A COMPETITION BASED ROOF DETECTION ALGORITHM FROM AIRBORNE LIDAR DATA

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KEY WORDS: LiDAR; Detection; Aerial Photogrammetry; Feature Detection; Buildings

ABSTRACT:

3D city model reconstruction is one of the main application of airborne laser scanning system. Roof detection is a primary step which needs to find each roof from irregular point clouds with noise points involved. Another problem existed in roof detection is that the detected sequence of roofs will affect the size and shape of detected roofs even though a lot fancy algorithm are applied. In this paper, we first analyzed the reason of roof size changing caused by detected sequence, then an weighted points normal voting based algorithm is proposed to detect roofs with multiple threshold applied. After than a boundary points competition approach is investigated to optimize the gained roof which can re-adjust the size and shape of detected roof and reduce the influence of roof detection sequence. Experiments is given to prove the algorithm proposed.

1. INTRODUCTION

Airborne laser scanning (ALS) system is an new surveying and mapping system which has been in rapidly development in recent years. Building model reconstruction using ALS system is becoming one of the important approach for 3D city modeling application. In the building model reconstruction procedure, features of building are often needed especially the roof planes and edges of roofs. The building reconstruction technique can be seemed as a method about how to utilize the detected features to find a right or logical model according the given data by means of feature fusion, analyzing and grouping, etc. Roof planes are primary and important features for building model reconstruction in ALS data which gained much focus(Brenner 2005).

As a basic technique which not only widely used in photogrammetry but also in compute vision area, roof plane detected has been deeply investigated. Region segmentation is one of the method used which grow up from small piece based on similar feature property which is similar to region growing. The roof data in ALS often has similar height or height change, so this method often works but it cannot works well for data with much noise and roof size changes a lot. Hough transformation and extended hough transformation methods are often used for roof planes detection which extend the basic formula of Hough transformation from 2D line to 3D plane searching(Takano, Doihara et al. 2004). As we all know, the Hough Transformation needs a lot of computation cost and can be easily influenced by planes far away but has similar directions. Normal voting is much simpler than Hough Transformation for plane detection in ALS data. Theoretically, after the irregular point clouds being organized as a mesh, the triangles belong to same plane will have normal of almost same direction. Because the existence of noise, triangles belong to one plane won't have same normal direction but will have near direction, thus the main direction of plane can be gotten by a voting algorithm(Maas and Vosselman 1999; Vosselman 1999). However, the roof detection is detecting of points belong to planes rather triangle belong to planes, so the algorithm should be based on points rather on triangles. Even though each roof can be detected from irregular point clouds using various fancy techniques, the detected roofs are often larger or smaller than its real size for the reason of detected sequence. Because of the existence of thresholds which is inevitable for all the detection algorithm, the previous detected planes will have more points than its real size, so the shape and direction will change and will influent the later building reconstruction results.

In the paper, a roof detection method from ALS data based on points' normal with weight is proposed. The normal of the plane, which is composed of point and its neighbor points, is counted to find out the high frequency, and the roofs are detected as a result. Each point's weight is considered to determine the contribution to the plane which diminishes the affection of noises to some extent, and increases the accuracy of the small roof detection. In addition, multiple thresholds are adopted to detect roof planes with different sizes. After primary roof detection step, a boundary points competition based algorithm is presented to adjust the detected roofs after a detailed analyst to the reason of roof area changing. Distance of points to the neighbor planes is considered and used to decide which plane the boundary points should belong to. After iteratively re-assignment of the boundary points, each planes are adjust. This step can decrease the error of roof detection by detect sequence. And experiments are also given to prove the algorithm proposed.

2. POINT NORMAL COMPUTATION

2.1 Plane and Normal

In three dimensional space, plane Π's normal can be represented as a vector $\overline{N}(x, y, z)$ which meant that all the lines in the plane are perpendicular to $\overline{N}$. Usually, the normal means plane's normal. A single point cannot has normal information. But normal is often assign to a point when there are a lots points which can form into some kinds of surface while the points' normal means the normal belong to the micro-plane composed by the point and its neighborhood points. Because the parameters to represent a plane is non-linear parameters which are not easily used for voting as that in Hough Transformation. However, the parameters of plane in polar coordinate system is much simpler for plane detection or voting. In polar coordinate, plane Π can be represented by formula

$x\cos\alpha + y\cos\beta + z\cos\gamma + d = 0$, α, β, γ means the angle between $\vec{N}$ and X-axis, Y-axis and Z-axis, and the angle relation satisfy the equation: $\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$. The distance from origin point to the plane is $dis_o = |d|$ which usually be symbolized as ρ in polar coordinate system.

$(\alpha, \beta, \gamma, \rho)$ is a kind of parameters which used for plane detection by voting algorithm or Hough Transformation. In order to make problem simpler, Sagi proposed a three parameters group with one parameter reducing for plane which using (θ, φ, ρ) (Filin 2002), as shown in Figure 1. However, this parameters space may has problem in clustering for the planes parallel to plane XOY as shown in Figure 1. Two planes have angle φ close to $\pi/2$, θ_1 is the angle between X-axis and the projection line of plane Π_1's normal to plane XOY, and θ_2 is the same of plane Π_2. Plane Π_1 and Π_2 are belong to same plane because they are nearby and has close normal direction. But using the three parameters representation space, they has much different θ_1 and θ_2 value just because their normal direction slight to opposite direction along the X-axis.

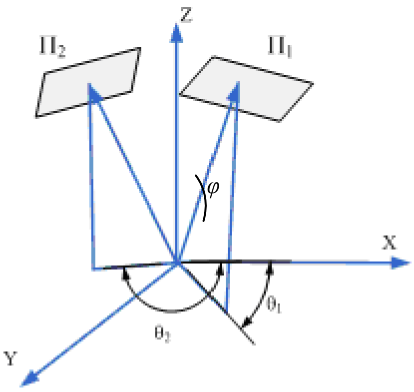


Figure 1. It's difficult to deal with the planes parallel to the XOY using (θ, φ, ρ).

From the discuss above, we can find three parameters is simple but may have small problem in deal with some extreme condition. In the paper, $(\alpha, \beta, \gamma, \rho)$ parameters for plane clustering is applied for detection plane from irregular points.

2.2 Weight of Point's Normal

For a given point, the normal of the point is often influenced by the neighbor points and existed noise. A carefully designed neighborhood points selection strategy can greatly reduce the influence of noise points to normal computation result. The neighborhood system of airborne laser data has been deeply investigated in (Filin and Pfeifer 2005) and can be greatly help to the make a right selection of neighbor points. In order to make a fast neighbor points searching, TIN is created to help to find relation of points and its neighbor points.

Because of the existence of noise and points on the furniture upon roofs, the point's normal contribution to the plane should be different. In order to measure the contribution, weight of point's normal is used in the paper in the plane clustering. The distance of point to the plane fitted by the point and the neighbor points is calculated as the input for weight computation. If the distance is large enough than a given threshold, that means the points should not belong to this plane, and the weight should be given a small value. As shown in Figure 2, point p and its neighbor points compose the plane Π, d_p is the distance of p to plane Π, if d_p is bigger than a given threshold T_d, then set the weight of p a small value near to 0.

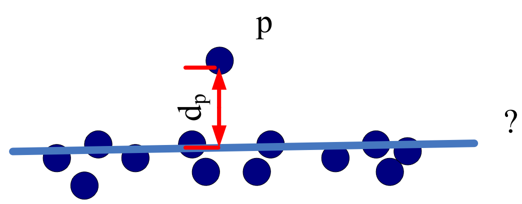


Figure 2. The weight of the line is determined by the distance of a point to the line.

Weight function is another issue need to considered. The basic rule of weight is that with the distance increasing, the weight should decrease. There are many kind of selection to make a decreasing function according to a given distance. In the experiment, a simple sign function as shown in formula (0.1) is used and which also can produce acceptable result.

$$w_p = \begin{cases} 1 & if(d_p \geq T_d) \\ 0 & if(d_p < T_d) \end{cases} \quad (0.1)$$

3. PLANE DETECTION BASE ON POINTS' NORMAL

3.1 Two Steps Voting

Each point and its neighbor points can form into a plane. If N neighbor points belong to a plane, then it will create a peak value in statistics. This is the basic idea of voting algorithm. Each point votes and decides which plane it belong to. And plane has enough number of points can be seemed as one valid plane.

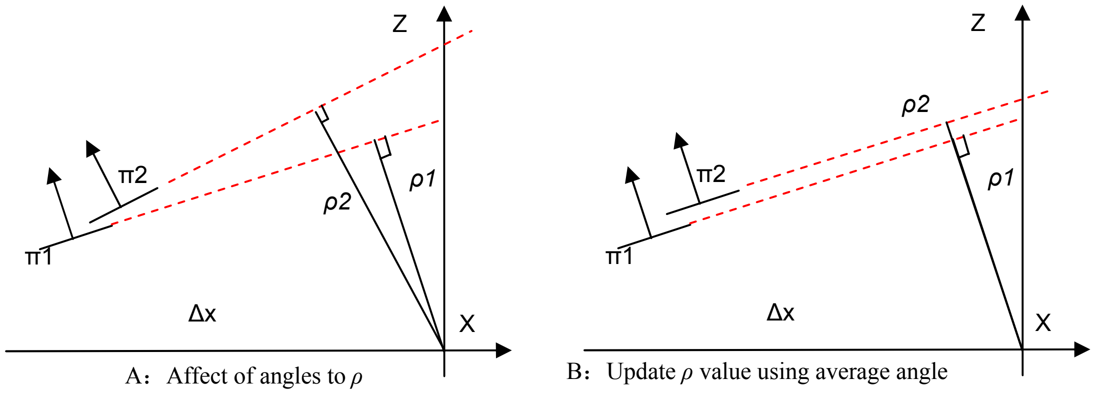


Figure 3.The affection of angles changing to ρ.

In the previous analysis, four parameters $(\alpha,\beta,\gamma,\rho)$ are used to represent the plane, but in the real processing step, ρ is not used as voting parameter with (α,β,γ), because ρ is not same data type as angle, and also because ρ value is easily affected by the angle parameters. Also because of the existence of noise points, the angle value fitted by small plane may not be a stable result, which will greatly affect the ρ value if the point is far away from the original point. As shown in Figure 3-A, plane Π1 and Π2 are almost parallel planes with a small angle, however, with the increase of Δx, the ρ values may change a lot which will bring some problem in peak value searching in voting. In order to solve the problem, a two steps voting algorithm is proposed: to voting angle and ρ value separately. First, the three-dimensional grid is created to store the value of angle, after the peak is found in three dimensional grid, the average value of angles is computed for updating each points' ρ value in the peak. Then re-voting based on updated ρ values. Figure 3- B shows a updated ρ value.

3.2 Isolate points assignment

After the voting processing, a lot planes can be found. However, the existence of noise will make some points cannot be assigned to a plane. These points are called isolated points. The isolated points need to be assigned to a plane it should belong to. Usually, when a point is near to a plane enough, the point will be assigned to the plane. But, distance is not the only constrain for isolated points assignment. In some occasion shown in Figure 4, distance of point p to plane Π_1 is nearly to 0, but distance of point to plane Π_2 is large than to plane Π_1 obviously. But in this condition, it is definitely to assign p to plane Π_2 rather than Π_1, because distance of p to points in plane Π_2 is much small rather than just to plane. So how to assign the isolated points should not only consider the distance to plane, but also the distance of point to points inside the plane.

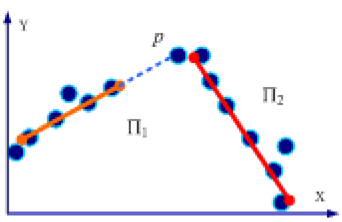


Figure 4. Which line is a isolated point belong to is determined by the distance of the point to line

3.3 Adjacent Planes Union

After voting and isolated points assignment steps, there are planes which are adjacent and have almost same normal angles and ρ values. Joint processing is need to union them into one plane. The condition need for join is: (1) planes should be adjacent; (2) angles between two planes should be small enough; (3) the different of ρ values between two planes should be small enough. In the planes join processing step in the paper, a adaptive threshold is applied, if two planes have a small inner angle, that means a tight threshold for ρ is needed. This can partly avoid the influence of noise.

3.4 Multi-Threshold Plane Detection

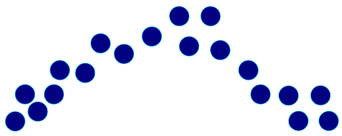
A series of thresholds are needed in the previous processes. The thresholds direct influence the detection result, such as, the minimum number of points that form into a roof, the angle and distance between two planes that should be combined. The thresholds depend on the size and angle of the roofs. Tight thresholds are propitious to detect the larger roofs with more points, while, loose thresholds will lead to some broken planes. However, the loose thresholds are fit to the small roofs with few points, while tight thresholds will leave them out. Single thresholds are hard to get the approving result. Therefore, the strategy of multi-thresholds are adopted to solve the problem: firstly, apply the tight thresholds for detection the large roofs, and then, loose thresholds are employed to detect the small roofs, at last, integrate the both detection results. The strategy of multi-threshold can improve the avalability of algorithm and improve the performance of the algorithm to detect small planes.

4. BOUNDARY POINT COMPETITION FOR PLANE OPTIMIZATION

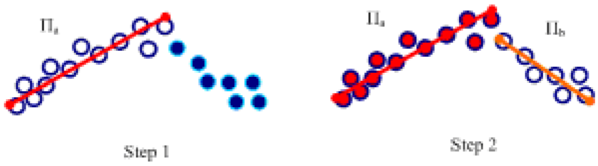
4.1 Influence of Detection Sequence to Final Result

Even though plane detection algorithm is carefully designed, the plane cluster sequence still has a large influence to the results especially when deal with non-parallel adjacent planes. For example, when detecting planes of garbled roofs, the earlier the plane be detected, the size of the plane will be larger. That means the sequence of detection will has some affection to the final results. The reason is easy to understand, if a plane is detected, it will collect points around the planes, because the thresholds are often needed in deal with noise and inaccuracy of data, it will collect more points than it real needed. As shown in

Figure 5-(a), the points represent two planes adjacent, Figure 5-(b) shows the result of first plane detected, it will collect points belong to plane Πa which decided by a give distance threshold. In the right side of Figure 5- (b) shows when it comes to detect plane Πb,there are no enough points left. Because the first comer takes away more points, and the later comer have no much choice.



(a):Points of two planes before detection



(b) the first and second detected roofs has different size

Figure 5: Influence of detection sequence to final results, step1 is the first detected plane Πa, step2 detect plane Πb, and Πb is smaller than it real size.

This kind of problem brings inaccuracy to the detected planes in shape and coordinate which will bring more errors in the later building model reconstruction steps. In fact, the points collected by a given threshold means it is acceptable to assign the point to a plane rather a best selection. So, after plane detection, the points located at the middle parts between different planes should be re-assigned. The point will decide which is best choice plane and re-assign the point to the best suitable plane. This step can be seemed as a competition step.

4.2 Boundary Points Identification

Changing of plane area mainly occurs at plane boundary are with too more or too less points added to plane. Therefore, competition only appears between the boundary points which in two neighborhood planes. A plane boundary points are points belong to a plane, at the same time it has neighborhood relationship with other points in the neighborhood planes. As shown in Figure 6, if a part of points in A and in B can compose a boundary (described in dash line) after triangularization, these points which make up of the boundary are considered as boundary points, as shown in solid points the figure.

Boundary points identification need to analyze the adjacent planes. TIN is used as a basic tool to analyze spatial relation of planes. And relation matrix is applied to describe the planes neighborhood relation. Suppose each plane is assigned an ID, and all the points in the plane are also assigned same ID value of the plane. Then the points in TIN will be iteratively searched and if two points with different ID but belong to same triangle, that means the two planes are adjacent planes. And the two points are boundary points.

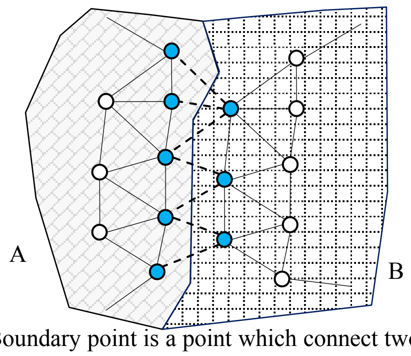


Figure 6: Boundary point is a point which connect two neighbor planes, solid points in the middle are boundary points of plane A and plane B.

4.3 Boundary Points Robbery

Because of the boundary points are points located between different planes and have small distance to the planes. The best choice for the boundary points are assigning them to the plane which has the minimum distance. The robbery, also called boundary points reassignment, can be achieved by an iterative procedure. The boundary points will be robbed from one plane and the number of points of the plane will decrease, the plane's parameters change and need recomputed. When some small planes continue lost their points to a rather small number, such as 5 points, the plane will become an invalid plane. The invalid plane will be deleted from the planes array and all the points in the plane will be assigned as isolate points. Table 1 describes the procession step using a pseudo codes. Firstly, boundary points are identified, and the distance of the points to neighbor planes are calculated, the points will be assigned to plane which has minimum distance; iteratively apply the procedure to all the points until no points need to adjust.

```
Robery( ArrayPlanar  planes, double Td ) {
   // Identify boundary points
   PointArray pts  =  FindJointPoints( planes );
   int nCount  =  1;
   while( nCount > 0 ) {
      nCount = 0;
      //iteratively apply to all the boundary points
      for( int i=0; i < Num(pts); i++ )      {
         POINT3D pt =  pts[i] ;
         ArrayPlanars  plane_nb = GetNeighborPlanes( pt ) ;
         // Find nearest plane the point has distance to.
         CPlanar p = FindBestPointLocateAt( pt, plane_nb ) ;
         if( Distance( p, pt )>Td )continue;//distance is large
         AddPtToPlane( p, pt ) ;
         nCount = nCount + 1 ;
    //change the neighborhood relation of planes and points
    RecomputeRelation( );
} }}
```

Table 2：Procedure of boundary point robbery

5. EXPERIMENTS

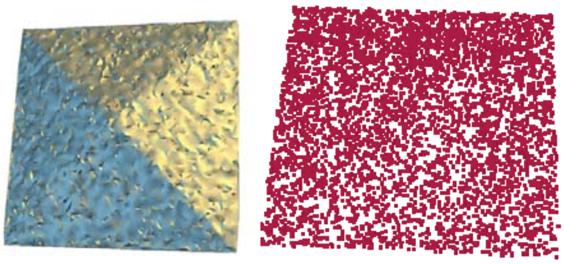
Three experiments are presented in the paper. Experiment I shows the results of analogue data and experiment II shows the result of real data. Experiment III using a building with several small planes to verify the algorithm for detailed roofs detection.

5.1 Experiment I

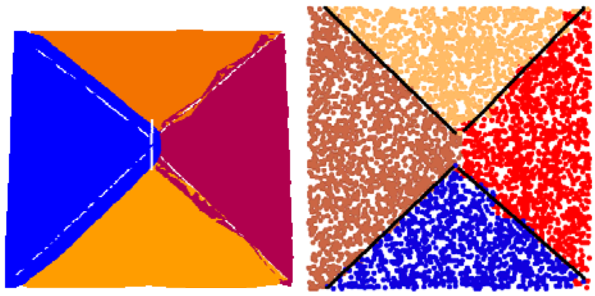
Experiment I: the test data was created using a program to simulate the real data so that it could have pyramid shape. Random noise was added to the data. In this way, it could be more close to the real one, as shown in Figure 7(a). Figure 7(b) is the result without the process of point competition and the left part of it is shown in the form of plane and the right part in the form of point. The boundaries between planes obviously depart from the real data. Figure 7(c) is the result that has come through the process of planes boundary points' competition. It's clearly shown that the effect of boundaries between planes is further improved and the classification of planes is more precise.

5.2 Experiment II

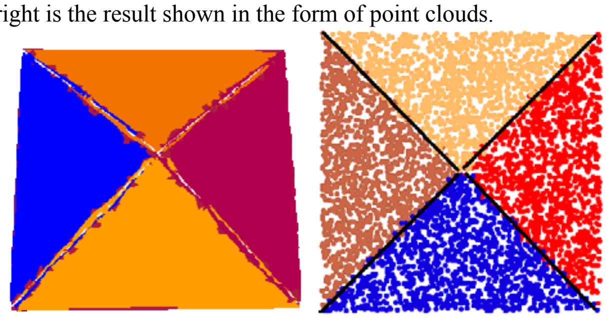
Experiment II: in the data of Toronto acquired by Optech ALTM LiDAR, the point distance is between 0.6 meter and 1 meter. Figure 8(a) is corresponding reference data. Test data had passed roof detection and undergone boundary point competition. The result is shown in Figure 8(b) in the form of TIN. Figure 8(c) is the result colored according to the ID of each roof plane.



(a) Test data: left is the result shown in the form of plane and right is the result shown in the form of point clouds.

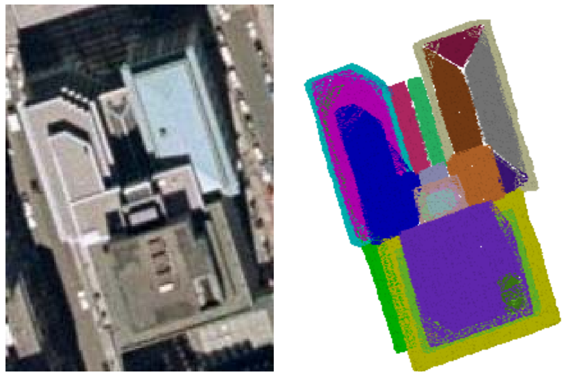


(b) The result is gotten without undergoing boundary point competition, left is the result shown in the form of plane and right is the result shown in the form of point clouds.

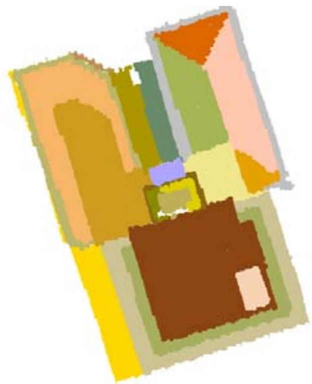


(c) The result undergone boundary point competition, left is the result shown in the form of plane and right is the result shown in the form of point clouds.

Figure 7: The plane results of before and after boundary points competition.



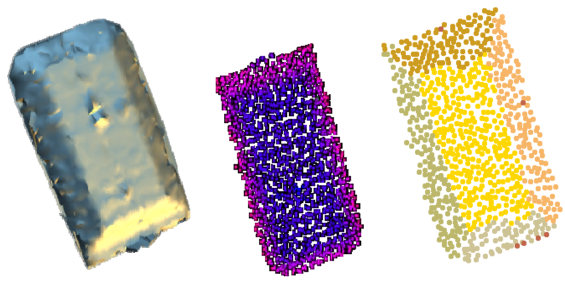
(a) reference image (b) roof detection shown in mesh



(c) roof detection result shown in densify points

Figure 8. The roof planes segmentation result of plane A

Figure 9 also shows another result using building with different shapes.



(a) (b) (c)

Figure 9: The results of a building with four different slopes. (a) The 3D data of building roof (b) the data in (a) shown in the form of point clouds (c) the segmentation result of roof planes.

5.3 Experiment III

The data source is same as experiment II. But in this test data, the building has several small planes at the corners. An plane segmentation experiment was done to one building A in the district of Toronto as shown in Figure 10, 1 is the 3D shape of the building after the data formed a TIN, 2 is corresponding image, 3 is discrete points and 4 is each roof plane detecting result after processing to discrete points with the methods presented in this paper. Nearly all the planes were got. Four roof planes with quite small areas in the corners were successfully detected because multi-threshold is used.

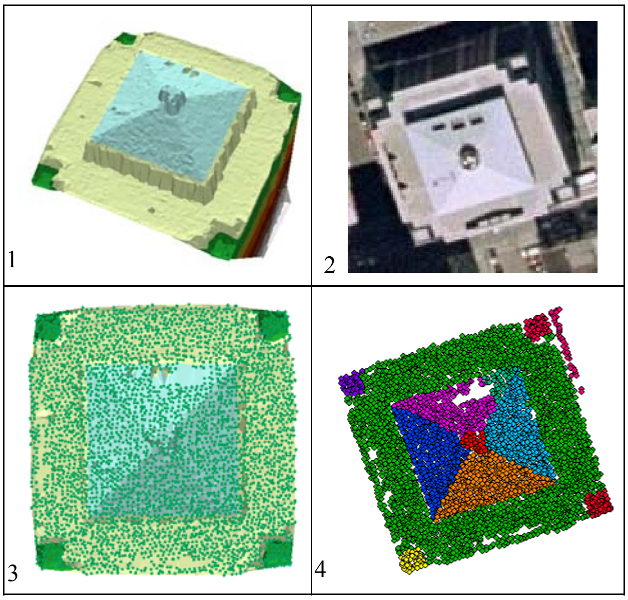


Figure 10: Results of roofs detection, 1 is the surface of roofs, 2 is reference image, 3 is point clouds, 4 is the detection result of roof using point clouds

6. CONCLUSION

In the paper, a weighted point's normal voting algorithm for plane detection from airborne laser scanning data is proposed. And a competition based post processing approach is also discussed to optimize the planes detected. Experiments has been given to prove the algorithm proposed. But how much noisy data the algorithm can deal with is still in research. In the future, extensive research on evaluation of roof detection will be focus more.

7. ACKNOWLEDGEMENT

Thanks for the support from Natural Science Fund of P. R. China (40701154), Chinese National Project (863) (SQ2006AA12Z108506, 2006AA12A115).

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