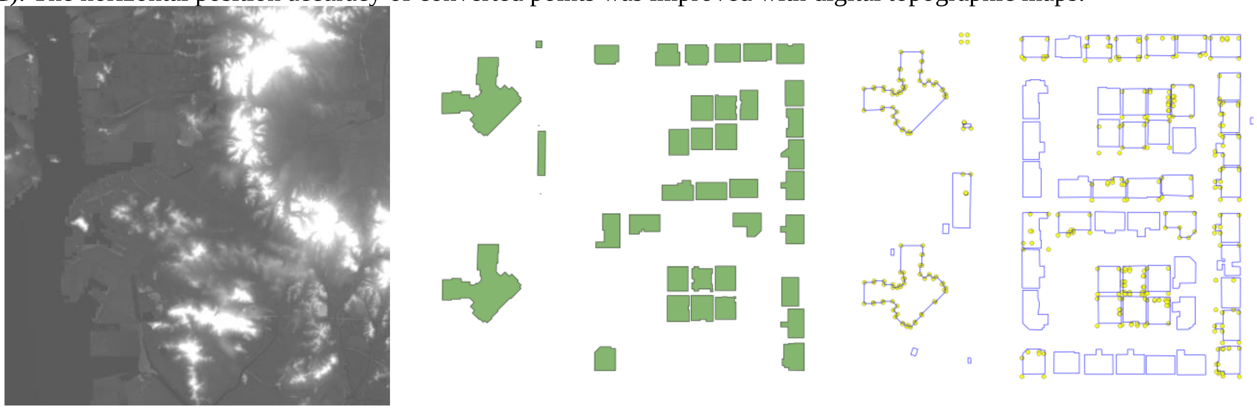


Figure 5. Images used for experiments.

As shown in Figure 6, two types of height reference data were used in the experiment. One was a DEM data for terrain ortho rectification such as Figure 6(A), which was in a raster format. The DEM data was provided by the National Geographic Information Institute and was cut and interpolated to the same extent and same resolution as the satellite image. The other was a building DB, which was polygon data provided by the public data portal as shown in Figure 6 (B). However, the polygon data may be distorted during process of mapping a building. For this reason, we extracted only node information from polygons. It was converted to point data of building corner contained height values as Figure 6 (C). The horizontal position accuracy of converted points was improved with digital topographic maps.



(A) **(B)** **(C)**

Figure 6. Used height reference data. (A) is DEM. (B) is Building height information in polygon form. (C) is Overlapping point-type building height information and digital topography map

4. RESULTS AND DISCUSSION

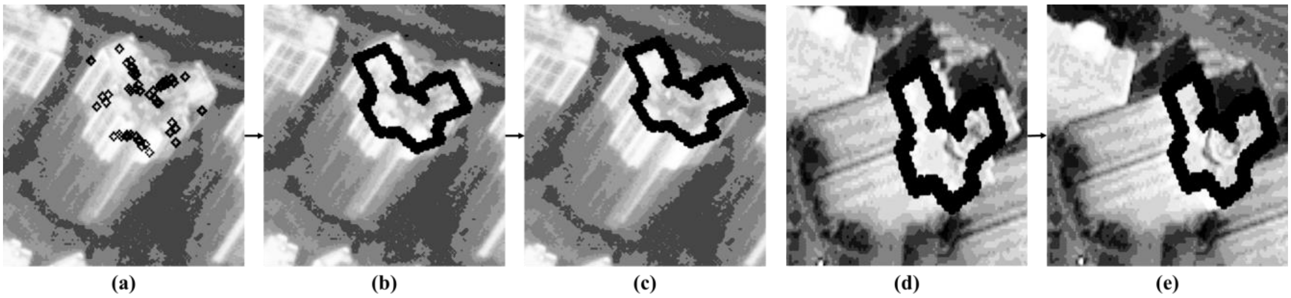


Figure 7. Result of roof contour mapping. (a) Mapping roof point. (b) Roof contour in image 1.

(c) Roof contour in image 1 with manual correction.

(d) roof contour in image 2. Roof contour in image 2 with image 1 Z value after manual correction

Using the RFM established for a single image, rooftop points were mapped as shown in (a) of Figure 7. In both images, it was found that there was a shift between contour line and the actual building roof edge for some buildings shown in Figure 7 (b) and (d). It was determined that this shift occurred due to height error in the DEM or building DB. Therefore, the image was identified with the naked eye and manual correction of the height value was performed. The X and Y coordinates for each building were the same as before, but the height value was manually adjusted. As a result of adjusting the height values of individual building units, the contour lines moved correctly as shown in Figure 7 (c). The manually corrected height value from one image was used as input data for another image to confirm the roof area extraction results. As a result, the contour lines were extracted properly, as shown in Figure 7 (e).

Figure 8 is the result of drawing the building contour for Area1 and Area2 in the two images, respectively. The roofs of each building were extracted without sift in both images after manual correction performed.

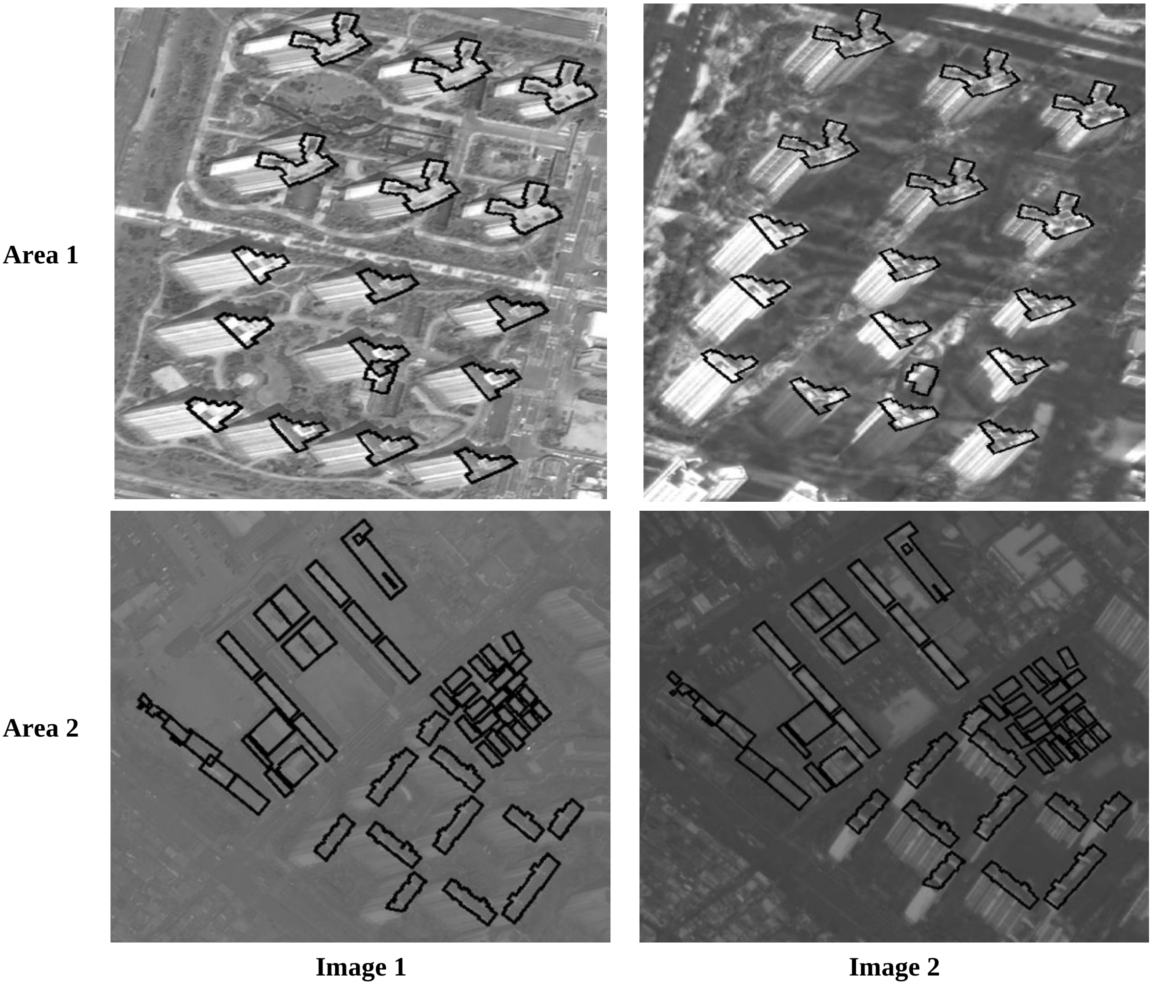


Figure 8. Results of drawing building contour.

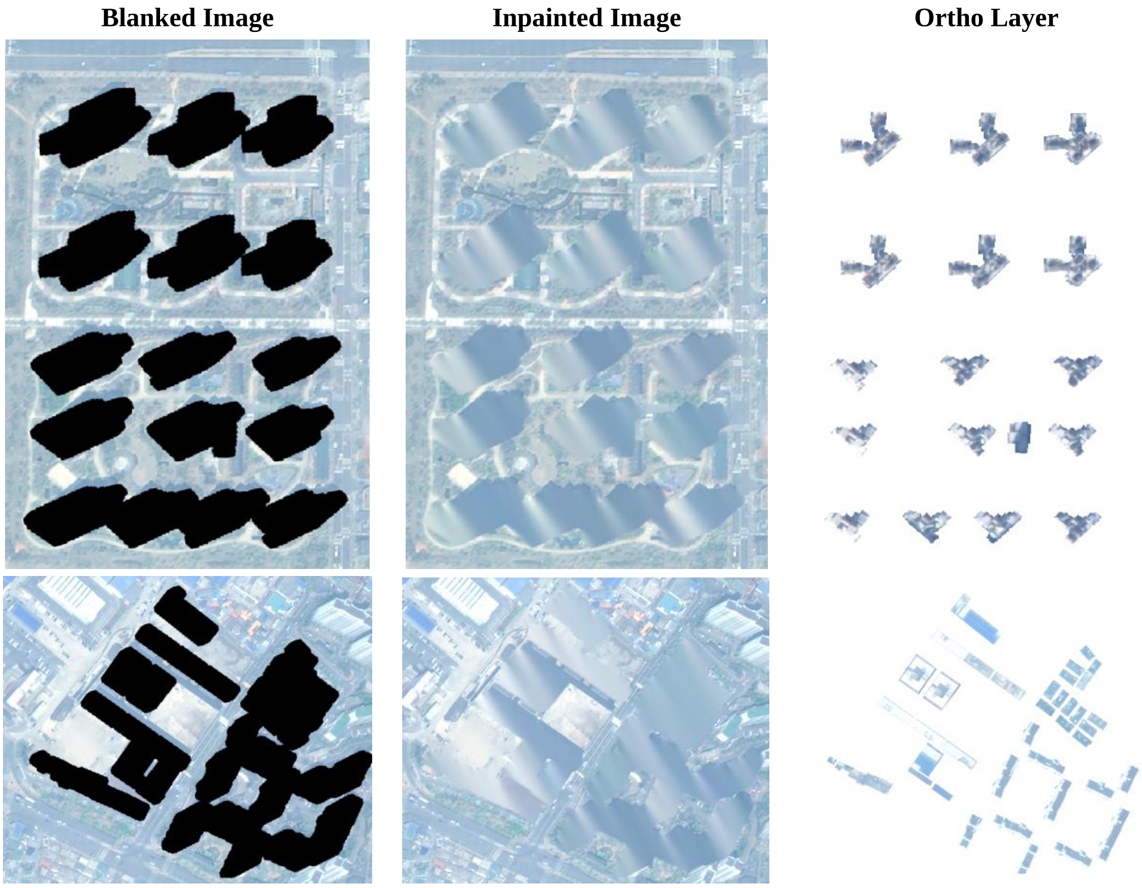


Figure 9. Results of blank, inpainting, ortho layer in image 1.

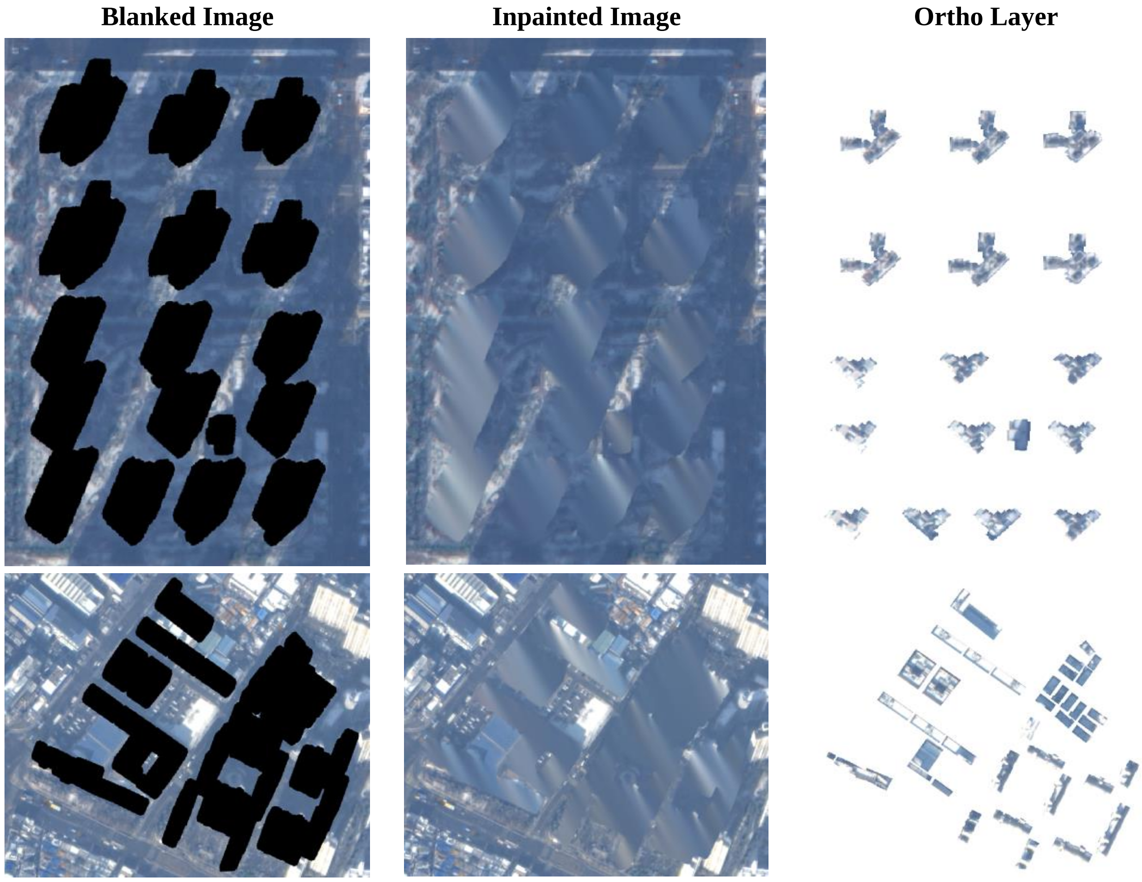


Figure 10. Results of blank, inpainting, ortho layer in image 2.

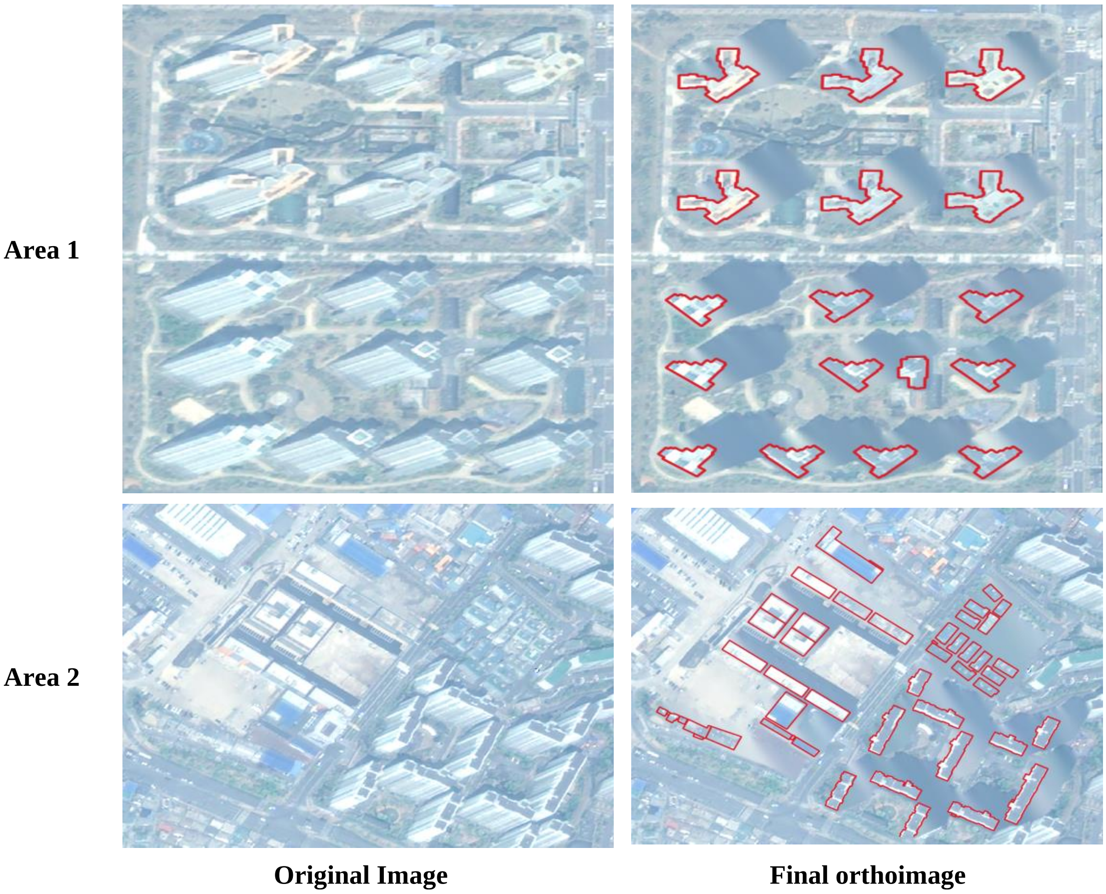


Figure 11. Results of final orthoimage in image 1.

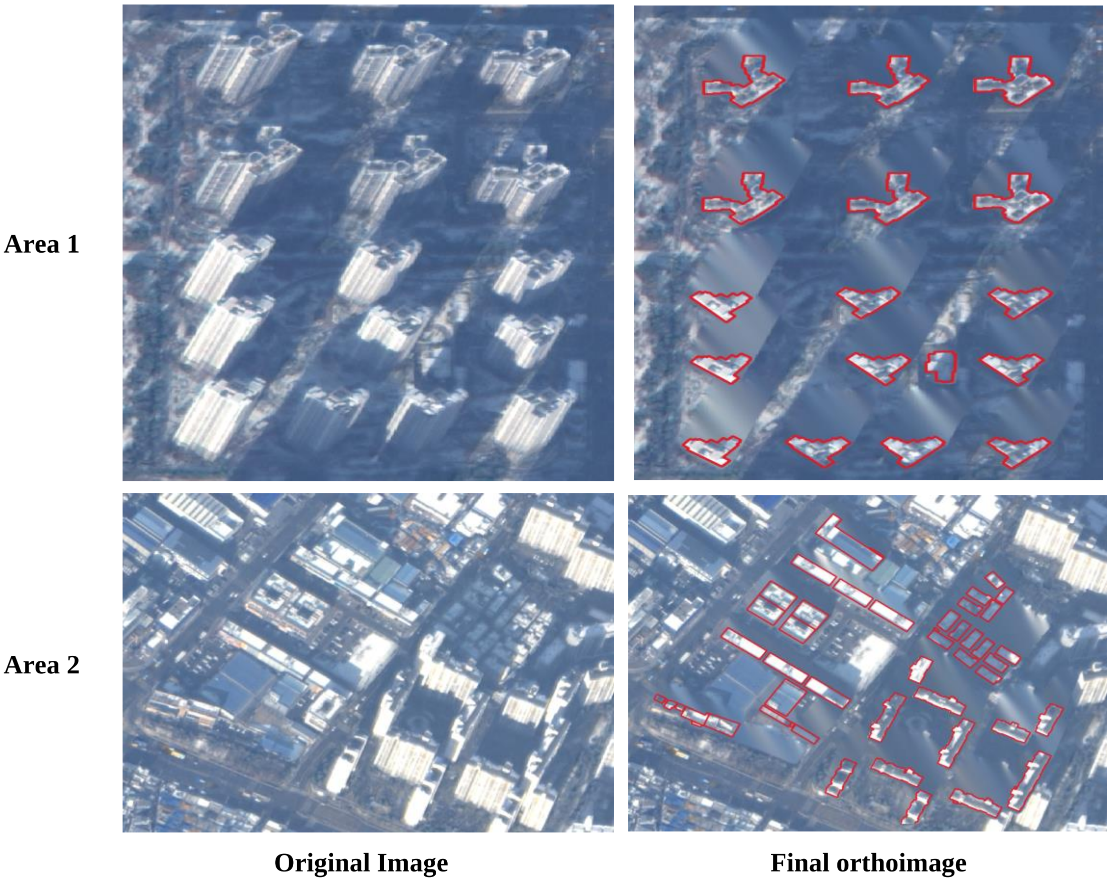
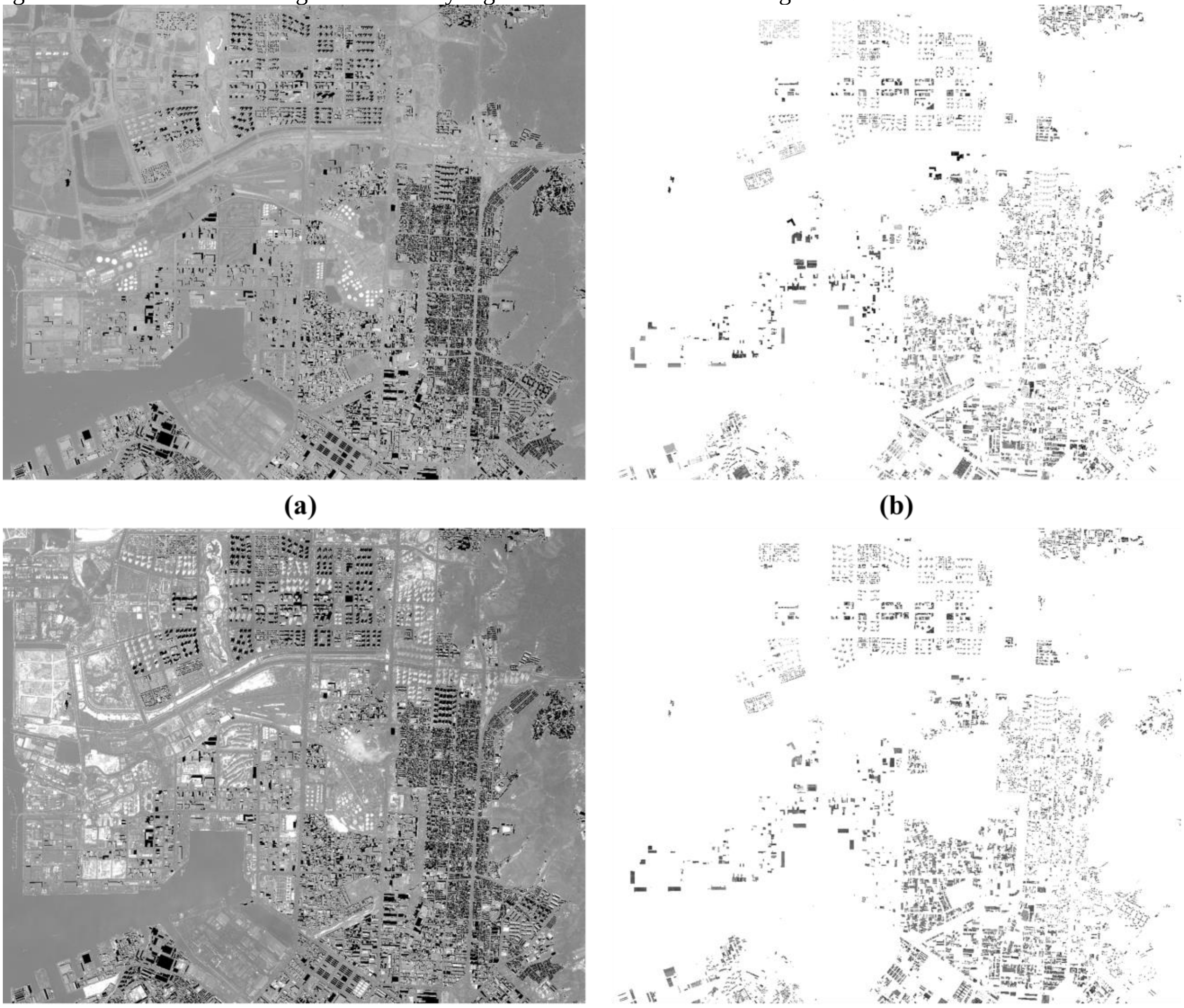


Figure 12. Results of final orthoimage in image 2.

Figure 9 and Figure 10 show blanked layers, inpainted layers, and ortho layers for the two images, respectively. In the case of the blanked layer, overall total building areas were processed. However, some part of building area remained due to errors. To remove this, a morphology expansion operation was performed using a blank area. As a result of inpainting, input DN values were generally similar to the DN values of nearby elevations. There were some blurring effects in DN value corresponding to the inpainting process. They occurred by remaining building areas. Blurring occurred even when the surrounding buildings were not blanked out. Ortho layer was well extracted from contours of the original image. The extracted building roof was moved to the orientation of orthorectification. An ortho image was created using the ortho layer in which the building position was established.

The result of generating the final orthoimage is shown in Figure 11 and Figure 12. The red line is a digital topographic map, overlaid with the final orthoimage. The extracted ortho layer almost matched the digital topographic map. It was confirmed that the DN had generally similar values except for the part where the roof was orthorectified. In the case of blurring, high rise buildings had more relief displacement than low buildings, so there were more error remaining after blanking. Because of this, we can check that areas with many tall buildings have more blurring and errors after inpainting. Figure 13 is the final orthoimage and ortho layer generated for the satellite image area.


(a) (b)

(c) (d)

Figure 13. Results of final orthoimage.

5. CONCLUSIONS

In this paper, we used building height and DEM data constructed to automatically remove building relief displacement and create orthoimages through inpainting. The orientation of the building was established based on the roof of the building extracted during orthorectification. Through this, the possibility of generating orthoimages in the satellite image range was confirmed.

To extract the building roof, inaccurate height information in the building database was manually adjusted. As a result of using the updated height, shifts that occurred when using the original height disappeared. Therefore, it can be expected that proper extraction of the ortho layer and removal of relief displacement will be performed when accurate elevation reference data is used. In addition, the height of the building DB was adjusted during the manual correction process. Through this, we confirmed the possibility of error analysis and update of previously constructed altitude data. If multiple satellite images are used in the correction process, it is possible to determine building elevation more precisely.

In this study, we attempted to improve the accuracy of true orthorectification using only DN value of a single image through. As a result of inpainting the blank area, the output appeared similar to the DN value of the ground surface, such as a road near a building. However, since the inpainting technique does not use the actual DN value of the position, errors were inevitable. Therefore, additional follow-up research is needed to detect changes between images that use a single image-based inpainting technique and images that fill in the occlusion area by inputting the DN values of multiple images.

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