ORTHORECTIFICATION OF A DIGITAL AERIAL IMAGE USING LIDAR-DRIVEN ELEVATION INFORMATION

Jong-suk Yoon

Land Monitoring Research Center, Inha University
rs_yjs@inha.ac.kr

ABSTRACT The quality of orthoimages mainly depends on the elevation information and exterior orientation (EO) parameters. Since LiDAR data directly provides the elevation information over the earth's surface including buildings and trees, the concept of true orthorectification has been rapidly developed and implemented. If a LiDAR-driven digital surface model (DSM) is used for orthorectification, the displacements caused by trees and buildings are effectively removed when compared with the conventional orthoimages processed with a digital elevation model (DEM). This study sequentially utilized LiDAR data to generate orthorectified digital aerial images. Experimental orthoimages were produced using DTM and DSM. For the preparation of orthorectification, EO components, one of the inputs for orthorectification, were adjusted with the ground control points (GCPs) collected from the LiDAR point data, and the ground points were extracted by a filtering method. The orthoimage generated by DSM corresponded more closely to non-ground LiDAR points than the orthoimage produced by DTM.

KEY WORDS: Orthorectification, Aerial Image, LiDAR, DTM, DSM

1. INTRODUCTION

Orthorectification is the process of correcting the displacements caused by topography and tall buildings and finding the correct position of objects on aerial photographs and satellite imagery. Since precise vertical and horizontal information are prerequisites for orthorectification, orthorectified images are commonly produced with the digital elevation model (DEM) prepared by the sequential procedures of photogrammetry or the extraction of elevation information from digital topographic maps. However, when orthorectification is implemented in highly urbanized areas, a digital surface model (DSM) or digital building model (DBM) is necessary to solve the double mapping and occlusion problems because the displacements caused by buildings are not geometrically corrected in the conventional orthorectification using a DEM or a digital terrain model (DTM). Amhar et al. (1998) explained the concept of true orthoimages, which completely eliminate distortions, and tested orthophoto generation with DBM. For true orthorectification, elevation information of objects including buildings and trees is necessary. Most of the past research produced the DSM, DBM and canopy height model except DTM for the generation of orthoimages (Amhar et al. (1998) and Zhou et al. (2005)).

Either for true orthorectification or general orthorectification, LiDAR has a great advantage in providing elevation information of the ground and buildings. With the benefits of decreasing cost and increasing accuracy, LiDAR data has been actively applied to orthorectification. While the ground coordinates are calculated after matching to find corresponding image points between the stereo images as in photogrammetry, LiDAR directly provides surface elevation information with high density of points. Many studies have applied LiDAR data to orthorectify images because of the advantages this method offers. Liu et al. (2007) performed aerial triangulation and orthorectified scanned aerial photographs with a LiDAR-driven DEM and ground control points (GCPs) from the LiDAR. They referenced LiDAR intensity to collect GCPs for the planimetric coordinates and used LiDAR-driven DEM to refine the exterior orientation for the vertical information. While the RMSE of the planimetric accuracy of the orthorectified image that resulted from the DEM of digital maps was 7.26 m, the RMSE of the planimetric accuracy of the LiDAR-driven orthoimage was 1.30 m in their study. When the DSM interpolated from LiDAR data is used for orthorectification, the boundaries of tall buildings close to the ground become blurred and inaccurate because of the large differences in elevation. Some researchers attempted to solve this problem in their research. Barazzetti et al. (2007) proposed a method to orthorectify a digital aerial photograph with a dense DSM obtained from LiDAR. They compared the orthorectification results produced from the 20 m DEM, LiDAR DTM (2 m resolution), and LiDAR DSM (2 m and 20 cm resolution). The orthorectification generated from DEM and DTM had displacements caused by tall buildings. Even though LiDAR DSM was used for orthorectification, the boundary of the buildings was not matched with the digital map because DSM was interpolated. Barazzetti et al. (2007) proposed the use of 20-cm dense DSM and DEM to orthorectify the building and ground parts of the image separately; they then suggested that the two parts be combined. Kim et al. (2002) focused on the quality of orthorectification in the boundaries of buildings when using the DSM generated from LiDAR data; their objective was to determine the feasibility of LiDAR for orthorectification. They proposed the combined use of DSM and DEM of LiDAR to orthorectify digital photographs and evaluated the positional accuracy of the orthorectified images to be commensurate with the positional accuracy of 1:5000 maps.

As far as the quality of orthorectification is concerned, accurate exterior orientation (EO) and DEM are essential for the process. In this study, we introduce the sequential availability of LiDAR data for orthoimage generation: refinement of Eos and orthorectification. Orthorectified images were produced using the DTM and DSM retrieved form LiDAR data; these images were then used to orthorectify the digital aerial images. The orthoimages obtained from DTM and DSM were compared with respect to the effect of different elevation sources. The inputs required for orthorectification are perspective images, ground information, sensor information.

2. DATA PREPARATION

2.1 LiDAR and digital aerial images

The study data covered were taken from the YangPyung area in the middle region of the Korean peninsula. Strips of aerial photographs were taken by a digital metric camera (4K02 by Optech) installed with a LiDAR system in April 2004. One of the photographs selected for this study is shown in Figure 1. The image size (Figure 1) was approximately 4,000 × 4,000 pixels, and the ground sample distance was 0.25 m per pixel. The focal length of the camera is 55.156 mm, and the principal point is 0.061 and -0.07 mm in X and Y, respectively. The red box, 200 m × 200 m area, in Figure 1 indicates the part of the aerial image to be experimentally orthorectified in this study. A laser scanner, Airborne Laser Terrain Mapper (ALTM) 3070 by Optech, was used to collect LiDAR points over the area, and the nominal vertical accuracy of the LiDAR data was approximately ±0.15 m at a flying height of 1,200 m. The horizontal accuracy was estimated by the flying height/2000, and the point density was 2.2 points/ m^2.

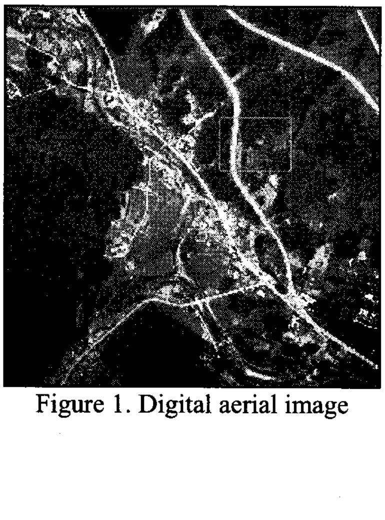

Figure 1. Digital aerial image

2.2 Ground points from LiDAR

The role of DEM in orthorectification is to provide the horizontal and vertical information of the surface to correct the displacements caused by topography and to find the exact location on the image. When LiDAR data are utilized for orthorectification, the subsequent procedure will be determined depending on the use of surface or ground elevation information. If DTM is used for elimination of the relief of terrain, the ground points should be filtered from the entire LiDAR data set. In order to obtain ground elevation information from LiDAR in this study, ground points were extracted from the complete LiDAR data set in the previous study related to the filtering method. The original density of LiDAR was approximately 2.2 points/m^2, and the density of ground points after filtering was approximately 1 point/m^2. Because the study site is confined to a forested area, the distribution of the filtered ground points over the space depended on the density of the existing trees. Even though the density of ground points after filtering was lower than the density of the original LiDAR data, the resolution of the interpolated DTM from the ground points was much higher than the resolution of DEM extracted from the existing topographic maps. Considering the resolution of the perspective image to be orthorectified, namely, 0.25 m/pixel, the resolution of DTM is sufficient for the resolution of the orthoimages.

2.3 Adjusted Eos of digital aerial images

As another input for orthorectification, precise sensor location and attitude information should be guaranteed. During orthorectification, the relationship between the ground and the image space are established with the colinearity equations. The location and attitude information of the sensor should be precise to determine the digital number (DN) at the exact position on the orthoimages. The parameters related to the sensor were adjusted with the GCPs from LiDAR data, which were collected from the LiDAR intensity data. Figure 2 shows an example of GCPs collected from LiDAR intensity data.

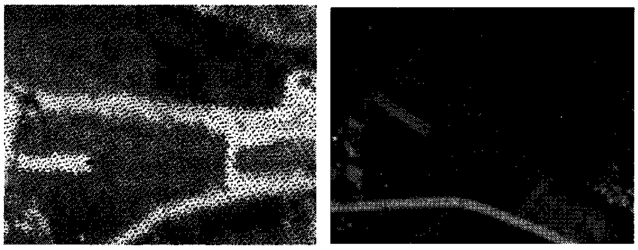

Figure 2. GCPs collected from LiDAR intensity and the aerial image

3. METHODOLOGY

3.1 Adjustments of EO

Precise EO registered ground points to the same location of stereo pair images. The initial EO provided by vendor did not register the ground points to the right places on the images. Figure 3 shows the behavior of initial EO to register the same ground points to the different locations on the stereo pair images. The initial EO was adjusted with the GCPs collected from the overlapping area between two stereo pair images. With the initial EO, the calculated image coordinates corresponding to the ground LiDAR data were not matched to the locations on the image; however, Figure 4 shows that the LiDAR points were correctly backprojected to the aerial images after the EO adjustments.

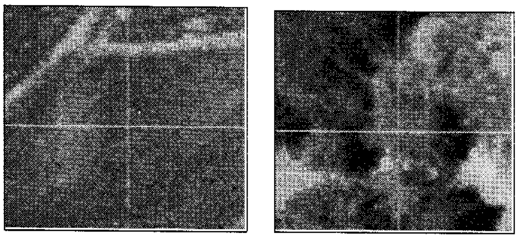
Figure 3. The behaviour of initial EO

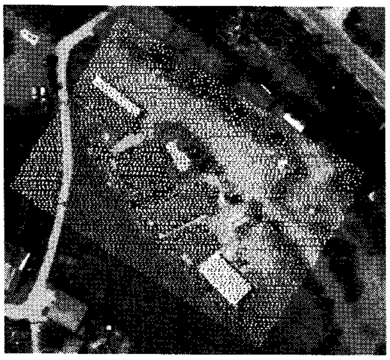
Figure 4. Back-projected LiDAR points overlaid with one of stereo images

3.2 Orthorectification

The algorithms for orthorectification can be mainly classified into two types: direct and indirect. This study used the indirect method, which is a straightforward process of orthorectification. Starting from the allocation of elevation in the image coordinates, the indirect algorithm calculated the image coordinates of the orthorectified image through the colinearity equations, with three coordinates (X, Y, and Z) on the ground and the adjusted EO parameters. After determination of the image location, DNs of the orthorectified image were allocated by estimation through the interpolation with neighboring pixels. Bilinear interpolation was used for the determination of the DN in this study. The resolution of the orthoimages is the same as that of digital aerial images, namely, 0.25 m.

The ground points resulting from the filtering procedure were irregularly distributed, and there were empty spaces under the footprints of trees. The average point density of ground points was approximately 1 point/m^2 because of the presence of trees in the study area. The irregularly spaced ground points were interpolated to a 1-m resolution DTM for orthorectification through the inverse distance weight (IDW) method. For the second experimental orthorectification, this study attempted to use DSM from the LiDAR data. Although LiDAR is an effective elevation source of DSM, the interpolation of the entire LiDAR data at the same time is inconvenient as the process time required increases; further, geometric errors can be caused in the boundaries of objects with high elevation surrounded by objects with large differences in elevation during the interpolation. Therefore, if the surface information was used for orthorectification after interpolation of the LiDAR data, the orthorectification did not show the correct roof edges, especially in the case when the building was surrounded by the ground. The reason is that the interpolation method estimated the elevation of roof edge with the neighboring elevation between buildings and the ground.

In order to avoid the abovementioned problem, this study applied interpolation for DSM separately to the ground points and non-ground points. Because of the limitation of the study area, the non-ground points were separated from the points from trees in this study with the objective of maintaining the elevation difference between trees and the ground. The separately interpolated grids were joined to represent the entire DSM over the study area. Therefore, the final DSM included the ground and trees; the edges, however, were not smoothened. Figure 5 shows the interpolation result of non-ground points (left) and the DSM over the study area after joining the two grid datasets (right).

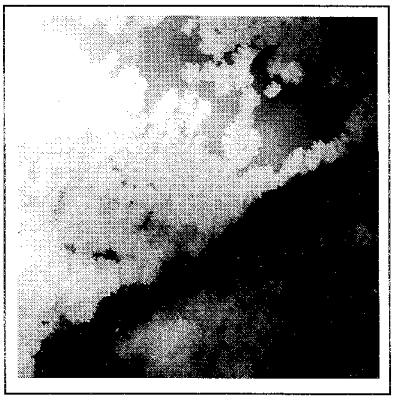
Figure 6. DSM used for the orthorectification

4. RESULTS

Two experimental orthorectified images were generated from the different elevation sources produced from LiDAR data, even though the entire orthorectification methodology was the same. The first orthoimage was produced with DTM generated by the filtered ground points, while the second orthoimage used elevation information from DSM. When the DTM was used for orthorectification, only the displacements caused by topography were removed; the displacements caused by both topography and trees were removed when the DSM was considered.

Figure 6 is the orthoimage overlaid with non-ground LiDAR points and the orthoimage in figure 6 is the orthoimage generated with DSM. It is observed that the orthoimage generated by DSM corresponded more closely to the non-ground LiDAR points than the orthoimage produced by DTM. Figure 7 shows the orthorectified images draped with DSM. Since the heights of the trees in the study site reached up to 20 ~ 30 m, the exact corresponding location on the images exhibited differences when the DTM was employed in orthorectification.

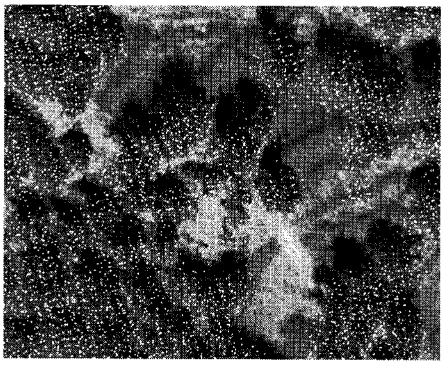

Figure 6. Orthoimages produced by DSM

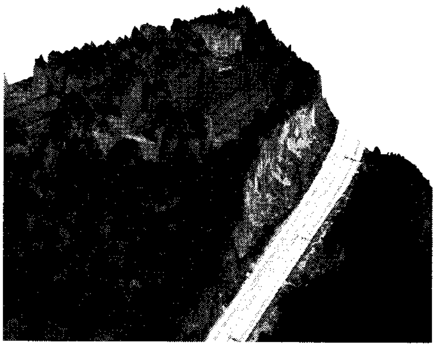

Figure 7. Visualization of orthoimages with DSM

5. CONCLUSIONS

This study utilized LiDAR for the preparation of orthorectification of an aerial image and finally produced experimental orthoimages using elevation information from DTM and DSM driven from LiDAR data. When DSM generated from LiDAR is considered for orthorectification, the methodology of producing DSM affects the quality of orthoimages.

When we consider true-orthorectified images, LiDAR data has the greatest advantage for the supply of surface elevation. The availability of LiDAR data makes true orthorectification possible from accurate and high-density elevation information about the surface. For true orthorectification, however, occlusion and shadow problems should be resolved. Since the experimental orthorectified image did not include buildings in the study area, the displacements mainly resulted from the trees. Thus, the experimental orthoimage still has problems of occlusion and shadow problems. In future studies, it will be necessary to scrutinize these problems for true orthorectification.

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