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Ortho-rectification of a Digital Aerial Image using LiDAR-derived Elevation Model in Forested Area

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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 utilized LiDAR data to generate orthorectified digital aerial images. Experimental orthoimages were produced using digital terrain model (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 used in a previous research. 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 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 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 DTM. Amhar *et al.* (1998) explained the concept of true orthoimages, which completely eliminate distortions, and tested orthophoto generation with DBM. Zhou *et al.* (2005) explained in detail the drawbacks caused by the traditional orthorectification method for true orthorectification in an urbanized area, namely, ghost

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images, occlusion and building lean, shadows of buildings, incomplete orthorectification by DSM, refilling problems, etc. 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 GCPs from the LiDAR. They referenced LiDAR intensity to collect GCPs for the planimetric coordinates and used LiDAR-derived 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-derived 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 explained by Zhou *et al.* (2005), there are two problems with orthorectification of images obtained from urban areas; they are building occlusion and space-filling. Some studies have focused on solving these problems in order to achieve true orthorectification. Generally, a z-buffer algorithm has been used to detect the occlusion area of buildings and the stereo images used for the filling the area. Sheng *et al.* (2003) also applied LiDAR data to orthorectification and detected the occlusion area of trees by a z-buffer algorithm and produced the true orthoimage for forested areas. As sufficient elevation information is provided by LiDAR technology, LiDAR is actively used for orthorectification.

Orthophoto generation requires three inputs: a perspective image, sensor EO parameters, and elevation information. As far as the quality of orthorectification is concerned, accurate EO and

DEM are essential for the process. We introduced the sequential availability of LiDAR data for orthoimage generation produced using the DTM and DSM retrieved form LiDAR data. The orthoimages obtained from DTM and DSM were compared with respect to the effect of different elevation sources. Both ground points and sensor EO parameters were prepared from the previous researches (Yoon *et al.* 2006 and Yoon 2008). With regard to elevation information for orthorectification, this study used DTM generated by the filtered ground points for the conventional orthorectification and DSM interpolated with ground and non-ground points for the consideration the heights of objects.

2. Data Preparation

1) LiDAR and digital aerial images

The LiDAR system acquired LiDAR point clouds and digital aerial images simultaneously. 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 is shown in Fig. 1. The image size (Fig. 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 in Fig. 1 indicates the part of the aerial image to be experimentally orthorectified in this study. Because the filtered ground points were limited to the forest area, the orthorectification was also confined to 200 m × 200 m area (red box). 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.

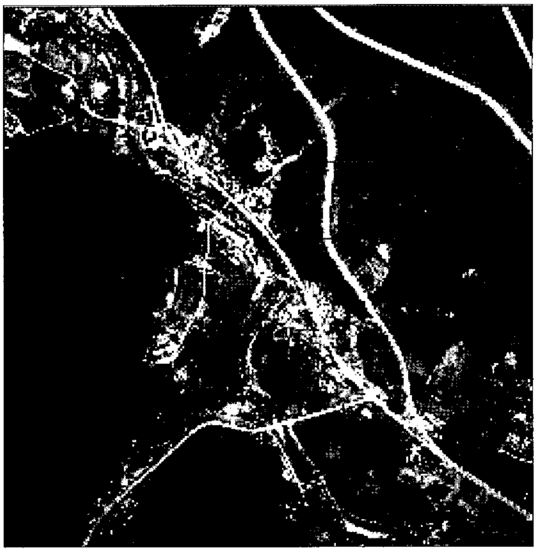

Fig. 1. Digital aerial image.

2) Ground points from LiDAR

LiDAR is an effective information source of elevation because it provides accurate elevation information regarding both the surface and the ground. 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, ground points were extracted from the complete LiDAR data set in the previous study related to the filtering method. The filtering method was based on

Fig. 2. Extracted ground points after filtering.

the elevation difference between the first and last returns of multiple returns of LiDAR data. 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. Fig. 2 shows the ground points filtered from LiDAR data. 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. While the footprint of individual trees can be recognized from gaps between trees, the ground points are rarely scattered under the densely planted area. 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.

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 co-linearity equations (equation 1). The location and attitude information of the sensor should be precise to determine the digital number (DN) at the exact position on the orthoimages. In the previous work, the parameters related to the sensor were adjusted with the GCPs from LiDAR data, which were collected from the LiDAR intensity data. The initial exterior orientation provided by the vendor was adjusted with the GCPs collected from the overlapping area between two stereo pair images; and Table 1 shows the adjusted EO parameters of the stereo pair of aerial 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, Fig. 3 shows that

Table 1. Adjusted exterior orientation parameters

	Image #1	Image #2
Xc (m)	243,498.050	243,200.586
Yc (m)	455,226.222	454,897.617
Zc (m)	1,805.396	1,800.480
ω (°)	-1.35664	-0.56826
ρ (°)	4.22695	4.12414
κ (°)	212.51704	212.75051

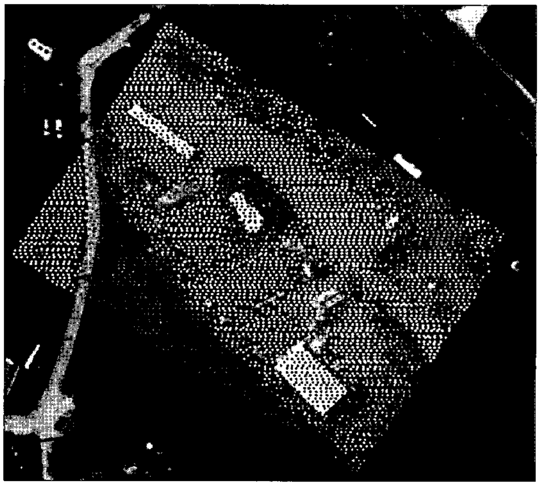

Fig. 3. Backprojected LiDAR points overlaid with one of the stereo images.

the LiDAR points were correctly back-projected to the aerial images after the EO adjustments.

3. 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 co-linearity equations, equation (1), 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. The resolution of the orthoimages is the same as that of digital aerial images, namely, 0.25 m.

$$x_i = x_o - f\frac{m_{11}(X-Xc)+m_{12}(Y-Yc)+m_{13}(Z-Zc)}{m_{31}(X-Xc)+m_{32}(Y-Yc)+m_{33}(Z-Zc)}$$
$$y_i = y_o - f\frac{m_{21}(X-Xc)+m_{22}(Y-Yc)+m_{23}(Z-Zc)}{m_{31}(X-Xc)+m_{32}(Y-Yc)+m_{33}(Z-Zc)} \qquad (1)$$

where, x_o, y_o: *principle points*
f: *focal length*
X, Y, Z: *ground coordinates*
m11~m33: components of rotation matrix depending on the camera orientation
Xc, Yc, Zc, ω, φ, κ: *exterior orientation parameters*

The ground points resulting from the filtering procedure were irregularly distributed, and there were empty spaces under the footprints of trees. In case of open space, the density of ground points remained 2.2 points/m^2. However, the average point density of ground points was approximately 1 point/m^2 because of the presence of trees in the study area. Even though the point density was lower than that in the original LiDAR data after filtering, sufficient ground information was provided for the estimation of the elevation under the objects. The irregularly spaced ground points were interpolated to a 1-m resolution DTM for orthorectification through the inverse distance weight (IDW) method. When it comes to interpolation methods, there is no big difference between methods if the sampling density of LiDAR is high. Thus, the fast and simple IDW was chosen to interpolate the LiDAR points among several interpolation methods.

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. As indicated by Barazzetti *et al.* (2007), if the entire LiDAR data set were to be applied to the interpolation for DSM, boundary problems occur in the boundaries of tall trees surrounded by ground in this study site. Fig. 4 shows the interpolated DSM of LiDAR points. Since the forest area contained mixed points from both the canopy and the ground, the interpolated DSM at the top of the canopy are not uniform, as shown in Fig. 4. In an urban area, because LiDAR was not recorded

Fig. 4. Interpolated DSM of entire LiDAR data.

into multiple returns under the roof, the problem was not very serious.

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 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. Fig. 5 shows the interpolation result of non-ground points (left) and the DSM over the study area after joining the two grid datasets (right).

4. Results and discussions

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.

When DSM of LiDAR is used for orthorectification, interpolated DSM from the entire LiDAR data set can

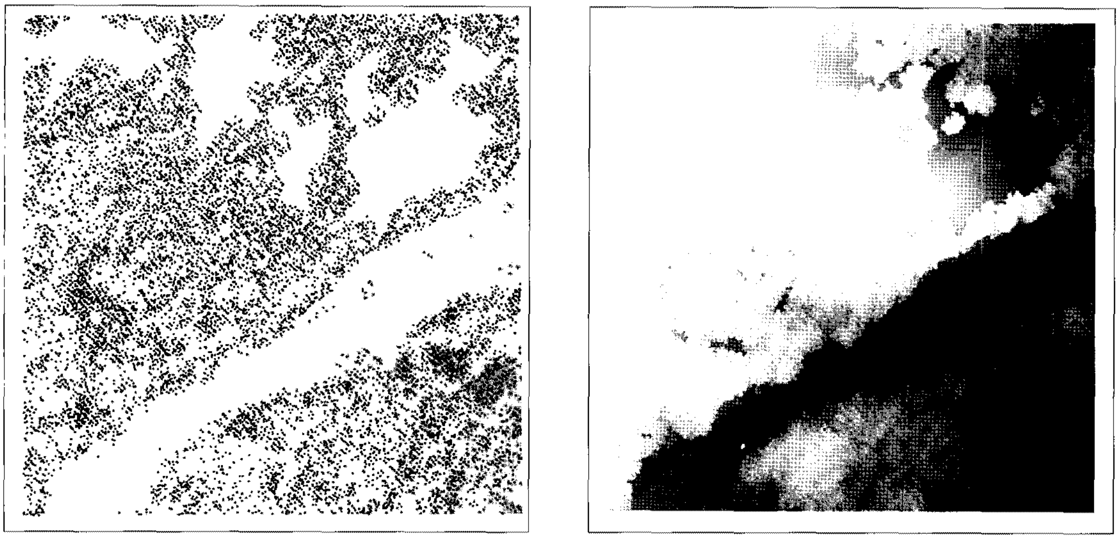

Fig. 5. The grid format of tree points (left) and DSM over the study area (right).

Table 2. Horizontal differences between orthoimages (in m)

	$\lvert X_2 - X_1 \rvert$	$\lvert Y_2 - Y_1 \rvert$	RMSE
1	0.38	0.17	0.42
2	0.38	0.40	0.55
3	0.34	0.39	0.52
4	0.35	0.35	0.49
5	3.63	0.27	3.64
6	3.21	1.11	3.40
7	3.55	2.05	4.10
8	4.10	0.09	4.10

cause other errors in edges of objects and forested area. Thus, this study interpolated ground and non-ground points separately. Table 2 shows the differences of the horizontal coordinates X and Y of eight locations randomly selected from the orthoimages. Four points among the samples were collected from the ground, including roads, and four points were selected from the non-ground parts. The first two columns in Table 2 show the differences of the X and Y coordinates on the orthorectified images, and the third column shows the horizontal RMSE. Four points from the ground show approximately 0.5 m RMSE in the horizontal coordinates, while four points from the non-ground parts show approximately 3.8 m RMSE. Fig. 6 shows the two orthoimages overlaid with non-ground LiDAR points. Fig. 6 (a) is the orthoimage generated by DTM, and Fig. 6 (b) is the orthoimage generated with DSM. Conspicuous differences exist in the tree parts depending on which elevation sources are used. It is observed that the

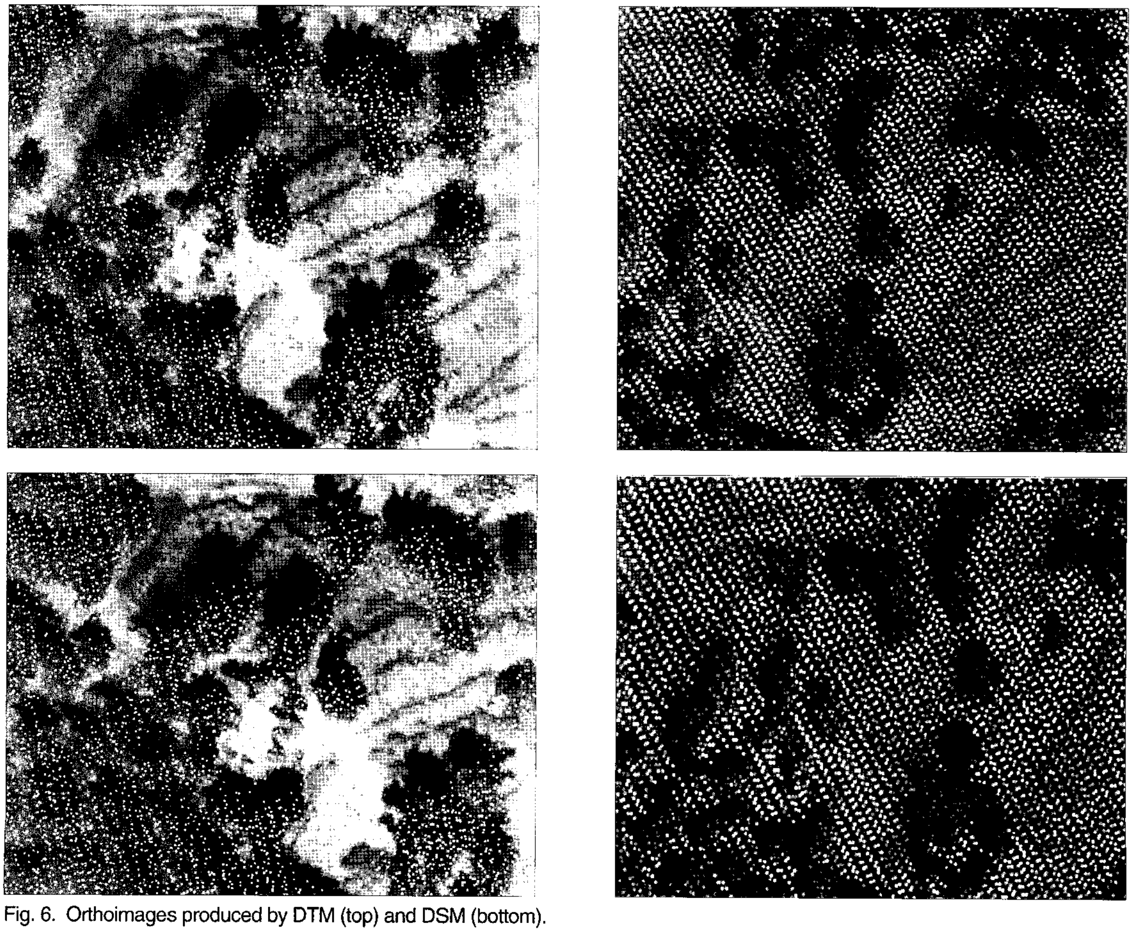

Fig. 6. Orthoimages produced by DTM (top) and DSM (bottom).

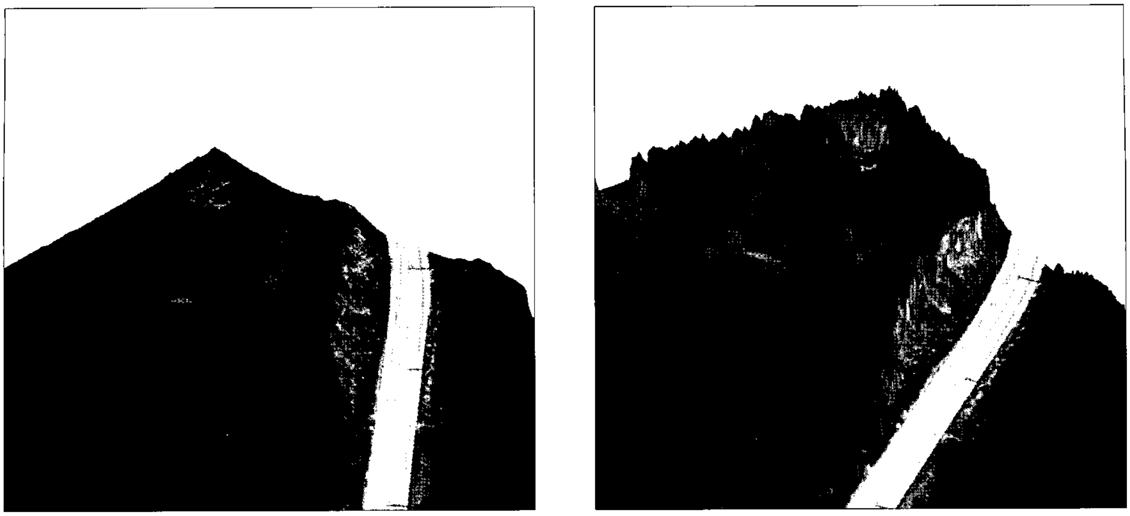

Fig. 7. Visualization of orthoimages draped with DTM (left) and DSM (right).

orthoimage generated by DSM corresponded more closely to the non-ground LiDAR points than the orthoimage produced by DTM, as shown in fig. 6 (a) and (b). Fig. 7 shows the orthorectified images draped with DEM and DSM, respectively. 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.

When the DSM is used for orthorectification, the displacement caused by non-ground objects is eliminated; however, the occlusion problem should be solved. This implies that shadow areas caused by the height of buildings and the sides of buildings demonstrated by the relief effect should be eliminated and substituted by the adequate DNs. In the second orthoimage, the shadows of trees show some strange shapes caused by orthorectification. Occlusion problems are handled as essential problems for the generation of orthoimages in an urban area. The problems also appeared in the second orthoimage, but the effect was not as obvious or as serious as the effect of the buildings in an urban area.

5. Conclusions

When orthoimages are produced using only the ground elevation information, inaccurate location of tall buildings and trees can arise due to displacements. In order to accurately rectify the image, surface information should be considered. LiDAR is a rapidly growing technology in mapping areas, and it is a valuable source of information for DSM. The greatest advantage of LiDAR, therefore, is that it provides accurate ground elevation as well as surface information with high sampling density. However, when DSM generated from LiDAR is considered for orthorectification, the methodology of producing DSM affects the quality of orthoimages.

LiDAR data was utilized to generate experimental orthorectified digital aerial images using elevation information from DTM and DSM derived from LiDAR data. Considering the boundary problems of objects, ground and non-ground points were interpolated separately to maintain sharp boundaries, and then the two grids were joined into one DSM for the study area. The orthoimages produced with DSM show more accurate rectification than the orthoimages with DTM in the non-ground parts, as shown by the orthoimages overlaid with LiDAR points. Since LiDAR data provide elevation information of surfaces including buildings and trees, it is a very convenient and efficient elevation source for orthorectification with the rapid development of LiDAR technology. However, the use of DSM leads to other problems due to which true orthorectification cannot be performed.

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.

References

Amhar, F., J. Jansa, and C. Ries, 1998. The Generation of true orthophotos using a 3D building model in conjunction with a conventional DTM, *IAPRS Vol. 32, Part 4 GIS-between visions and applications*, Stuttgart. pp. 16-22.

Barazzetti, L., M. Brovelli, and M. Scaioni, 2007. Problems related to the generation of trueorthophotos with LiDAR DDSMs, ISPRS *Workshop on Laser Scanning 2007 and SilviLaser 2007*, Espoo, September 12-14, 2007, Finland.

Kim, H. T., Y. W. Sim, S. L. Park, and Y. I. Kim, 2002. Digital orthophoto generation from LiDAR data, *International Journal of Korean Society of Surveying, Geodesy, Photogrammetry, and Cartography*, 20(2): 137-143.

Liu, X., Z. Zhang, J. Peterson, and S. Chandra, 2007. LiDAR-derived high quality ground control information and DEM for image orthorectification, *Geoinformatica*, 11: 37-53.

Sheng, Y., P. Gong, and G. S. Bining, 2003. True orthoimage production for forested areas from large-scale aerial photographs, *Photogrametric Engineering and Remote sensing*, 69(3): 259-266.

Yoon, J-S, 2008. Adjustment of Exterior Orientations of the Digital Aerial Images using LiDAR Ground Control Points, *International Journal of Korean Society of Surveying*, 26(5), in printing.

Yoon, J-S., K-S. Lee, J-I. Shin, and C-S. Woo, 2006. Characteristics of airborne Lidar data and ground point separation in forested area, *Korean Journal of Remote Sensing*, 22(6): 533-542.

Zhou, G., W. Chen, J. A. Kelmelis, and D. Zhang, 2005. A comprehensive study on urban true orthorectification. *IEEE Transactions on geoscience and remote sensing*, 43(9): 2138-2147.