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Improving the Quality of Filtered Lidar Data by Local Operations

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Abstract : Introduction of lidar technology have contributed to a wide range of applications in generating quality surface models. Accordingly, because of the importance of terrain surface models in mapping applications, rigorous studies have been performed to extract ground points from a lidar data point cloud. Although most filters have been shown abilities to extract ground points with their parameters tuned, however, most experiments revealed that there are certain limitations in optimizing filter parameters and the correction of remaining misclassified points is not straightforward. In this study, therefore, a method to improve the quality of filtered lidar data is proposed, which exploits neighboring surface properties arising between immediate neighbors. The method comprises a sequence of procedures which can reduce commission and omission errors. Commission errors occurring in low-rise objects are reduced by utilizing morphological operations. On the other hand, omission errors are reduced by adding missing ground points around step edges. Experimental results show that the qualities of filtered data can be improved considerably by the proposed method.

Key Words : lidar data filtering, filtering quality, omission errors, commission errors.

1. Introduction

Because of accuracy and rapid acquisition, airborne laser scanning data has been utilized in many mapping applications such as forest inventory management, change detection, and virtual city modeling. One essential step for most of the applications, however, is to extract ground points from a lidar point cloud. Accordingly, there have been rigorous studies to filter lidar data.

Vosselman (2000) proposed a slope-based filter that removes nonground points above a slope profile centered at its neighboring points. The method was revised by Sithole (2001) to reduce omission errors occurring around steep ground features by adjusting slope factor adaptively according to local slopes computed in a preliminarily process. Kilian (1996) presented a morphological operation-based filter, whereby the likelihood of points to be ground is evaluated at each window size and then the classes of points are determined at one final step. Zhang *et al.* (2003) proposed a filter that preserves certain mound-like ground features while removing certain points based on their deviations from the surfaces derived by

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progressively increasing morphological operations.

Local surface properties such as gradients and Laplacian of Gaussian (LoG) have been employed to distinguish ground and nonground features (Brovelli *et al.*, 2002; Wack and Wimmer, 2002). Histogram, and surface profiles were used in Jacobsen and Lohmann (2003). Elmqvist (2002) proposed to integrate local gradient properties into an active contour model to construct intermediate base surface models. Triangulated irregular networks (TINs) have been used as based surface models in many filtering approaches. Axelsson (2000) classified points based on angle difference between points and their base triangles. Sohn and Dowman (2002) found optimal ground points which maximize the connectivity among ground points and separability among nonground points, whereby those geometric characteristics are obtained from hypothesized triangulations. Kraus and Pfeifer (1998) proposed a lidar filter utilizing kriging interpolation and skewed weighting scheme. Briese and Pfeifer (2001) revised their method such that the filtering process can be expedited and large nonground objects removed more efficiently.

In response to rigorous studies on lidar data filtering, some evaluations on their performance have been conducted. Sithole and Vosselman (2004) compared the performance of lidar filters using filtered data generated with their parameters adjusted optimally and stated advantages and drawbacks of the lidar filters tested. Zhang and Whitman (2005) evaluated the performance of lidar filters which use spatial operations such as minimum, slope-profile, and morphological openings.

From the previous studies, it has been shown that most lidar filters exploit smoothness and continuity that can be observed in most ground features, assuming that ground features are not connected smoothly to nonground objects. Although utilizing those characteristics is essential in filtering lidar data, however, it is not unusual that resulting ground data misses ground points from sharp ground features such as step edges and ditches while it has nonground points from low-rise objects such as shrubs and terraces. Because of the discrepancies between filtering assumptions and the landscape complexity in real world, tuning parameters for a filter would have limitations in improving the quality of lidar data filtering. Filtered data generated even with parameters tuned optimally, thereafter, always has a certain amount of commission and omission errors, which may not be trivial to disregard for real world applications and hence require subsequent interactive corrections.

Fig. 1 illustrates problems caused by commission and omission errors stated above. While manual corrections can be tedious and take times significantly, however, there have been relatively few studies on improving the quality of filtered lidar data in an automated way. Hence, this paper proposes a procedure to enhance the quality of filtered lidar data in an automated way using local operations so that the interactive edition time can be minimized and the DTMs can represent real world landscapes in a more accurate way. “Local operations” in this study are referred to as processes that are applied at a certain location based on values of local areas within an image window or a certain radius. In this study, there are two types of local operations. Firstly, morphological operations were applied in the first and third processes with 3 by 3 windows. Secondly, points classified as nonground points were checked if they fulfill a step edge condition, whereby the elevation of a nonground candidate point is compared with that of a certain ground point in its local neighborhood. In the following, the methodology is described first in Section 2. Then, experimental results will be presented in and discussed in Section 3, followed by concluding remarks in Section 4.

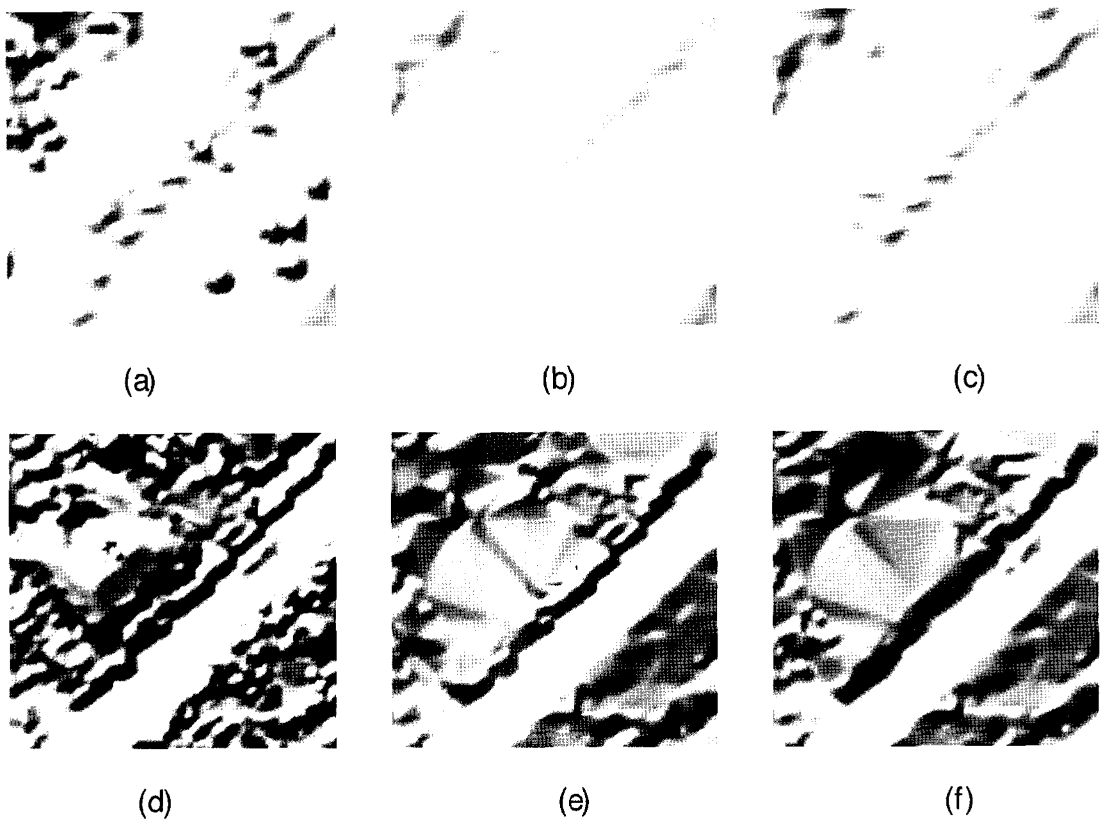

Fig. 1. Example of commission and omission errors in filtered data. (a)-(c) are shaded relief maps of 30m × 30m showing effects of commission errors: (a) Raw data, (b) reference data, and (c) filtered data. Filtered data has low-rise nonground features along the upper right diagonal direction. (d)-(f) are shaded relief maps of 50m × 50m showing effects of omission errors: (d) Raw data, (e) reference data, and (f) filtered data. A step edge immediately below a building and above the road has lost its sharpness in filtered data.

2. Proposed Method

As lidar filters are tuned by following general properties of ground and nonground features described in the foregoing section, most errors in filtered data are caused by the deviations from the general assumptions at certain ground and nonground features Thus, the approach proposed is to compensate for the weaknesses of general concepts in lidar data filtering.

The proposed method exploits neighborhood surface characteristics in filtered data, which is subdivided into three steps. In the first step, commission errors which are likely to arise at low-rise objects are reduced by using surfaces derived from a sequence of morphological operations. Then, in the second step, omission errors are reduced by comparison with the elevation of neighboring points. Here, it should be noted that the process reducing commission errors is performed before that reducing omission errors. This sequence was designed to suppress commission errors first because some commission errors are likely to cause addition of nonground points into ground around them during the process of reducing omission errors so that commission error reduction lessens this problem. Finally, reduction of commission error is performed again but with a generous condition. The purpose of this process is to suppress some commission errors which may be newly generated during the second step. In the following, each step is described in detail.

1) First Process: Reducing Commission Errors

The purpose of the first step is to suppress points from low-rise objects such as cars and small plants. Fig. 2 illustrates the concepts of this process, showing

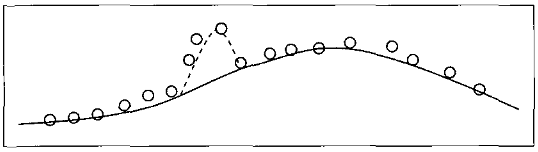

Fig. 2. Illustration of the process reducing commission errors. This process removes nonground points from low-rise objects (shaded circles) on ground (solid line).

a low-rise object and ground surface to be obtained. Low-rise objects may be detected by analyzing topographic primal sketch (Haralick *et al.*, 1983) or by checking points located inside enclosed contours (Seo, 2003). One efficient way is to exploit surfaces derived from morphological opening operations (Zhang *et al.*, 2003). Their approach generates base surfaces through a sequence of morphological operations with expanding windows and removes nonground points which are displaced over a certain amount from the base surfaces.

In this study, the approach by Zhang *et al.* (2003) is adopted to reduce commission errors. However, the approach in this study uses small windows so that small low-rise objects should be removed. For each window size, the maximum difference (Δz_{max})

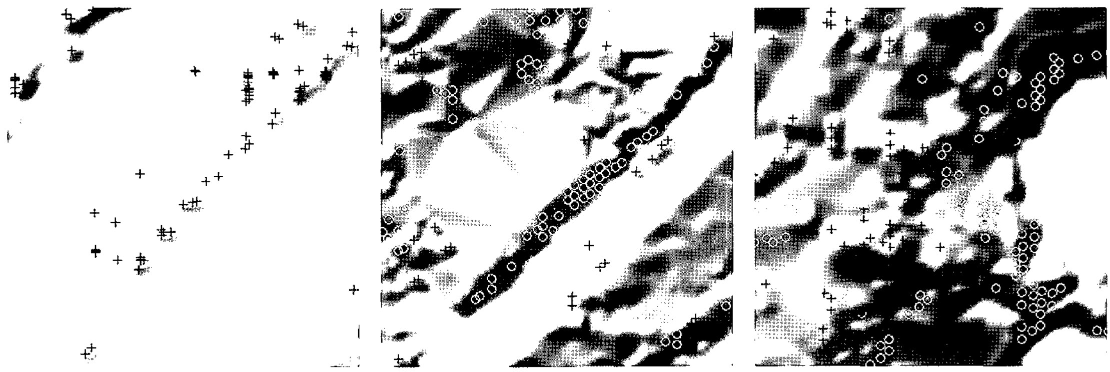

Fig. 3. Examples of errors in filtered data. Commission errors are denoted by black crosses and omission errors by white circles.

Fig. 4. Results after the first process reducing commission errors. Commission and omission errors after the first process on given filtered data shown in Fig. 3 are shown in black crosses and white circles, respectively.

allowed is computed by

$$\Delta z_{max} = \varepsilon + s_{max} \cdot c \cdot hw \qquad (1)$$

where ε is a constant to allow small ground variation, s_{max} denotes maximum slope, c is the grid cell size and hw is half window size. Then, ground points in filtered data which are deviated more than the maximum difference from the base surface are reclassified into nonground. Fig. 3 shows examples of errors existing in a filtered data as compared with reference data. Given the filtered data, Fig. 4 presents effects of the first process, whereby an elevation model of cell size 0.5 m was generated, maximum slope factor in Equation 1 was set to 0.2, and window sizes applied for morphological operations were 3×3 and 5×5 pixels. Fig. 3 shows that many points from small low-rise peaks were removed successfully while some valid ground points were also removed mistakenly, which will be discussed further in the subsequent processes.

2) Second Process: Reducing Omission Errors

After commission errors being suppressed in the first process, the second process is designed to add missing ground points around sharp ground features, in particular, step edges. Omission errors tend to arise frequently around sharp ground features (Fig. 5). Fig. 6 illustrates missing ground points on top and bottom of a step edge.

To resolve the problem of losing sharp ground features around step edges, omission errors are reduced by the following process. A nonground point is selected and its elevation is compared with neighboring ground points within a specified distance. If any elevation difference with neighboring points is smaller than a specified value, then the nonground point is reclassified into ground. This can be summarized as:

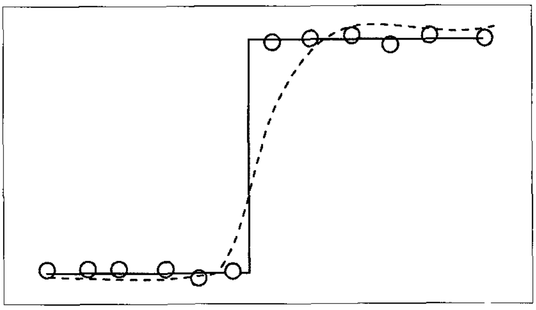

Fig. 6. Illustration of the second process reducing omission errors. Ground surface is assumed to be smooth (dashed line) in most lidar filters, which causes missing ground points (shaded points) at sharp ground features (solid line). The second process reduces this type of omission errors, enhancing sharpness at step edges.

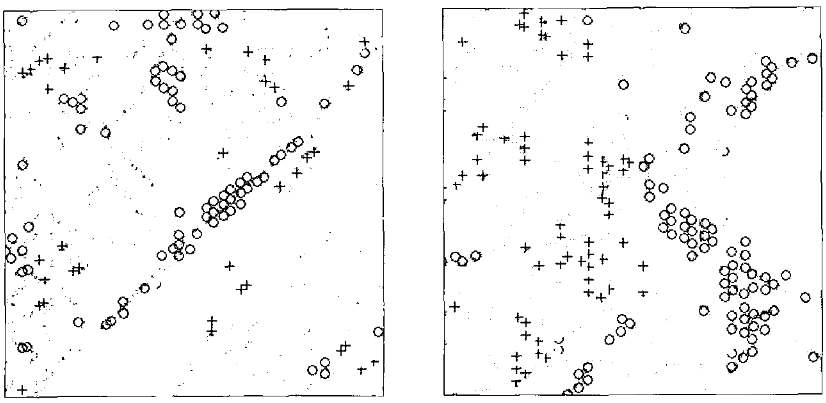

Fig. 5. Distribution of omission and commission errors in edge maps. Omission and commission errors of filtered data are displayed by circles and crosses, respectively in edge maps (gray pixels) generated by a Canny edge operator.

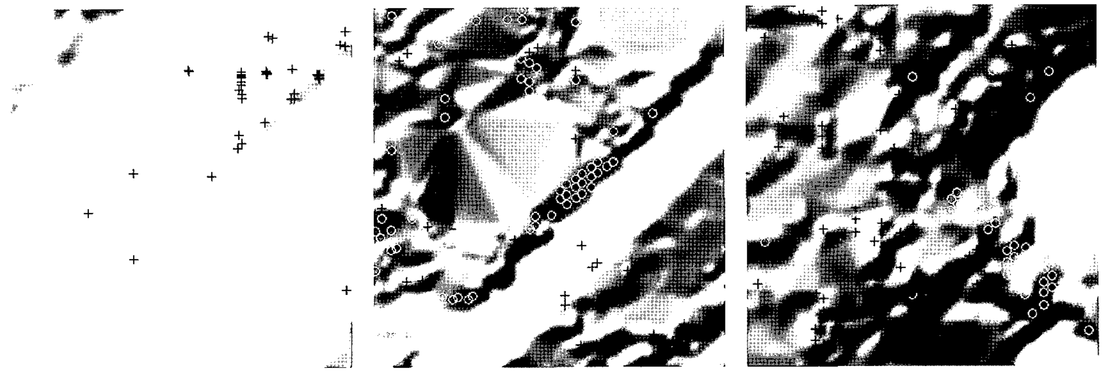

Fig. 7. Results after the second process reducing omission errors.

$$\text{class}(P_i) = \begin{cases} \text{ground} & \text{if } P_j, \text{class}(P_j) = \text{ground}, P_j \text{ neighborhood}(P_i), \text{ and } P_i - P_j < \Delta z_{\max} \\ \text{nonground} & \text{otherwise} \end{cases} \quad (2)$$

Fig. 7 shows results of this refinement process with search radius 2 m and Δz_{max}, 0.0 in Equation 2. As can be seen, many missing ground points were successfully identified. However, some nonground points were also added mistakenly into the ground class since their elevations are similar to their neighborhood elevations. The following process will reduce this problem.

3) Third Process: Moderate Reducing Commission Errors

As stated previously, the objective of this process is to suppress commission errors during the second process. For example, in the second process, some points from low-rise objects which are close to sharp ground features would be mistakenly classified into ground by fulfilling the ground condition stated in Equation 2. Hence, this process was added in order to remove such points. This process performs a process similar to that of the first process. However, this process takes a relatively large slope factor in order to preserve the sharpness of ground features achieved by the second step. Fig. 8 presents some results from this refinement step. As can be seen, through the step, many nonground points were removed as compared with Fig. 7, whereby commission errors were reduced significantly with minor acceptance of omission errors.

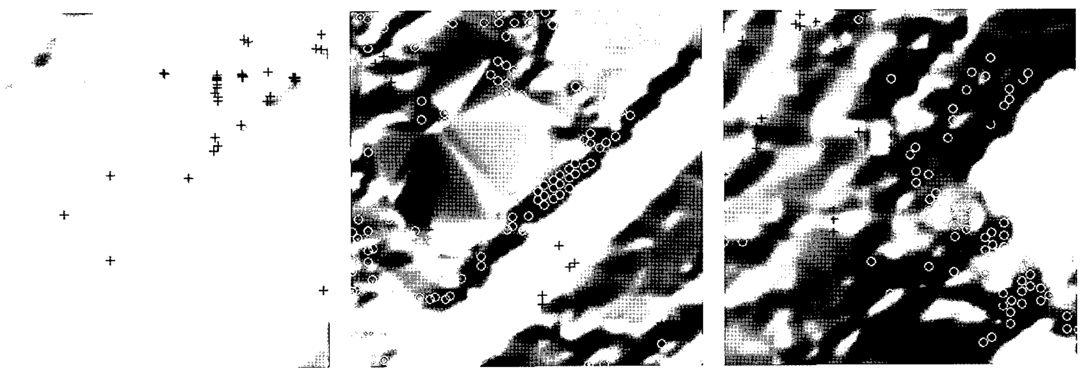

Fig. 8. Results after the third process reducing commission errors in a moderate way.

3. Experiments

1) Test Data

A dataset was downloaded from a lidar filter test website published by ISPRS, which is http:// enterprise.lr.tudelft.nl/frs/isprs/filtertest/ (last accessed on November 4, 2005). The ISPRS datasets used in this study are subsets of the lidar survey performed by FOTONOR AS with an Optech ALTM scanner in 2000. The dataset spans about 133 meters by 195meters in the X and Y directions (Fig. 9-a). Its point density is 1.04 (points/m^2) and spacing 0.97 meters. As can be seen, it contains roads, vegetation, and residential buildings on steep terrain and many ground step edges aligned in the northeast direction. It is notable that the height of trees on steep terrain is low and increases the difficulty in filtering. Reference

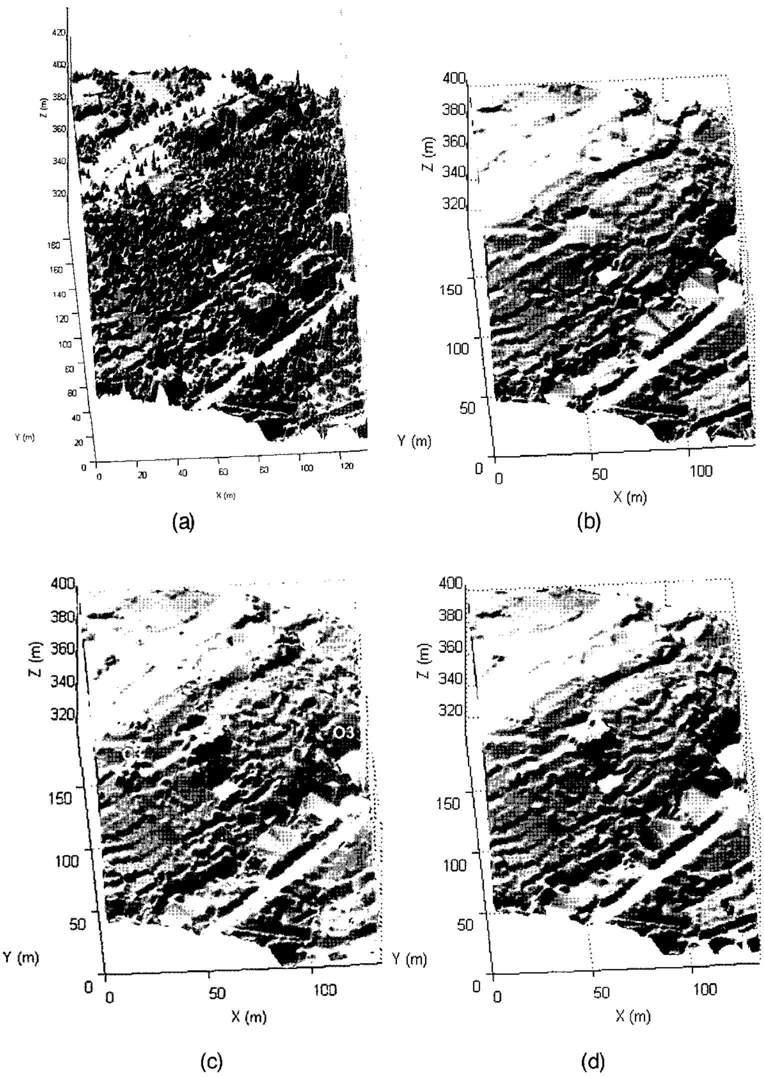

Fig. 9. Terrain models from lidar data. Shaded relief maps were generated from (a) raw data, and ground points in (b) reference data, (c) filtered data, and (d) improved data.

data was also obtained from the ISPRS test site together (Fig. 9-b). In the reference data, the number of ground points is 16,501 among the total of 27,470 points.

From the downloaded data, blunders were first detected and excluded at the initial step of filtering. Then main filtering process was performed on the lidar data by a linear prediction method which is similar to the approach by Kraus and Pfeifer (1998) but uses a constant threshold value instead of the skewed weighting scheme. After testing with varying parameter, a filtered data with good quality was chosen as input data for experiment on the proposed method (Fig. 9-c).

2) Results

For implementing the procedure, first the point cloud of input filtered data was converted into a grid of cell size 0.5 m, where the Delaunay triangulation-based cubic interpolation was applied for interpolation (Fig. 9-c). Then, in the first process, after a few trials, the maximum slope factor, 0.1 and the maximum window size, 5 by 5 pixels were set for removing low-rise nonground points based on progressive morphological operations. In the second process, the maximum elevation difference parameter described in Equation 2 was set to 0.0 and search distance to 2.0m, assuming that most sharp features to be added are apart less than the distance from ground points in filtered data. Finally, in the third process, the maximum slope factor was set to 0.2 with all the other parameters set to the same values as in the first process.

With comparison to the given reference classification, initial filtered data had the total of 3065 erroneous points and the filtered data improved through the proposed method the total of 2315 points. Although the difference in terms of error counts may not appear significant, however, the comparison of resulting terrain models presented in Fig. 9-c and Fig. 9-d shows that the improving method removed low-rise objects and sharpened some step edges satisfactorily over the study site. In detail, some commission errors caused by low-rise objects indicated by C1 in Fig. 9-c which may be from shrubs beside a road and by C2 which may be from vehicles were removed successfully. Also, nonground low objects indicated by C3 which appear to be from small trees or plants could be completely removed. In addition, the step edges marked by O1 and O2 were sharpened by capturing missing ground points around the edges.

Although the procedure improved the quality of extracted terrain model in terms of error counts and visual quality, however, many errors still remained and in some cases hindered the improving procedure. For example, a group of points which seem to be from a building indicated by C4 affected the procedure, increasing commission errors at the location through the procedure. Also, ground points from some ramp type of edges whose elevations increase gradually, for example, the area marked by O3 were not classified correctly as ground in the procedure.

4. Concluding Remarks

In this study, the causes of errors in lidar filtered data were discussed and a sequence of processed were proposed to lessen the errors. It was stated that most lidar filters exploit the smoothness and continuity of terrain surface and thus their filtering errors tend to occur at areas such as sharp ground features and smooth connection between ground and nonground features. With these ideas, a procedure was proposed to reduce filtering errors based on local surface properties.

The experimental results demonstrate that the method improved the quality of the terrain model in terms of error counts and visualization. From our experiments, it was found that filtered data can be improved automatically by incorporating local surface properties in post-processing. The automation will cut down the overload in manual editing of filtered data. Further research and development are needed to achieve high quality terrain models from lidar data by integrating complex ground features and their relationships in post-filtering processes which tend to be neglected in general filtering concepts.

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