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Ground Point Extraction by Iterative Labeling of Airborne LiDAR Data in a Forested Area

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Abstract

Given that the distribution of trees is irregular and individual trees differ from one another, applying a Digital Terrain Model (DTM) for cityscapes to a forest inventory causes many errors. In this study, a new DTM-generating technique that utilizes airborne Light Detection And Ranging (LiDAR), with iterative labeling for recovery of ground points, is proposed to solve the inaccuracy problem that occurs when DTMs are generated in forested areas. The proposed method consists of three steps: (1) generation of the initial DTM by a process that performs mean planar filtering and multireturn filtering, (2) recovery of ground points by iterative labeling through application of a ground extraction filter and limitation conditions, and (3) refinement to create the final DTM. The proposed method was tested at the experimental site with morphological and TerraScan DTM-generating techniques, followed by a visual assessment and a quantitative accuracy assessment through comparison with in-situ data. In the visual assessment, the proposed method exhibits such advantages as less noise and more precise representation of topographic features. Also, the method shows excellent performance in improving the average absolute deviation values of 110.3 cm and 50.4 cm over the morphological method and the TerraScan method, respectively, in the quantitative assessment. Thus, the proposed method is judged to have successfully solved the inaccuracy problem that often occurs with generation of DTMs for a forested area.

Keywords: *DTM, mean planar filtering, recovery, refinement*

1. Introduction

The Digital Surface Model (DSM) represents the Earth's surface and includes all objects on it, whereas the Digital Terrain Model (DTM) represents the bare ground surface without objects such as tree canopies and buildings. The canopy-height model, or data on the height of objects on the ground, can be obtained by subtracting the DTM from the corresponding DSM (Susaki, 2012; St-Onge and Achaichia, 2001). Therefore, the DTM is widely utilized in applications such as city planning, disaster prevention, and creation of 3-D models. DTMs play a particularly important role as source data for estimation of treetops and biomass in forest measurement (Chang *et al.*, 2013; Edson and Wing, 2012; Nicholas *et al.*, 2012).

Generally, DTMs can be generated from remote-sensing data sources of satellite imagery, from air photos using stereo photogrammetry, and from airborne Light Detection And Ranging (LiDAR). The stereo images have been used to generate a digital elevation model of an extensive area. However, difficulties that affect image matching in forested areas include occlusions, repetitive patterns, shadows, perspective differences, rough surfaces, surface discontinuities, and mixed surfaces (Baltsavias *et al.*, 2006). LiDAR determines distances to objects on the surface by emitting high-frequency pulses of infrared light and recording the amount of time required for the pulses to be reflected back to the sensor (James *et al.*, 2007). Multiple returns are recorded for vertical sampling of forest and the ground surface. LiDAR data would be most useful in a forested area if an accurate, high-resolution ground-surface DTM could be generated from the filtered last return (Reutebuch *et al.*, 2003).

Many researchers have attempted to generate accurate DTMs using airborne LiDAR data. Morphological filtering, a broad set of image-processing operations, has the advantages of very simple conceptualization and easy application, and it has proved to be useful for removing nonground (or off-terrain) points, such as buildings and trees (Meng *et al.*, 2009a; Kobler *et al.*, 2007; Zhang *et al.*, 2003). Several filtering techniques, such as opening, closing, dilation, and erosion, are used to produce DTMs in morphological operations. However, a significant drawback of the morphological method is the need for a filter with a fixed window size. If a small window is applied, large objects such as buildings cannot be removed, although small objects are removed. If a large window is applied, some of the ground points are extracted as nonground points, causing topographical skewing

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(Zhang *et al.*, 2003). To solve the problem, alternative methods that remove nonground points and rebuild surface terrain by gradually increasing or changing window sizes have been proposed (Arefi *et al.*, 2007; Zhang *et al.*, 2003). Chen *et al.* (2007) developed a morphological method that gradually removes nonground points by gradually increasing window size. This technique allows unwanted objects such as trees to be removed by a relatively small filter, and larger unwanted objects such as buildings to be removed by expanding the size of the filter. The process is an iterative method. These morphological methods require determination of the variable filter sizes, depending on the sizes of objects in a target area, to create DTMs, which demonstrates that filter size has a direct effect on accuracy of DTMs.

In contrast to the morphological methods, studies have been conducted on labeling ground points in the airborne LiDAR dataset to generate DTMs (Filin and Pfeifer, 2009; Yuan *et al.*, 2009; Rabbania *et al.*, 2006; Sithole and Vosselman, 2005; Tóvári and Pfeifer, 2005). In these studies, the classification procedure is used to locate points grouped into one region on the basis of mathematical measurements, which is normally a region growing–based method (Meng *et al.*, 2010). Grouped points are classified into ground points on the basis of existing profiling information (Sithole and Vosselman, 2005), or extracted as ground points utilizing attribute information, such as slope, slope direction, and texture (Jacobsen and Lohmann, 2003; Schiewe, 2001). In addition to these methods, Ma (2005) extracted ground points by labeling airborne LiDAR data into planar surfaces and nonplanar surfaces after constructing a regression plane with a fixed filter. Algorithms in most of these studies were applied to relatively flat topography, such as urban areas, so the applications were set to flat areas (Filin and Pfeifer, 2009; Tóvári and Pfeifer, 2005; Jacobsen and Lohmann, 2003; Roggero, 2001). Therefore, the reliability of these labeling models for mountainous, forested, or urban-outskirt areas that have various aspects of landscapes must be verified (Meng *et al.*, 2010).

The International Society for Photogrammetry and Remote Sensing (ISRPS) constructs various reference databases over test areas under diverse conditions for use by researchers. Filtering methods that utilize these data have been developed, and comparative analyses with conventional methods have been conducted (Meng *et al.*, 2009a; Silváan-Cáardenasz and Wang, 2006; Sithole and Vosselman, 2005). Sithole and Vosselman (2005) conducted a comparative assessment of filtering methods for 12 ISPRS test areas by application of 8 conventional methods of extracting ground points. Their results show good performance for conventional methods in areas with flat or smoothly contoured terrain but revealed many errors in areas with steep slopes, man-made structures, and complicated vegetation.

Thus, the problem with the morphological method is that the accuracy of the DTM is dependent on filter size, and the problem with the labeling method is that it is optimized to urban areas. A technique is needed that will be independent of filter size and will show high performance in forested areas for generation of DTMs. This study proposes to demonstrate that the iterative labeling method is applicable to forested areas with rugged terrains.

2. Methodology and Materials

2.1 Methodology

The conceptual work flow of the proposed method is shown in Fig. 1. Step 1 is the generation of a DTM by a process that performs Mean Planar Filtering (MPF) and multireturn filtering. Step 2 is recovery of ground points in an iterative process that utilizes a ground extraction filter and limitation conditions. Step 3 is creation of the final DTM through the process of refinement. The applicability of the proposed method is verified by comparison with data acquired during the field survey. In this study, ArcGIS 9.3 software was used for Triangular Irregular Network (TIN) interpolation, and the Matlab program was used for all other processes.

2.1.1 Preprocessing

LiDAR data, which are point data defined by X, Y, and Z coordinates, are transformed to raster data by application of TIN interpolation and a nearest-neighborhood method because the proposed method uses the filtering processes based on raster. The size of raster is determined by the density of the LiDAR point cloud (Hu, 2003). For example, the size of raster can be determined to 50 cm when the density of point cloud is 4 points/m^2.

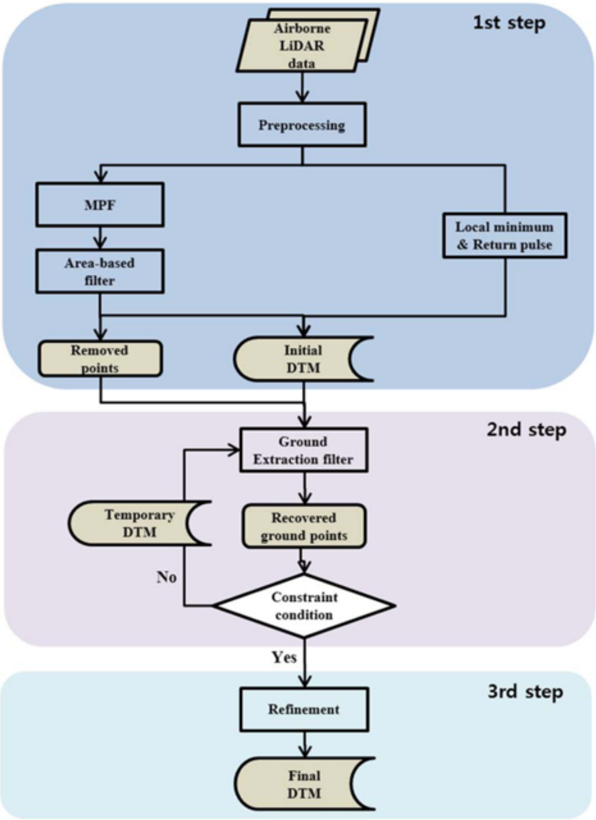


Fig. 1. Research Flow Diagram for Recovery of Ground Points in Forestry

Unexpected outliers that occur in the LiDAR acquisition process can generate serious distortions. These point outliers are often randomly distributed over a study area, and they have unrealistically high or low elevation values and must be removed during preprocessing (Meng *et al.*, 2009a; 2009b; Wang *et al.*, 2009). When the DTM is created, low outliers can give the appearance of sunken topography, and high outliers can give the appearance of cones. These outliers can be identified by examining the frequency distribution of elevation values (Silváan-Cáardenasz and Wang, 2006). In this study, a histogram showing the height distribution of the LiDAR data was used during preprocessing to remove outliers with high values or minus values. The last return pulse of the LiDAR data is used in all processes, except one process that utilizes multireturns.

2.1.2 Generation of Initial DTM

MPF is the simple manipulation of a 3 × 3 kernel that classifies LiDAR data into planar surfaces and nonplanar surfaces (Kim *et al.*, 2013). MPF creates a mean plane of 3 × 3 size by the mean value of 9 height values. The center of the kernel is then defined as a nonplanar pixel if even one value is at a distance from the mean plane that is greater than a given threshold in the 9 height values. This process is applied across the entire image. The threshold is dependent on the raster size, and it is determined by the 5 to 3 ratio for the raster size (Kim *et al.*, 2013). For example, the threshold is 30 cm if the raster size is 50 cm. This process transforms the LiDAR data into a segmented binary image composed of planar surfaces and nonplanar surfaces.

Ground, roof, and flat tree canopy points were classified as planar surfaces after application of MPF. Therefore, roof and flat tree canopy points in a planar surface must be removed to obtain only ground points. An area-based filter is used for this purpose (Ma, 2005). The area of the largest roof segment in a binary image is set as the threshold, and then segments that have an area less than the threshold are removed. Because the area of a roof in an ordinary building is larger than a tree canopy, the largest roof area is used as a threshold value.

Extracting ground points through MPF and area-based filtering gives optimal results in urban areas. However, after segmentation by MPF, planar surfaces of forested areas are small because the tree canopy is classified as nonplanar and the roads in forested areas are covered by tree canopy. The ground points of forested areas are mostly eliminated by area-based filtering, and DTMs would generate numerous errors. Kim *et al.* (2013) used the multireturn pulse of LiDAR to solve this problem. LiDAR detects ground points at which the height difference between the first return and the last return is more than 5 m, which is the defined minimum height of trees in nonplanar surfaces (Korea Forest Service, 2009). When the tree height is greater than 5 m, however, the first LiDAR pulse and the last LiDAR pulse can be printed on the canopy, even though the height differences between the first and last returns are more than 5 m. This point is actually not a ground point, although it is classified as a ground point by the height difference of the return pulses. Therefore, an additional process is used to solve this problem. When the last return pulse indicates that a point extracted by height difference is a local minimum within a 2.5 m radius experimental value, the point is extracted as a ground point within the forested area (Kim *et al.*, 2013).

2.1.3 Iterative Labeling using Ground Extraction Filter

Although MPF and area-based filtering exhibit good performance for urban areas, they have the drawback of eliminating almost all ground points within forested areas. To compensate for this disadvantage, ground points within forested areas are added by the use of return-pulse and local-minimum filters, but these two filters are applicable only to the region of nonplanar points extracted from MPF. In other words, iterative labeling enables recovery of additional ground points that are otherwise nonusable because of removal via area-based filtering. The recovery process for ground points removed within forested areas is described as follows:

1. Generate the initial DTM using extracted ground points.
2. Recover points that have height differences between the initial DTM and the planar points removed by area-based filtering that are no more than 2 m. The height difference, 2 m, is a criterion representing lower vegetation, where points beyond 2 m are considered to be points reflected from the top of the lower vegetation (Korea Forest Service, 2009).
3. Perform the recovery process described in process 2 until the limitation condition is met. While the limitation condition is not satisfied, ground points recovered through the process described in item 2 will be added to existing ground points and the next DTM is generated.
4. When the threshold condition is met, the iteration is stopped, and the refinement process is the next phase.

At this point, the limitation condition is that “the number of recovered points must be no greater than 10% (ratio = 0.1) of the number of total points. The recovered points indicate ground points extracted through iteration, and the sum of the recovered points and nonrecovered points in each iteration is the total points. In particular, all points removed by the area-based filtering are total points in the initial iteration, and nonrecovered points detected in the previous iteration are total points in the next iteration.

2.1.4 Refinement

Refinement of the DTM involves repeated comparison of the DSM with the initial DTM generated in the previous steps. The refinement process regenerates an accurate and detailed DTM, with additional ground points detected when the height difference between the DSM and the initial DTM is less than 0.3 m. In other words, ground points used in TIN interpolation are additionally extracted by the repeated refinement process. The threshold of difference is based on the vertical accuracy (0.15 m) of LiDAR (Ma, 2005). If all the extracted ground points are used, an initial DTM is created by TIN interpolation.

2.2 Comparative Assessment Method

The technique for generating DTMs with morphological filtering methods is to first sequentially apply the erosion operation and the dilation operation to remove unwanted above-ground objects, such as buildings or trees. The erosion operation and the dilation operation are defined by Eqs. (1) and (2), respectively, in which the former removes above-ground objects and the latter expands shrunken objects to their original sizes. Although generating DTMs with morphological filters is a simple process with the advantage of fast and easy applicability, the method has the disadvantage of expanding sizes of morphological filters in proportion to the increase in the sizes of objects above the ground. This drawback may reduce the accuracy of DTMs. In this study, the filtering size that would remove tree canopies most effectively was selected.

$$\text{Erosion: } e_p = \min(z_{all}) \tag{1}$$

$$\text{Dilation: } d_p = \max(z_{all}) \tag{2}$$

d_p = Central value of filter newly replaced through dilation operation

e_p = Central value of filter newly replaced through erosion operation

Z_{all} = All height values within filter

TerraScan software is used to classify LiDAR data into ground surface, vegetations and buidings. It used advance ATIN filter to classify ground points. Nonetheless, according to TerraScan official website, advance ATIN in TerraScan has been improved whereby the classification process undergoes two phases; firstly, search initial points and builds an initial temporary TIN model and secondly, lift the model upwards by iteratively adds new laser points to it (Sulaiman *et al.*, 2010). Depending on the ground points and nonground points classification; in particular, the TerraScan divides the dataset into six block categories, that is, Ground, Low Vegetation, Medium Vegetation, High Vegetation, Building, and Low Point Items, according to predefined settings. Processing using the TerraScan can be done based on first return and last return, depending on return pulses in each category, possibly resulting in the generation of a total of 12 ASCII format files. In this study, the result of ground point classification extracted by use of last return values was used (Jeon *et al.*, 2010).

2.3 Materials

The experimental site is located around the Independence Hall of Korea in Cheonan, South Korea (36° 47' 1" N, 127° 13' 22" E). The forests are dominated by conifers, and the area has a few artificial objects. Airborne LiDAR data were acquired September 1, 2009, at an altitude of 1300 m above mean sea level by using an Optech ALTM 3070 system. Point density was approximately 4.3 points/m^2. The first return pulse and the last return pulse were collected, and the vertical accuracy was approximately ±15 cm (Fig. 2).

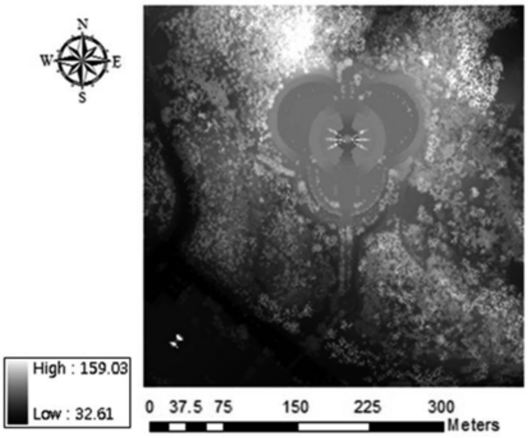
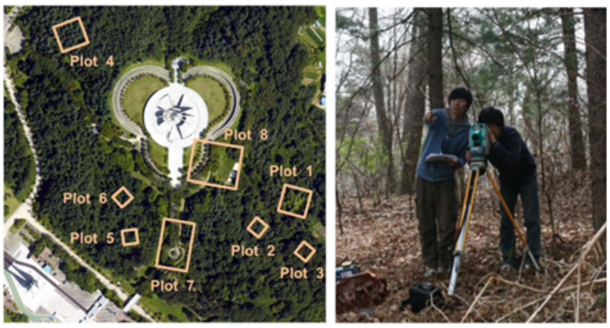


Fig. 2. DSM of Experimental Site Transformed into a Grid



(a) (b)

Fig. 3. (a) Plots based on Aerial Images and In-situ Data in the Experimental Site, (b) Photograph Showing Measurement of Ground Height with the Use of the Juno SB System

We selected two 20 m × 20 m plots and four 10 m × 10 m plots in the study area and conducted a careful field survey in April of 2011 to construct the reference data set. The reference data set included tree positions, diameter at breast height, crown area, and tree height by using a Juno SB hand-held Global Positioning System (GPS) manufactured by Trimble and Total Station. The plots were selected on the basis of their positional relations to the neighboring objects on the ground. Tree heights and heights of ground points were measured in 52 locations. Fig. 3 shows the locations of eight plots within the target area, as well as a photograph of the acquisition of in-situ data by using Total Station.

3. Results and Discussion

3.1 Visual Assessment

By sequential application of the proposed method at the experimental site, the result of each phase was extracted. Abnormal values in the raw airborne LiDAR data were eliminated by histograms, and the LiDAR raster size was converted to 0.5 m by TIN interpolation. Extraction of ground points for the initial DTM was performed to obtain the result shown in Fig. 4(a). This result verified that small ground clusters were removed by area-based filtering. Although return pulses and local minimums were used in an attempt to supplement the above result, extraction of a sufficient volume of ground points to generate the DTM in the

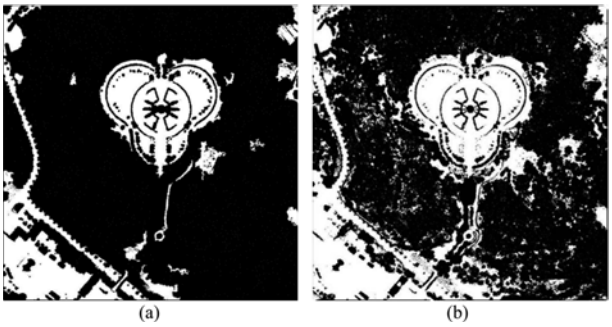


Fig. 4. Results of Extracting Ground Points: (a) Before Iterative Labeling, (B) After Iterative Labeling

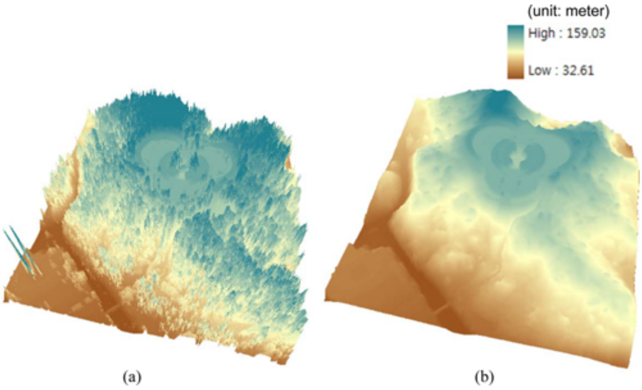


Fig. 5. (a) 3-D Rendering of DSM, (b) 3-D Rendering of DTM

area where many ground points had been removed was not possible. Nevertheless, a number of ground points, besides those extracted earlier, were successfully recovered within the forest as the iteration progressed. More ground points were added as the iteration continued. The processing stopped when the threshold condition was met during the execution of the third iteration. Comparison of the before (Fig. 4(a)) and after (Fig. 4(b)) results verifies that the proposed method allows a sufficient number of ground points to be recovered to generate more accurate and detailed DTMs of forested areas. This improvement is attributed to the recovery of ground points not available before the use of iterative labeling.

Figure 5 shows a 3-D rendering of a DSM and a 3-D rendering of a DTM generated by the proposed method. This method allows verification that artificial objects and tree canopies within the experimental site were effectively removed. Moreover, in light of the fact that forest roads as well as topographical features are represented in detail, this method also provides good visualization, particularly with respect to the forestry mensuration.

3.2 Quantitative Assessment

Figure 6 shows the results of applying three different filtering methods, including the proposed method, to the experimental site. The accuracy of the morphological method is dependent on filter size, as is seen in Fig. 6(a). Although all of the tree canopies were removed from the target area, traces of the morphological filter were found in the DTM, which caused local refinement to deteriorate. This side effect is caused by a filter size smaller than some objects in the target area. If the filter size is increased to solve this problem, large objects on the surface will be removed, but a smooth DTM that distorts actual topography may be generated. The result of the TerraScan method in Fig. 6(b) shows the refinement to some extent but includes salt-and-pepper noise because of the failure of sufficiently filtered pulses reflected on the tops of canopies. Therefore, additional processing that eliminates such forms of noise is needed. Despite the foregoing, the proposed method can improve the topographic refinement enough to show terrain sinuosity and forest roads through recovery of ground points, with little noise and natural geographic/topographic representation, as seen in Fig. 6(c). Whereas the morphological method and TerraScan method are able to finely represent topographic features but produces much noise, the proposed method successfully offers topographic refinement through recovery of additional ground points, which is verified through visual assessment.

To conduct a quantitative assessment of the comparative analysis, the Average Absolute Deviation (AAD) was computed from the

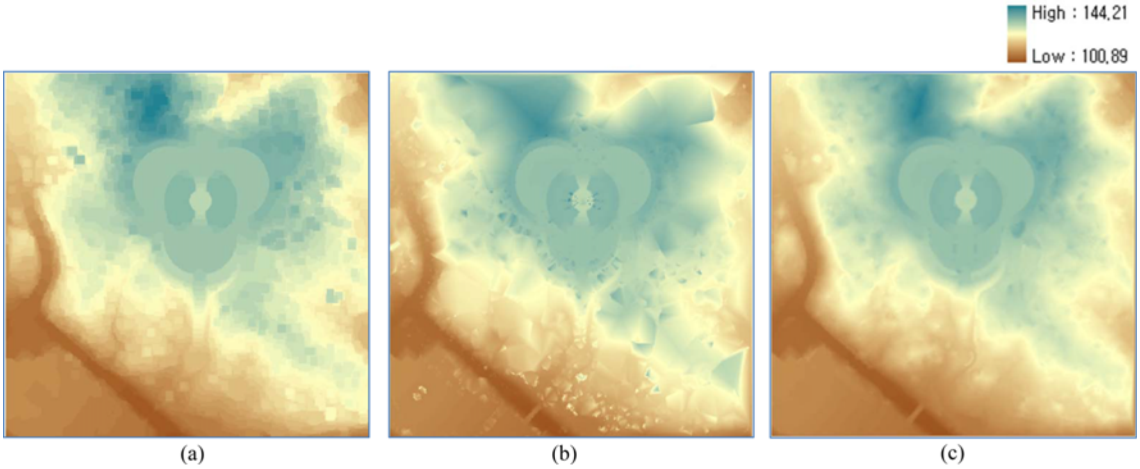
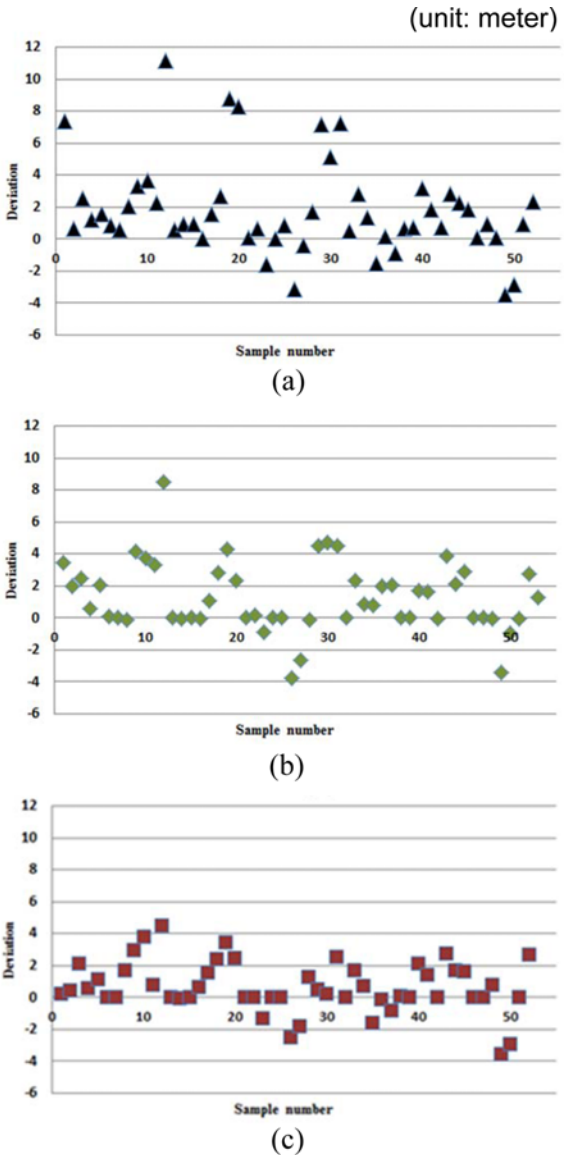


Fig. 6. Final DTM: (a) Morphological Method, (b) TerraScan Method, (c) Proposed Method



(a)

(b)

(c)

Fig. 7. Deviation between DTM and In-situ Data: (a) Morphological Method, (b) TerraScan Method, (c) Proposed Method

data acquired at the site. The AAD is found by calculating the absolute deviation of the in-situ acquisition value and the DTM value at the same location. Deviations in each measurement location are plotted in Fig. 7. AADs for each method are 2.331 m (morphological method), 1.732 m (TerraScan method), and 1.228 m (proposed method). The morphological method shows that errors caused by filter sizes still exist during the quantitative assessment, which is seen in the graph of Fig. 7(a). Therefore, large deviations exist. The TerraScan method shows that the tendency is similar to that of the morphological method in Fig. 7(b). The proposed method shows remarkably improved accuracy compared with the above two results in Fig. 7(c). This result demonstrates that the proposed method of extracting ground points within forests is more effective than the morphological method and TerraScan method. In the case of the proposed method, values improved by 110.3 cm and 50.4 cm over the morphological method and the TerraScan method, respectively. These quantitative assessment results emphasize that the proposed method produces comparatively less noise and is superior in representing local refinement.

However, in areas where tree canopies are in contact and their density is high, most multireturns in the airborne LiDAR are reflected in the tops of tree canopies, which causes the corresponding region to be interpreted as ground points. Such a problem occurred in the region at the uppermost elevation in the target area and is found in all three methods tested in this study.

4. Conclusions

The current study attempts to solve the accuracy deterioration problem that occurs in the morphological method and the labeling method of generating DTMs in forested areas and rough terrains. A DTM-generating method based on iterative labeling is proposed to recover ground points within forest areas. This proposed method, along with existing methods, was applied to the experimental site, and both visual assessment and quantitative assessment were carried out. The proposed method incurred less noise than other methods, while having the advantage of accounting for terrains more precisely. The proposed method demonstrated its effectiveness by showing values improved by 110.3 cm and 50.4 cm over the morphological method and the TerraScan method, respectively.

However, pulses of airborne LiDAR failed to penetrate tree canopies in areas where their density is very high, causing errors in generated DTMs. Future research should focus on rectifying such errors in areas with dense tree canopies.

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