MAP BASED SEGMENTATION OF AIRBORNE POINT CLOUDS

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February, 2016

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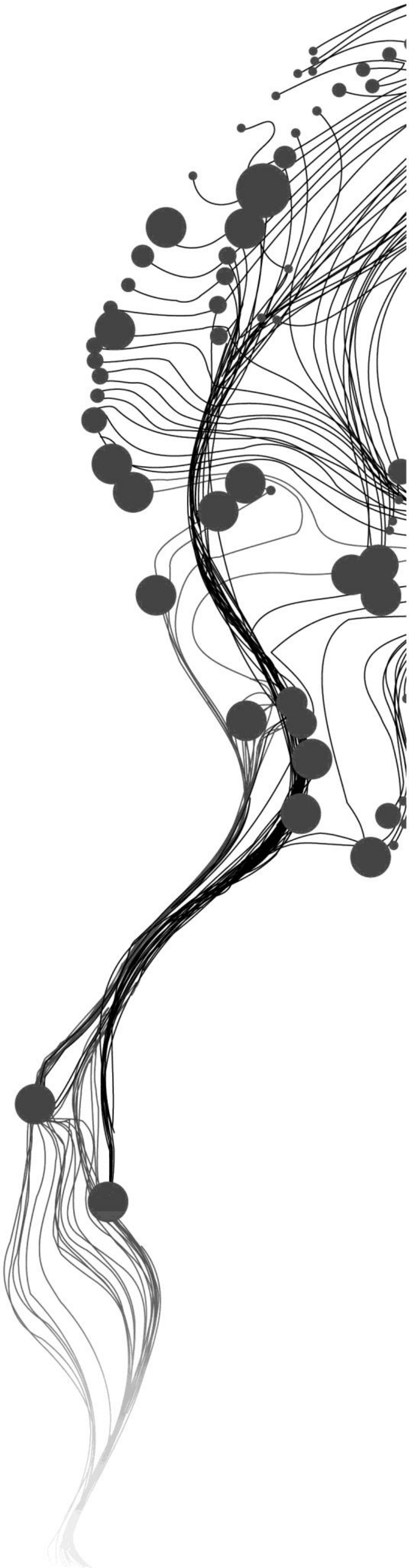

MAP BASED SEGMENTATION OF AIRBORNE POINT CLOUDS

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Enschede, The Netherlands, February, 2016

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Specialization: Geoinformatics

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ABSTRACT

The overall objective of this MSc research is to develop a segmentation model with the help of maps for laser point clouds of multi-land-cover landscape. Maps could offer the semantic information of land-cover class and 2D spatial information of object boundary. The proposed segmentation model is based on the combination of maps and laser data. First attach the laser data with map information through labeling the points which located in the map polygon with corresponding polygon number and class number. Then according to the characteristics of different land-cover classes, the segmentation strategy will be developed class by class. And the segmentation algorithms used in the strategy will be implemented polygon by polygon. 4 different land-cover classes which are building class, plant cover class, road class and water class are identified in this segmentation model. Segmentation algorithms like surface growing segmentation, connected component segmentation, local maxima and majority filtering are used according to needs in different phases of the strategy. As even in one land cover class area, different land covers may appear, so the segment features like flatness, max height difference, segment size and normal are used to classify the segments in order to indicate whether the segments belong to that land cover class or not. As the result, the points will be segmented as well as the segments will be classified to indicate whether the segments are that land cover class or not. That will benefit to do further processing like 3D Modelling of laser data, because the segments which are actually available could be selected to do the further processing. Through comparing the result of map based segmentation with the result of traditional segmentation for a common dataset, the map based segmentation obviously shows a better result than traditional segmentation.

Keywords

Airborne Laser Scanning (ALS), Point clouds, Segmentation, Surface Growing, Connected Component, Majority Filtering, Local Maxima, Flatness

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1 Introduction

1.1 Motivation

With the development of remote sensing, more and more techniques are developed into remote sensing field. Lidar is probably the most important technology introduced in the mainstream topographic mapping in the last ten years(Shan and Toth, 2008). Unlike traditional topographic mapping methods which acquire geo-information by taking photos for the study area, Lidar directly collects a set of unstructured dense point clouds with accurate 3D geo-referenced coordinates.

As the data collected by Lidar is a set of unstructured point clouds, it doesn't tell anything about the study objects, so we need to do a series of processes for the point clouds to extract the information we need. With the development of Lidar technology, more and more processing algorithms of point clouds are developed by researchers. In the working frame of autonomous perception from point clouds, segmentation is an critical step of the frame(Douillard et al., 2011). Segmentation is a process to label segment ID for laser points, so the points which belong to a surface or object are given the same segment ID. Many other processing, e.g. Classification and 3D Reconstruction, may base on the result of segmentation. So a good result of segmentation is precondition of good results of entire processing flow.

There are 3 kinds of laser scanning system based on the different platforms, respectively are airborne laser scanning system, terrain laser scanning system and mobile laser scanning system(Meding and Walch, 2013). As the ALS has advantages of bird's-eye view and large covering area, ALS surveys become a common way to acquire geo-information in urban area in the recent years. For many various objective, e.g. object recognition of urban scene(Golovinskiy et al., 2009), people need to identify the different surfaces of object, e.g. the roof, dormer and chimney of the buildings(Brenner, 2005). As laser scanning system is widely used, processing of laser data becomes a hot top. Through these processes like classification and segmentation people can get not only spatial information but also thematic information from laser data.

In order to get a better result of processing laser data, other relative information sources like maps of study area, local visit data and images of study area, may be used together with laser data. Maps can give us the location information, class information and boundary information of objects. Laser dataset can tell us the spatial information of objects. Laser points could get more semantic attributes by combining 2D topographic vector maps with 3D point clouds data. Through this kind of combination to deal with particular cases is not a new approach. Researches have been done in the fields of reconstruction and 3D modeling using the combination of laser data and maps for urban area(Koch and Heipke, 2006). In urban area the land covers are various, and these kinds of land covers show large different characteristics to each other. Topographic maps could offer referenced 2D coordinate information of the border of objects and semantic class information of these objects. Combining maps with the laser data, laser points can be divided into different classes as well as different polygon regions (the region in map polygons, in the following chapters, the term polygon means the region defined by map polygons). That will help us to segment multi-land-cover laser data (the laser data of multiple land covered landscape).

1.2 Problem Statement

This thesis is devoted to developing an accurate segmentation model for ALS point clouds of multi-land-cover landscapes with the help of maps. The main idea of this segmentation model is developing different segmentation strategies for different kinds of land covers. The maps used for this thesis are vector maps which contain a number of geo-referenced and class labelled polygons. Each polygon indicates an area with a kind of land cover. The map will help to separate the entire point clouds file into different classes dataset depends on the different land cover class, like e.g. building class, plant cover class and water class. For each land cover class, the objective of segmentation is different from each other. For example, the main objective of segmentation for building class is the identification the building planes, but the main objective of segmentation for plant cover class is to identify the ground patches and individual objects above the ground. As even in one land cover class area, different land covers may appear, in order to support the following processes of laser data, like 3D Modeling, which researchers may want to know whether the segments in the polygons are actually belong to that land cover class or not. So in the segmentation processes of this thesis will classify the segments to indicate whether them are that class or not.

As the result, the points will be grouped into segments by labeling the segment ID and a tag will be given to segments to indicate whether the segments belong to polygon class or not.

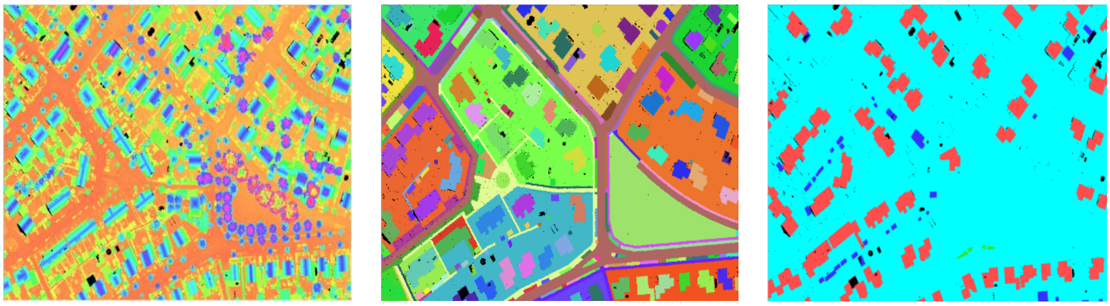


Figure 1-1 Visualization of data with different tags (Original point clouds colored by height (left), point clouds labeled with polygon ID (middle), point clouds labeled with class ID (right))

1.3 Research Identification

1.3.1 Research objectives

The objective of my thesis are to develop an accurate segmentation model for ALS point clouds of multiple-land-cover landscapes, for example urban landscapes, with the helping of maps and to indicate the segments whether belong to their polygon class or not. This method should have the ability to accurately identify the points which belong to a same surface of general objects in different kind of land covers and labeling them with a unique segment ID.

1.3.2 Research questions

In order to achieve the research objectives, the following questions should be answered:

1 Depend on what kinds of characteristics/features of objects the segmentation will be developed?

2 How is the segmentation framework for point cloud? Which algorithms will be used for what cases?

3 How to differentiate the segments which actually belong to their class from the segments which not belong to their class?

4 How to evaluate the segmentation model?

1.4 Innovation

The researches in the field of point clouds processing are increasing rapidly in recent years. Segmentation is one of the most important processes in automatic extract information of point clouds. In order to obtain a higher accuracy result of processing, an external data source often being used to help the process of point clouds. In this thesis, maps are used to combine with 3D point clouds, and a novel map based segmentation model for multi-land-cover laser data will be proposed.

1.5 Thesis structure

This thesis contains 6 chapters. Chapter 1 gives the general introduction of the thesis, including the motivation, problem statement, research objects, research questions and the innovation part of this thesis. Chapter 2 introduces some related researches, including the work principle of airborne laser scanning system and some segmentation methods of point clouds data. In chapter 3, the methodology of this thesis is detail introduced. In chapter 4, the methods which proposed in chapter 3 will implement on a dataset and the results will be presented. In chapter 5, the result of the chapter 4 will evaluated and the methods which proposed in this thesis will be discussed. The last chapter gives the conclusions of this thesis.

2 Literature Review

In this chapter, the related methods are reviewed. Section 2.1, mainly introduces the working principle of the airborne laser scanning system. In the section 2.2, the methods of segmentation are reviewed. At the final section, the summary of the methods is given.

2.1 Airborne Laser Scanning

The working principle of laser scanner is different from traditional photogrammetry methods. In traditional photogrammetry, people take photos of the earth and then recover the ground truth model and calculate the 3D coordinates of each object points in the laboratory. But in laser scanning, the laser scanners are the active sensing systems which emit laser beams to the ground objects and time the round trip of laser beams to calculate distance between laser scanner and objects (figure 2-1). There are 2 different ranging measurements sensors which are the pulsed ranging sensors and the phase difference ranging sensors (figure 2-2). Airborne laser scanning system (ALS) is an assembly of laser scanner, aircraft and real-time positioning system. The position of laser scanner can be recorded by the cooperation of GPS and IMU which could offer the real-time positioning function. The 3D coordinates of ground points can be directly calculate by the distance of laser scanner toward ground points and the coordinates of laser scanner with a high accuracy. As the ALS has advantages of bird's-eye view and large covering area, ALS surveys become a common way to acquire geo-information in urban area in the recent years.

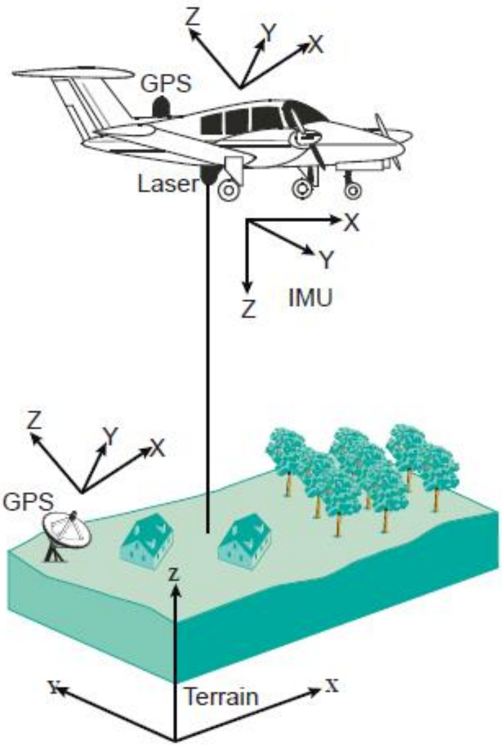


Figure 2-1 principle of airborne laser scanning(ITC, 2011)

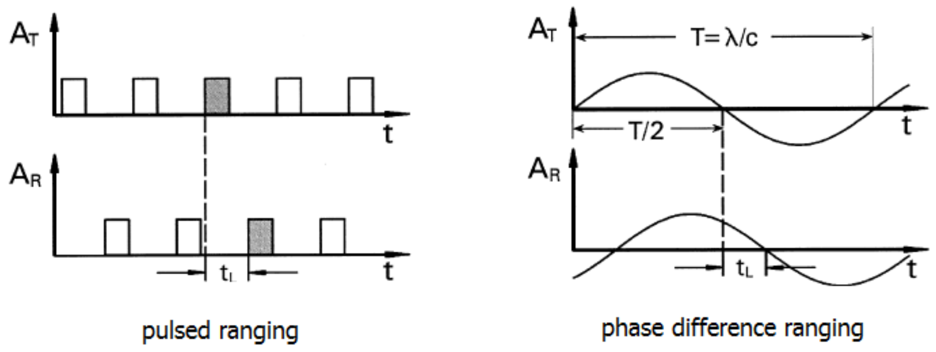


Figure 2-2 Ranging measurements(Wehr and Lohr, 1999)

2.2 Segmentation Strategy

In the last decade laser scanning has become a significant technique for the acquisition of 3D geo-information. As the development of the laser altimetry, more and more researches are done in the field of processing the point clouds. For different application the work flow for processing laser scanning data are different. But in general, the framework of handling laser scanning data mainly contains 2 steps which are calibration and interpretation (Figure 2-3). The main objective of calibration is to adjust the row data and produce a dataset which could satisfy the requirements of application. Some processes like geometry calibration, strip adjustment, and points reducing are enrolled in this step. In the interpretation step, according to specific application, people extract different needed information from the data which produced by calibration step. Some processes like segmentation, classification, reconstruction may be enrolled in this step.

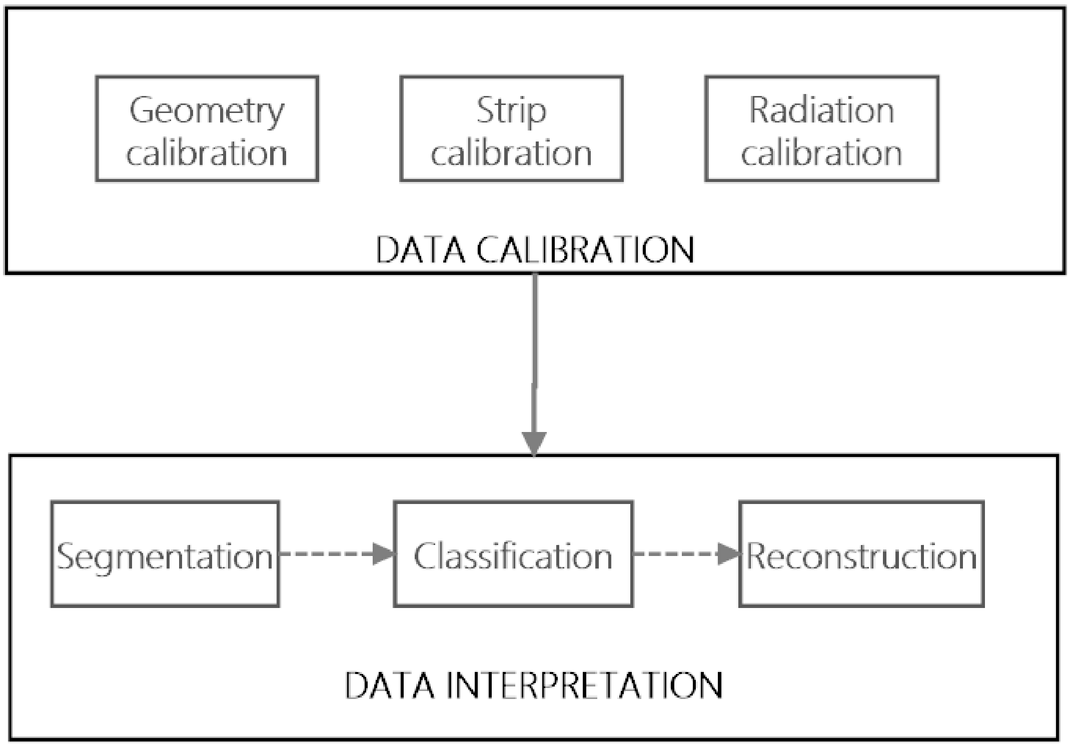


Figure 2-3 Mainstream processes of laser scanning data

Segmentation is an essential part of laser scanning point clouds data interpretation. It is mostly the first step to extract information which we are interested from the point clouds. More and more researches have been done in this field. For example (Wani and Arabnia, 2003) detected the edges which outline the borders of different regions, and then grouping the points inside the borders to be a segment. But the segmentation methods like this which based on edge-detection will show a shortage when dealing with situations like a portion of an edge has a small difference or regions are homogeneous. Another aspect of segmentation methods are based on surface-based segmentation, e.g. (Xiang and Wang, 2004) presented a split-merge clustering segmentation methods which starts iteratively splitting from a single Gaussian model and then merging the clusters iteratively. These methods which based on surface growing could not localize regional outlines accurately.

Some researchers develop hybrid segmentation methods which combine the edge-detection with surface based methods to avoid the shortages in both approaches (Woo et al., 2002). Like, e.g. (Yokoya and Levine, 1989) presented a method which do a region-based segmentation by computing the Gaussian and mean curvatures and do two edge-based segmentation by computing partial derivatives and depth values, then combine all these three results to produce the final segmentation.

Sometimes as the complexity of scene, a strategy of using segmentation algorithms may be need for segmentation. For example (Vosselman, 2013) proposed a strategy which original segmentation followed by connected components analysis, finally a post-processing implemented to improve the usefulness for the after processing.

In order to get a better result of segmentation, the sources except laser data will be used to help the segmentation. For example, some researchers combine 2D maps with 3D point clouds to solve particular case. (Haala et al., 1998) make a research on reconstruction of urban objects using the data combination of DSM and 2D map. (Elberink and Jantien, 2013) developed an automatic 3D city and landscape model in nationwide using TOP10NL maps and national height model which are acquired by ALS.

2.3 Segmentation Algorithm

There are many kinds of algorithms could be used for segmentation. According to their different principles, they are suitable to different cases. As the diversity of characteristics in multi-land-cover landscapes, this thesis will use different kinds of algorithms to segment the point clouds depending on the needs.

2.3.1 Surface growing algorithm

Like the region growing algorithm in image processing, the surface growing algorithm is based on similar principle. There are two main steps in surface growing algorithm, which are seed selection and growing.(Vosselman et al, 2004)

The methods to select points as seeds from a point cloud dataset are variance. For example, when one want to detect plane surfaces by surface growing algorithm, the seeds should be selected as they can fit a plane with their neighbors. For this instance, the method could be that fitting a plane for the candidate seeds by least square principle, and determine them to be seeds or not by comparing the least square sum with a threshold. But this method is sensitive to outliers, the more robust method could be 3D Hough transform-like detection of planes. Also when one want to detect a smooth surfaces but not planes, the seeds should be selected as they can fit smooth surfaces. The local normal could be used to check the points can be seeds or not. If the angles between the local surface normal vectors of points in a candidate seed are nearly 0, then this candidate seed accepted.

Growing step run after the seeds selection. According to different application the criteria for growing these seed surfaces to adjacent points are different. Normally, there are 3 kinds of criteria could be used to grow seeds, which are proximity of points which only consider the distance from the candidate points to the seed surface as the condition of growing, locally planar which consider the orthogonal distance of the candidate point to the current seed plane and the distance of the candidate point to the current seed plane as the conditions of growing, smooth normal vector filed which consider the angle between the normal vector of the candidate point and local vector of the seed surface as the condition of the growing. (Vosselman et al., 2004)

In order to get a faster surface growing algorithm, the growing step can be started once a seed surface is accepted, and then once no more points can be added to the surface, the seed detection will be run to detect another seed from the remaining points. (Vosselman et al., 2004)

2.3.2 Connected Component Segmentation

Connected component is a term in graph theory, a connected component of a graph is a subgraph in which any two vertices are connected to each other by paths. It mostly used in image processing to group the pixels into regions when they have a contrasting background.(Kong and Rosenfeld, 1996)

In laser data processing, the connected component segmentation algorithm also used to grouping points into segments based on their connectivity. The connectivity network of laser points can be built depends on TIN or K-d tree. So first, build a 3D TIN or a k-D tree for the point cloud. Then, delete the edges which are longer than the threshold. As the result, the points still connected with each other will be grouped into a segment.

The connected component segmentation is used to group points based on the distance. As we assume the points of an object are mostly get close to each other, and the distance to the points from other objects is farther than the interior points. After the background removed, the objects will detected by connected component segmentation. In (Vosselman, 2013), connected components are derived from the remaining data points of a surface growing segmentation is given.

2.3.3 Majority Filtering

The majority filtering is mostly used to label the attribute tag for the un-labeled points with the most frequency attribute value of its neighbors. The definition of neighbors could be the points within an area of a certain radius or a certain number of the most nearest neighbor points. In (Vosselman, 2013), majority filtering is used to label the segment tag for the isolate points which without a segment number.

2.4 Summary

Lidar becomes an important technology in remote sensing science. It can directly acquire the 3D coordinates of object points. Segmentation is an essential process of extracting information from the point clouds, and the algorithms of segmentation are various. Depending on different application objectives, different algorithms are used. And these algorithms could be mainly divided into 2 classes, which are surface growing and edge detection.

Some cases are complicated, in order to get better results of segmentation, strategies and other information which acquired from other sources of the case areas are used to help the segmentation, like the laser reflectance of objects, the spectral reflectance of case areas and the full-wave information of objects. This thesis proposes a segmentation method which using the land cover class information which derived from a vector map to help the segmentation of urban laser point clouds.

3 Methodology

3.1 Introduction of Methodology

As there are many different kinds of land covers in the urban area, the characteristics of a kind of land cover are different from others. So frequently a general segmentation method is not suitable for the entire urban area. The main purpose of this thesis is to develop an accurate segmentation framework for urban laser point clouds. This thesis use digital line maps to derive the information of different land covers and different map objects. Combining these information, the points could be labelled with different class values and polygon ID indicating them belonging to different land cover classes and different map objects. Then, different segmentation methods will be developed for corresponding class points.

The term object should be noticed. Map objects which I refer here are the objects identified by the maps, each object refers to a polygon on the map. The points which located within the polygons will be labeled with the corresponding polygon number. But in the following section the term objects means the objects need to be identified as segments. They refer to the segments in the result of segmentation.

3.2 Framework

The main work of this thesis is developing different segmentation methods for different land cover classes. The pre-processing is labeling the points with corresponding land cover class tags and map objects tags. Then segment them class by class (Figure 3-1).

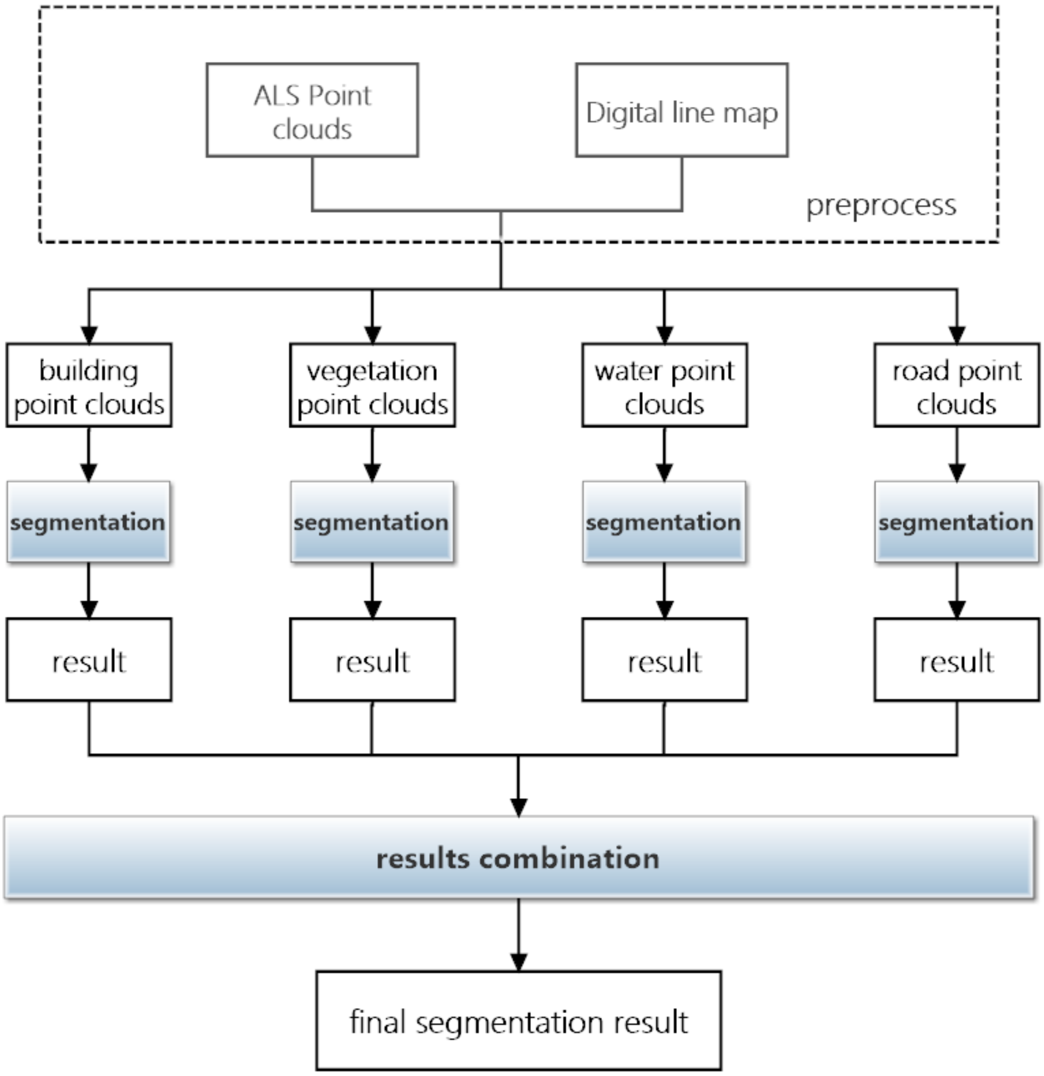


Figure 3-1 Framework of processes

3.3 Data Pre-processing

The purpose of pre-process is producing a combination dataset of maps and laser data. To be specific, the laser data will be added 2 attributes for each point to indicate the polygon ID as well as the land cover class number of the map polygon which the point located in. The maps used here should have consistency with laser data both in spatial scale and temporal scale. In some cases, there is no satisfied map, for example the map is outdated or map scale is not big enough, is available to fit the laser data. Then we need to produce a satisfied one. For the part of how to produce the satisfied map is out of the research scope of this thesis. The laser data should be separated into ground points and non-ground points, Algorithms like morphological filtering, progressive densification and surface-based filtering (Vosselman and Maas, 2010) can be used to extract ground points from laser data. When the maps and laser data are satisfied, transfer their coordinate systems to be common, overlay them into a 2D space, the points from laser data will get the same polygon ID and class number as the map polygon they located in (Figure 3-2). These works could be done directly by software e.g. FME Workbench.

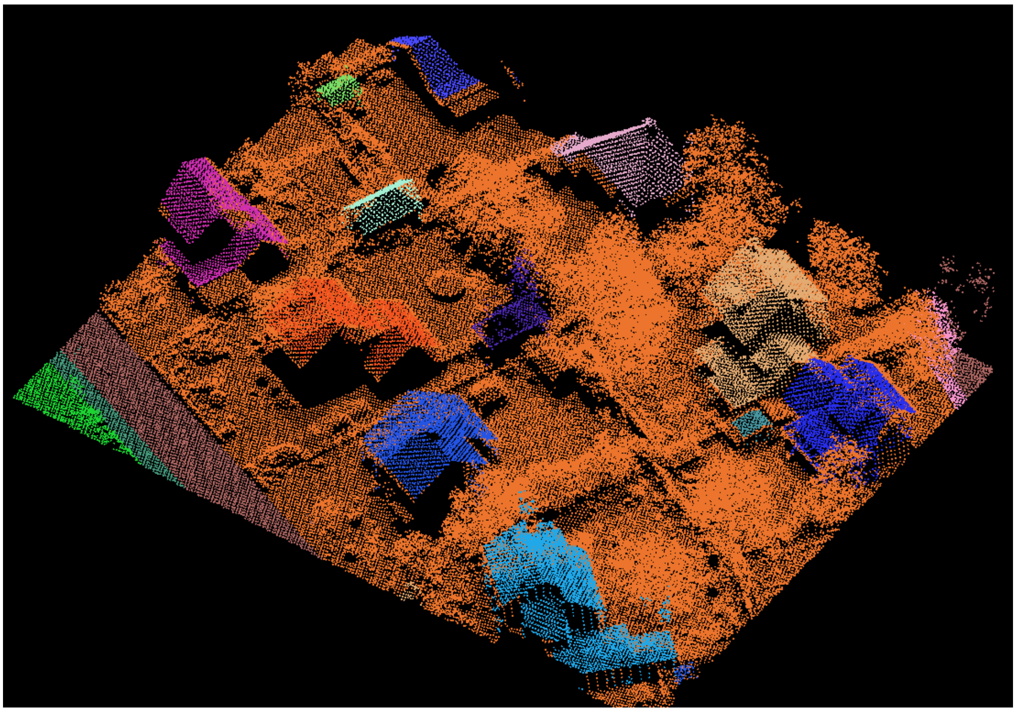


Figure 3-2 Overlay laser data with map polygons (points are colored according to polygons which they located in)

3.4 Segmentation Strategies

After the points are labeled with polygon ID and class values, the segmentation strategy will be developed class by class.

3.4.1 Building Class

In urban scenes, the most frequent objects are buildings. For building points, the main purpose of segmentation is to identify the plane surfaces, and the roof surfaces are the most important to identify, because roof surfaces are the main receiver of airborne laser beams in building objects. The segmentation model for building point clouds contains 2 main parts. The first part is re-assignment， after that the second part is segmentation strategy.

Re-assignment

As some reasons like projection deformation, generalization of cartography, the vector map will not completely fit with the real world objects. So there will be some misfits between vector map and laser scanning data (Figure 3-3). The polygons in the map may not actually include all the corresponding points and keep the non-corresponding points out. As the following segmentation algorithms are implemented for points which labeled with building class, and processed polygon by polygon, so it is important to make sure the points are correctly labelled with class value and polygon IDs.

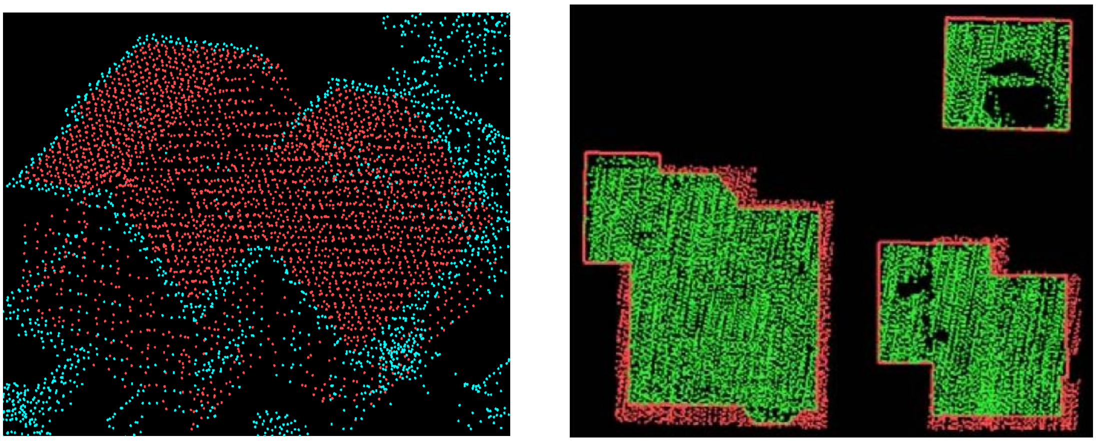


Figure 3-3 Misfit of laser data and map

The purpose of re-assignment is to make sure all the points which actually belong to the building objects are recognized as building points and labelled with correct corresponding polygon number. That will be done by relabeling some points which locate near the building polygons with building class and new Polygon IDs.

As the map and the laser data are not perfectly coincide, there are mostly some small offsets or changes. For the building area, that will behave as the points on the side walls are not included by the building polygons, and some points on roofs are out of the building polygons and some points belong to other land covers are included in the building polygons. According to these situations, the re-assignment will contain 2 steps. (Figure 3-4)

1 The purpose of the first step is to include the wall points and relabel them with correct polygon IDs. The processes are: First, extend the building polygons with a certain radius (r), e.g. 0.5m, in order to include wall points. Then set all the included points to be building points. After that, relabel the new building points which are not building points when previous process is not implemented with new polygon ID. The new polygon ID of these new building points is the same with their nearest old building points.

2 The purpose of the second step is to recognize the roof points which outside the building polygons, and add them into building class and relabeling them with correct polygon IDs (Figure 3-5). The processes are: First, a surface growing segmentation is implemented to detect the plane surfaces for the entire dataset. Then, selecting the segments which more than a certain percentage (p) e.g. 80%, are building points, and set the all the points of these segments to building points. After that, set the polygon ID of these segments to the majority polygon ID of themselves (Figure 3-6).

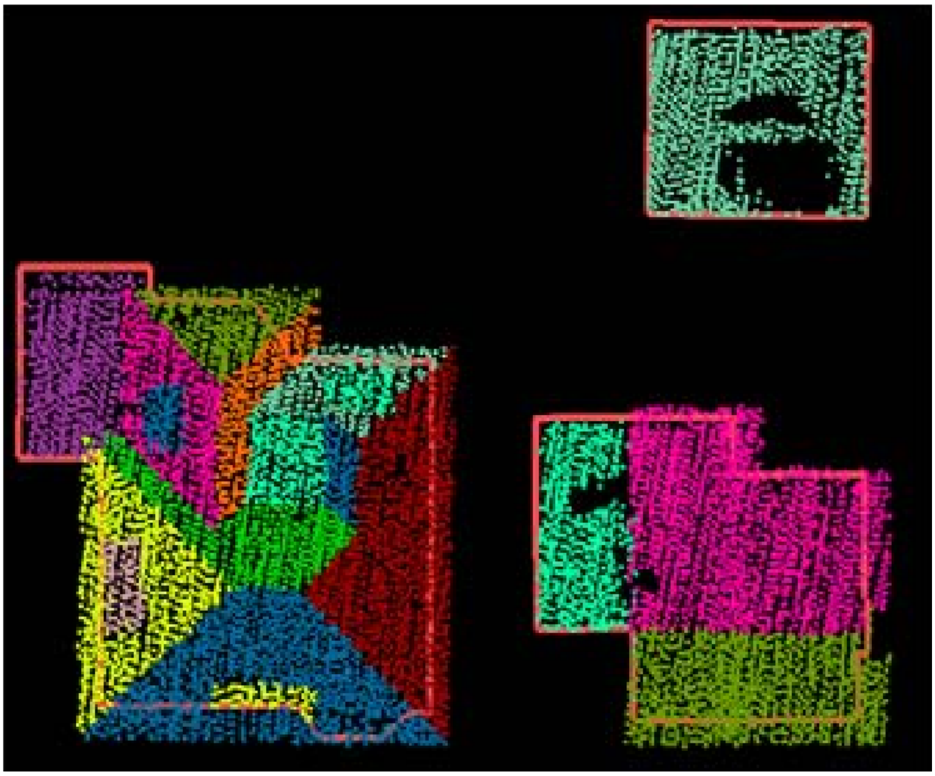
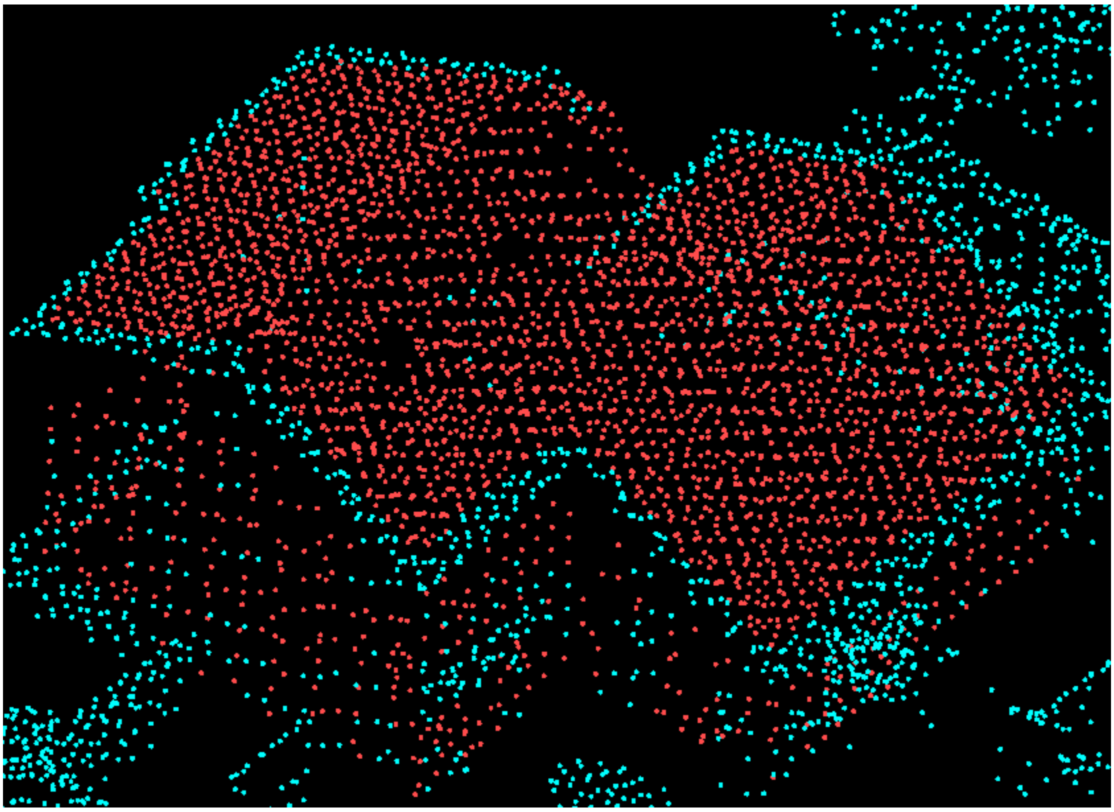


Figure 3-4 Outside border building segments (Oude Elberink, 2009)



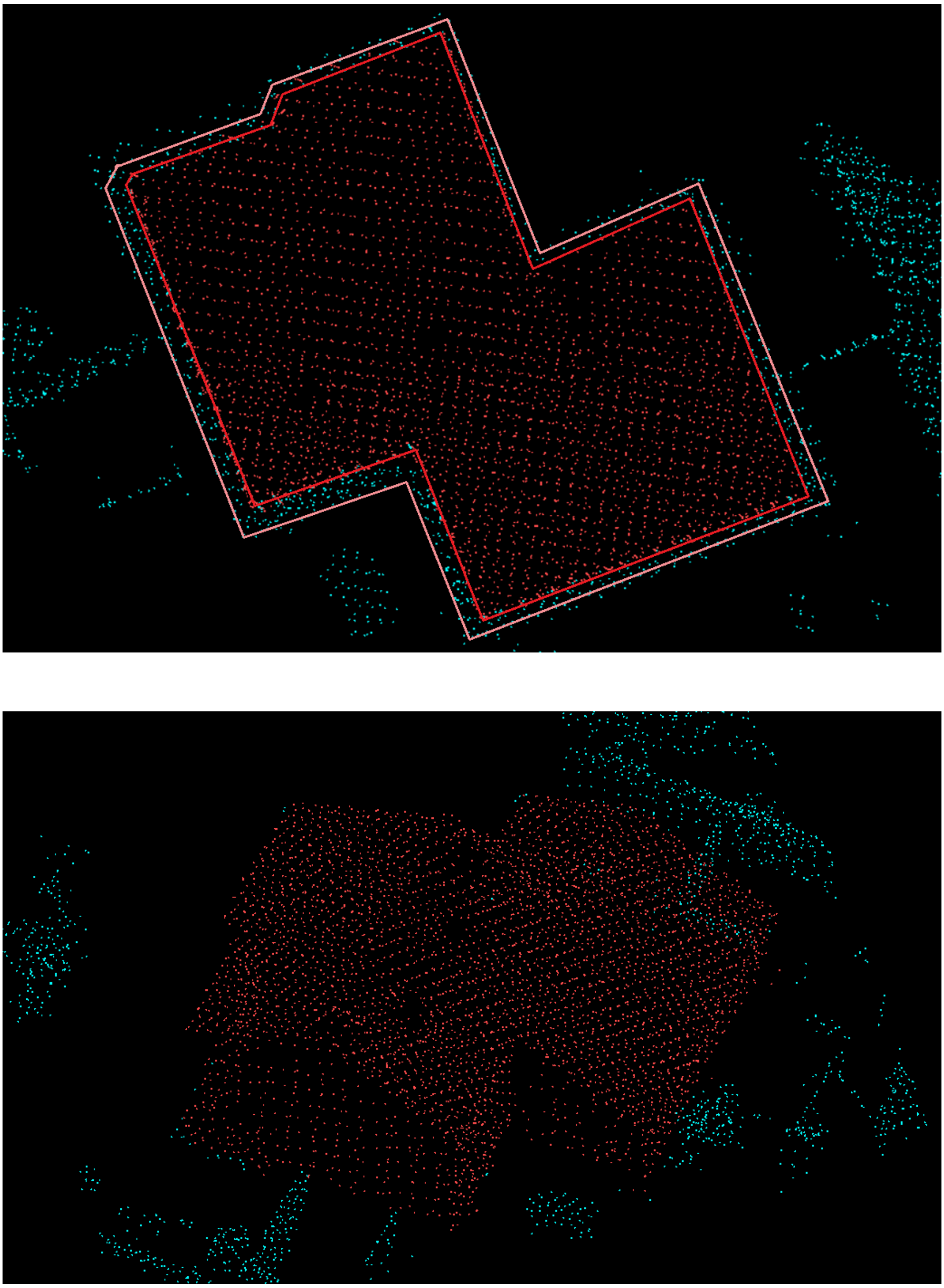


Figure 3-5 Before extending (top), outward extending the building polygon (middle), result of re-assignment (bottom) (building points are red points)

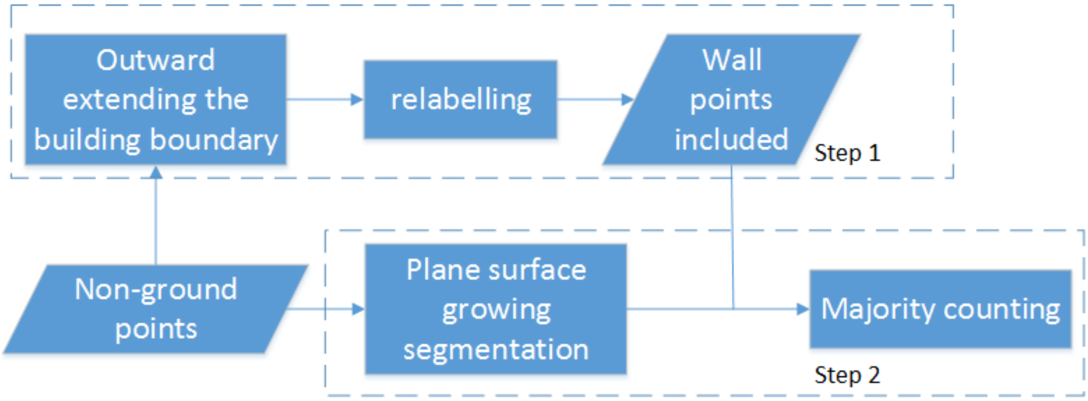


Figure 3-6 Framework of re-assignment

Segmentation Strategy

The segmentation strategy is developed depend on the characteristics of buildings. In general the characteristics are:

1 The surfaces of buildings are mostly planes.

2 The normal vectors of the building roofs are not in a certain direction, different from roofs are not vertical, the walls are mostly vertical.

3 The building points are non-ground points.

4 The main objects of buildings detected by ALS are roofs. As the airborne laser beams are shot from overhead sky.

5 The point density on the walls is lower than the point density on the roofs. As the roofs are face to the airborne laser beams, but the walls are not.

So according to these features, my segmentation strategy (Figure 3-7) for building class is:

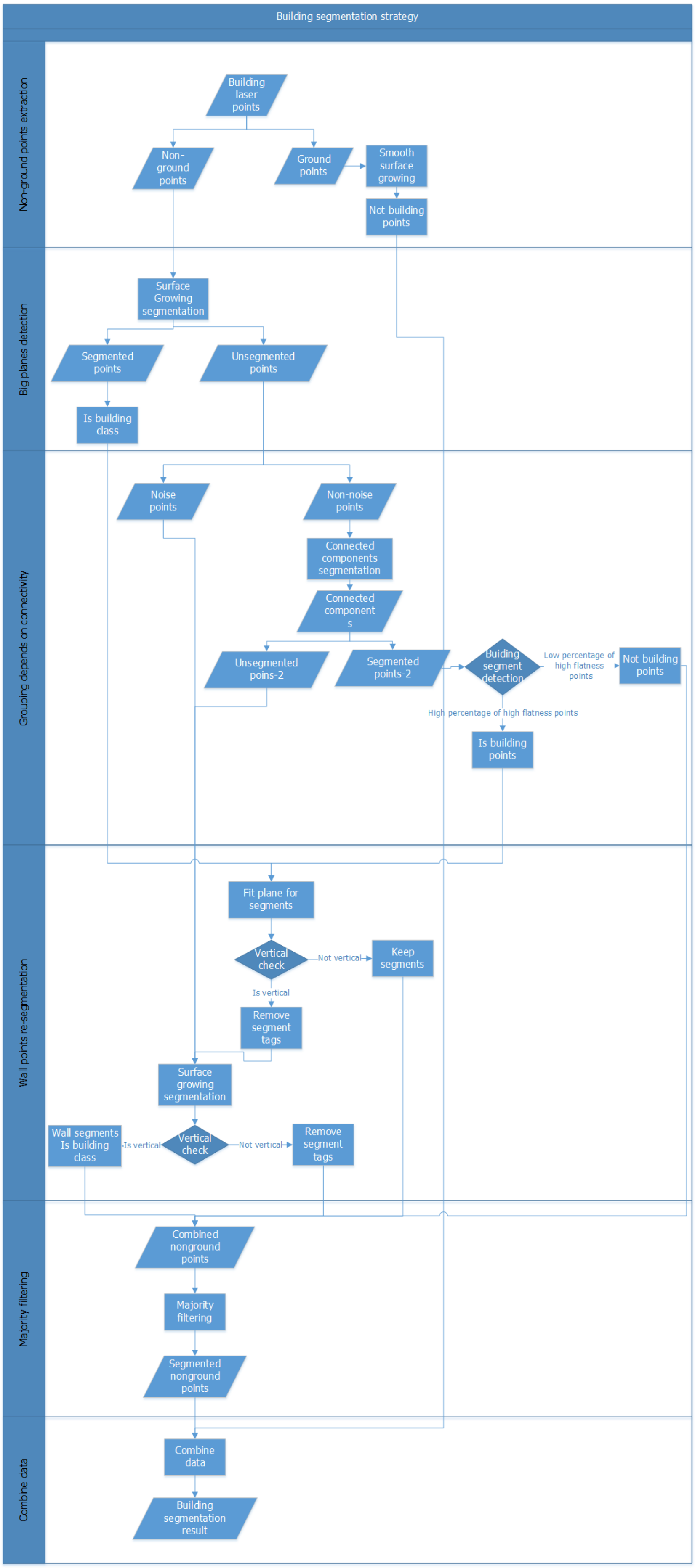

Building segmentation strategy
Non-ground points extraction
Big planes detection
Grouping depends on connectivity
Wall points re-segmentation
Majority filtering
Combine data
Building laser points
Non-ground points
Ground points
Smooth surface growing
Not building points
Surface Growing segmentation
Segmented points
Unsegmented points
Is building class
Noise points
Non-noise points
Connected components segmentation
Connected component s
Unsegmented poins-2
Segmented points-2
Buiding segment detection
Low percentage of high flatness points
Not building points
High percentage of high flatness points
Is building points
Fit plane for segments
Vertical check
Not vertical
Keep segments
Is vertical
Remove segment tags
Surface growing segmentation
Wall segments Is building class
Is vertical
Vertical check
Not vertical
Remove segment tags
Combined nonground points
Majority filtering
Segmented nonground points
Combine data
Building segmentation result

Figure 3-7 Workflow of building class segmentation

A. Non-ground points extraction. As the raw dataset already get a tag to indicate they are ground or not, so it is easy to separate ground points and non-ground points from the building point dataset. A smooth surface growing segmentation to detect smooth surfaces will run for the ground points. The parameters of smooth surface growing in this thesis are minimum size of ground segment (n), radius of searching window (r), max accepted distance from candidate points to local surface (d). Ground points will directly be labeled as not building points.

B. Large planes detection. As the points are located in different polygons and no one object will exist in more than one polygon. So run the plane surface growing segmentation polygon by polygon for non-ground points, which is to detect the large planes that are mostly roof surfaces. The parameters of plane surface growing are mostly common with parameters of smooth surface growing, except the max accepted distance (d) in plane surface growing is from candidate points to current plane surface, but in smooth surface growing is form candidate points to local surface. The parameters setting of surfaces growing segmentation should accord to the point density of the dataset and the real scenes. The segments detected by this process will be labeled as belonging to building class (Figure 3-8).

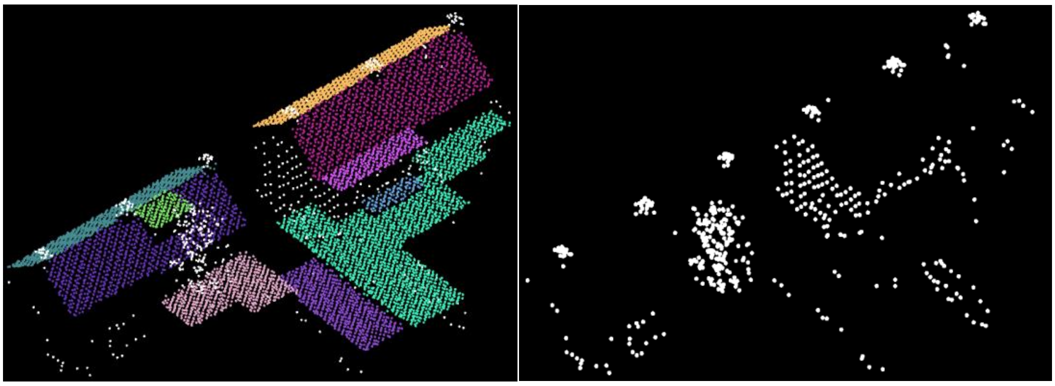


Figure 3-8 Large plane detection (left), remaining points (right)

C. Grouping depends on connectivity. After large planes are detected and labeled with segment numbers, for the remaining unsegmented non-ground points, the connected components segmentation polygon by polygon is used to identify objects depends on the connectivity. In order to get a better result, before I run the connected components algorithm, a step named noise identification should be done. The points which have less than a certain number (n) of neighbor points in a range of a certain radius (r) are considered as "noise". But some of them are not actually noise, but isolate points. So the only one purpose to do these process is decreasing more background, and get a better result of connected component segmentation, and these "noise" points (will called noise directly in the following part) will re-processing in the following processes. The determination of parameter n and r also should be depended on the point density and real scenes. After the noise recognized, the following connected components segmentation will be implemented for the unsegmented non-noise points. The parameter of connected component segmentation is the max distance

(d) between points in one component. The parameter setting of connected components segmentation also should be depended on the point density and real scenes.

The segments identify by this process will contain small roof surfaces, some wall surfaces, and some objects belong to other land cove which are mostly plants. So in this step I need to identify the segments which actually belong to the building class. The characteristics of the segments may exist in this step are:

1 Not building components: mostly plants, no regular surfaces. In a few cases, there will be parked cars closed to the building and construction material, they have regular surface but not belong to the building. But as they appear too few, they are ignored.

2 Building components: walls, windows or chimney, they have plane surfaces

So, according to these characteristics, the algorithm to differentiate these objects can be developed as:

1 Calculating the local flatness of each point of each segment. The flatness is calculated by $\lambda1 > \lambda2 > \lambda3$ which are the eigenvalues of the variance-covariance matrix which is produced within the local neighbor points of each point. For this step the flatness is computed for points, so each point will get a flatness value, the neighbor points which are involved to compute variance-covariance matrix are the k nearest points of the center point. $\lambda1$, $\lambda2$, $\lambda3$ are respectively the maximum, median and minimum eigenvalues of the variance-covariance matrix. In general the flatness (F_λ) is computed as (Chehata and Guo, 2010):

$$F_\lambda = \frac{\lambda2 - \lambda3}{\lambda1}$$

But for elongated pieces of wall there will lead to a low flatness as $\lambda1$ is too much larger than $\lambda2$, so in order to avoid this case. In this thesis the flatness is computed as (Vosselman, 2013):

$$F_\lambda = \frac{\lambda2 - \lambda3}{\lambda2}$$

2 The points on plane surfaces will get larger flatness than non-plane points. If a point gets a high flatness value, we do consider the local surface around this point is flat. The points of planes segments will mostly get a high flatness, but the points of non-plane segments (e.g. trees) will get a low flatness. Depending on this criteria, building surfaces will be identified by a large percentage of high local flatness points occupied in the segment, because building surfaces are mostly plane. And this segment will be labeled as not belong to building class (Figure 3-9). The parameters of this step need to be set are the number of neighbors (knn) involved to compute flatness, the lowest flatness of

planar points (threshold of flatness) and the lowest percentage (threshold of percentage) of planar points occupied in a building segment.

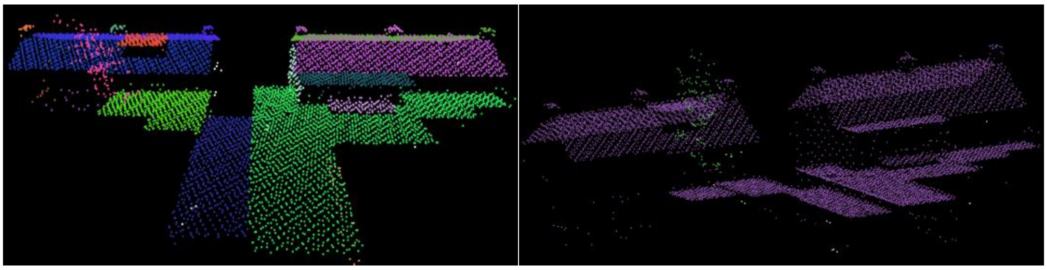


Figure 3-9 Building segments and non-building segments

D. Wall points re-segmentation. Because the density of wall points is much lower than the density of roof points and the previous processes devote to segment roof points, the segmentation parameters are not suitable to wall points, the segmentation result by now are not good enough for wall points. So I need another step to segment the wall points. (Figure 3-10) The logic is

1 Wall points detection. Select vertical building planes form previous processes and remove their segment tag. Then join them into the remaining unsegmented points. After that I will get a dataset of unsegmented points include all wall points.

2 Re-segmentation of wall points. A surface growing segmentation with another suit of parameters will implemented for the unsegmented points which produced in the step 1.

3 Identify the wall segments. I consider if a plane is vertical, then it will recognized as a wall segment. Check the segments which produced in step 2, the wall segments will retain, and be labeled as belonging to building class, but the non-wall segments will remove their segment tag.

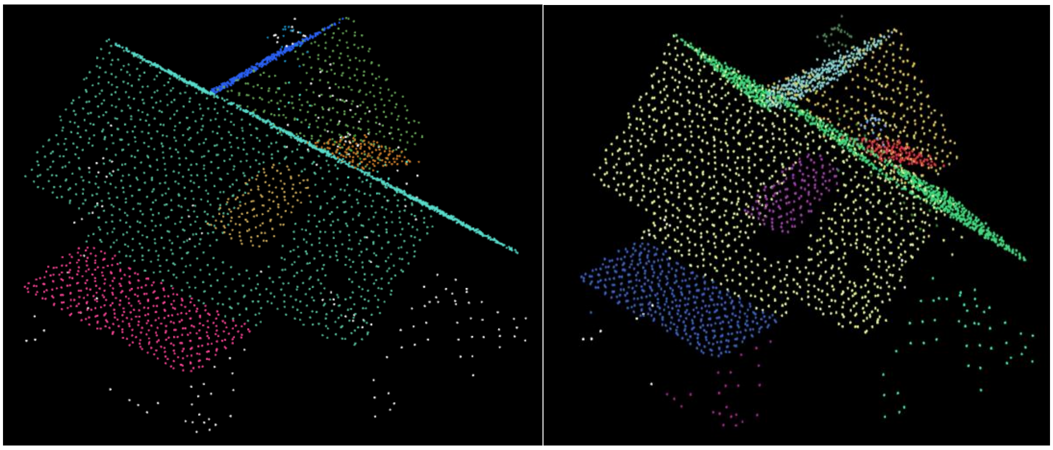


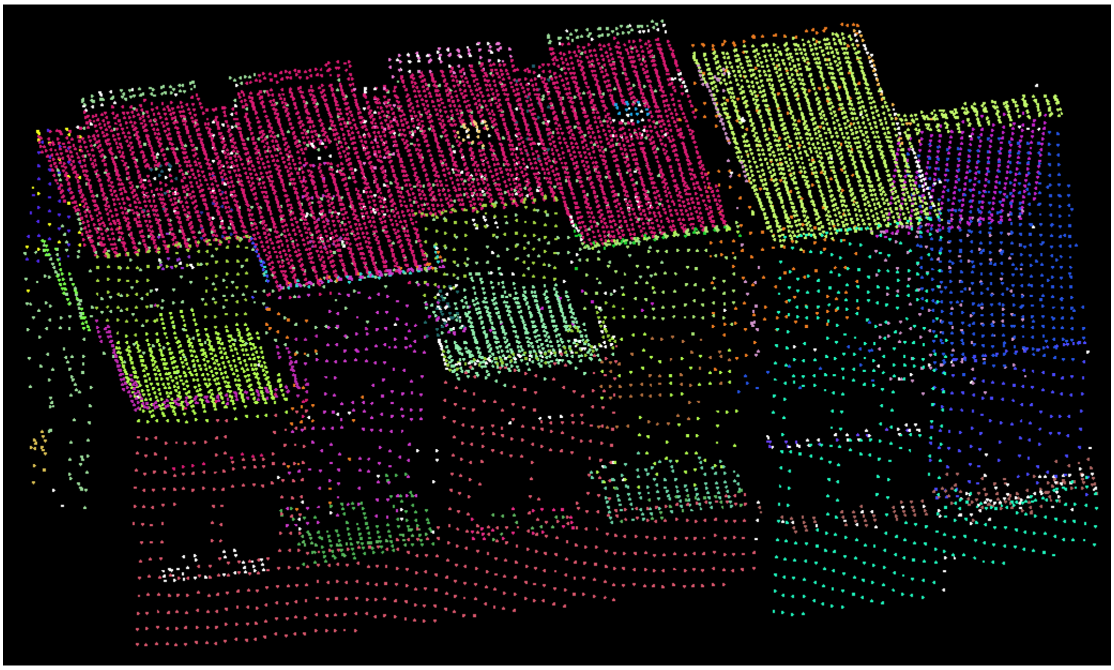
Figure 3-10 Before wall segmentation (left), after wall segmentation (right), (white points are unsegmented points)

E. Majority filtering. By now, most points get segment tags, and for each segment there is a tag to indicate whether it belong to building class or not. But still some points are not segmented. These points mostly come from the noise which I identified before the connected component segmentation, and the other part are isolate points which are not accepted by surface growing as they are not include in the growing window. A majority filtering is implemented to segment these points. The logic of majority filtering is:

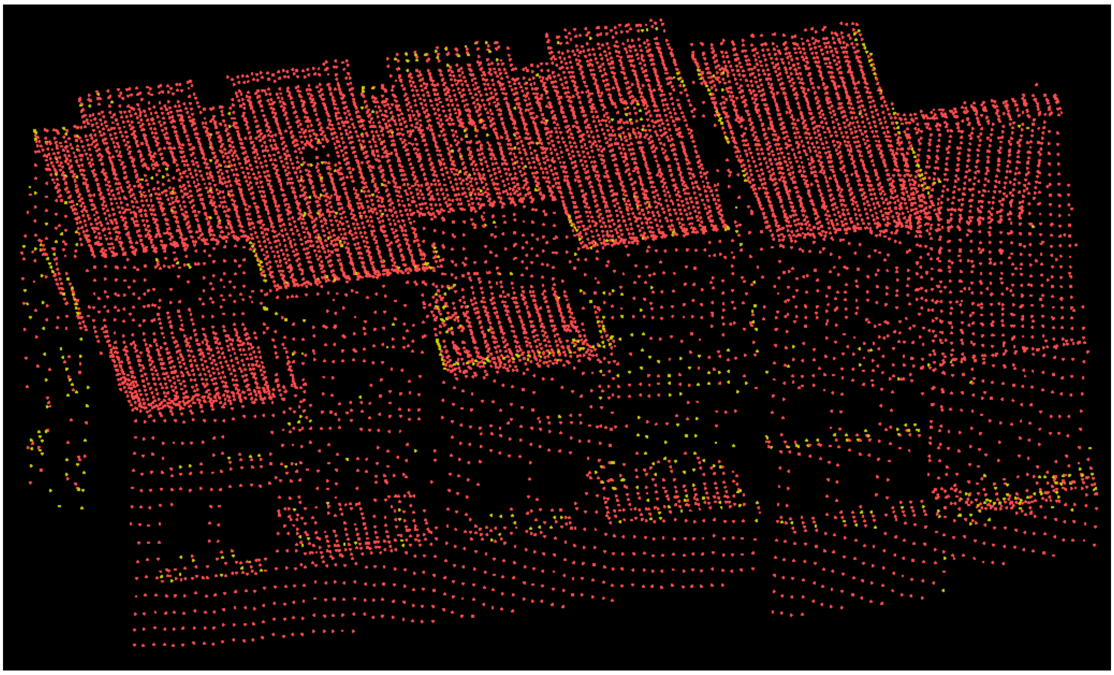
1 In this thesis, the neighbor model of majority filtering is knn neighbor model with a constraint of a certain radius. So the first step of majority filtering is searching the k nearest neighbor points in a certain radius (r). If no sufficient neighbor points available in the space of the certain radius, keep searched neighbors as the searching result.

2 Label the segment tag of each unsegmented point with the majority segment number of its neighbors.(Figure 3-11)

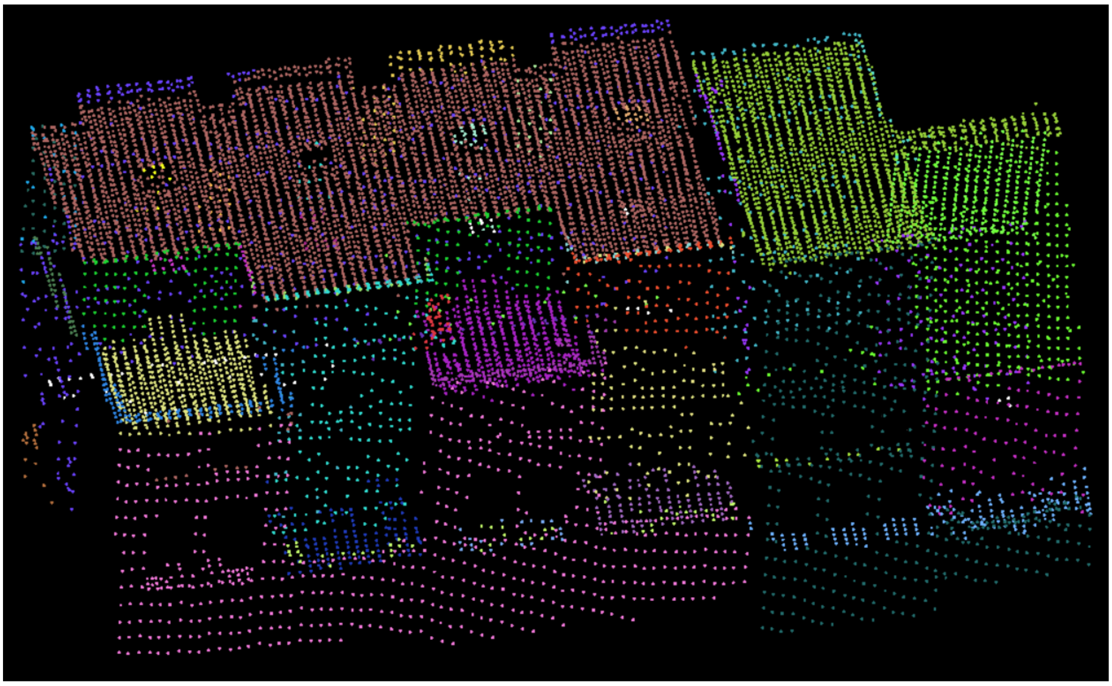
As the majority filtering will merge some unsegmented isolate points into segments, it will break the high accuracy of previous segmentation. So the points segmented in this step will be labeled to indicate they are segmented by majority filtering. That will convenient for one who will use this segmentation result to do other processing like 3D-modeling, they can choose the segmentation result with these points or not depend on their own need.



a) Before majority filtering (white points are unsegmented points)



b) Noise points (yellow points)



c) After majority filtering

Figure 3-11 Majority filtering

F. After all these done, combining the results to insure the integrality of dataset, the still unsegmented points will keep as non-segment points. In this step, the segment numbers of the points in different datasets will not overlay but will renumber the segment values be one sequence.

3.4.2 Plant Cover Class

In urban scene, some areas are full of plants like the town greenery. Not like building class which surfaces are planar, the surfaces in plant cover area are irregular surfaces. The segmentation purpose of vegetation class is identifying the individual objects, like a tree and a smooth terrain piece. Vegetation is the first priority to be identified in the non-ground objects, because they are the majority objects in plant cover class. And the terrain points should be group into smooth terrain patches. The characteristics in plant cover class are:

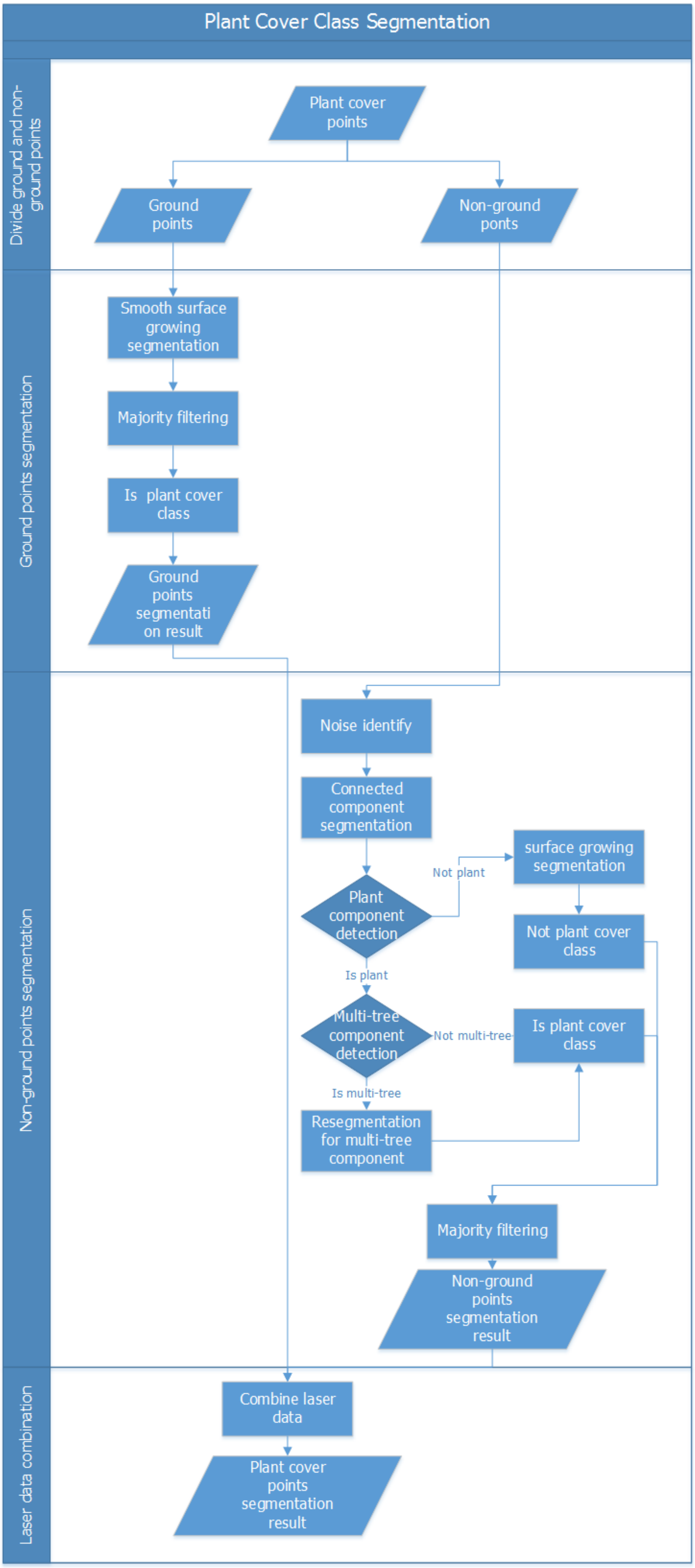
1 The plants or other objects are non-ground points.

2 The majority objects are vegetation, the surfaces of them are irregular.

3 Some plants are close to each other.

4 There also may some manmade objects existed in this class, like structures, electronic tower existed in these areas. Manmade objects' surfaces are regular.

So according to these characteristics, the segmentation strategy (Figure 3-12) of plant cover class is:



Plant Cover Class Segmentation
Divide ground and non-ground points
Plant cover points
Ground points
Non-ground ponts
Ground points segmentation
Smooth surface growing segmentation
Majority filtering
Is plant cover class
Ground points segmentati on result
Non-ground points segmentation
Noise identify
Connected component segmentation
Not plant
surface growing segmentation
Plant component detection
Not plant cover class
Is plant
Multi-tree component detection
Not multi-tree
Is plant cover class
Is multi-tree
Resegmentation for multi-tree component
Majority filtering
Non-ground points segmentation result
Laser data combination
Combine laser data
Plant cover points segmentation result

Figure 3-12 Workflow of plant cover class segmentation

A. Divide ground and non-ground points form plant cover class dataset and they will be segmented separately.

B. Ground point segmentation. The ground of this class is soil earth or grass, there exist some height difference between ground points, and the segmentation objective of ground points is to identify the smooth surfaces of ground. So a smooth surface growing segmentation polygon per polygon will run for ground points. As some isolate points existed, the following step is majority filtering, in order to label the segment tags for unsegmented isolated points with the majority segmentation numbers of their neighbor points. As a result, points belonging to one smooth surface will grouped in one segment. In this class, the ground is regarded as a part of plant cover, so the ground segments will be labeled as belonging to plant cover class.

C. Non-ground point segmentation. As the plant surfaces are irregular, so surface growing segmentation depending on smoothness or planarity are both not suitable for plants. So the strategy of non-ground point segmentation in plant cover class is:

1 Grouping depends on connectivity. The principle is the same with the connectivity grouping in building segmentation. A step of noise identify also should be done before the connected component segmentation. After these processes, the objects which get close to each other will group as one component. But our purpose of plant cover segmentation is to identify individual object, for example, a house (some manmade objects may existed in this class as non-plant segments) will group as one component in this step, but we need to derive each surface of the house to be one segment, and also we need to derive individual trees from a multi-tree component. So the following processes will devote to derive surfaces from non-plant components and individual objects from the multi-objects components.

2 Non-plant components segmentation. This process will contain 2 steps. The first one is non-plant components detection, the following step is segmentation for them.

Non-plant component detection. Because the non-plant components are mostly manmade objects, so the surfaces of non-plant components are mostly smooth, comparing with irregular plant surfaces, so flatness can be used to differentiate them. For each point in one component, calculate its local flatness. If the points with large flatness value count a large percentage in that segment, then I consider the surfaces of this segment are smooth, so this component is regarded as non-plant component. And will be labeled as not belonging to plant cover class. In this step, 2 parameters need to be set which are the lowest flatness of local flat points and the lowest percentage local flat points occupied in a non-plant component.

Non-plant component re-segmentation. A smooth surface growing segmentation will be run segment per segment on the manmade object points, following by a majority filtering to segment the points which do not get a segment tag in the smooth surface growing process. (Figure 3-13)

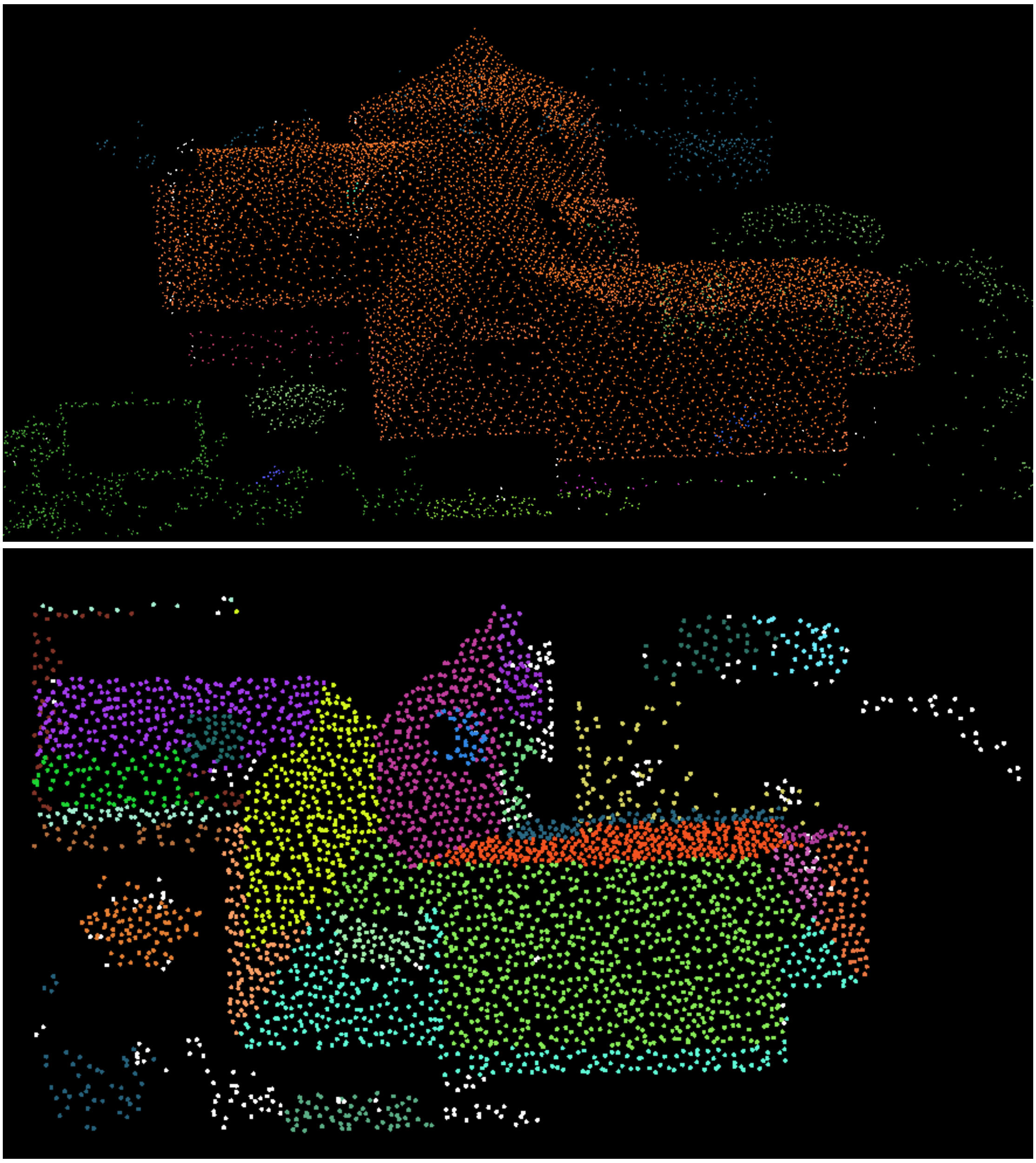


Figure 3-13 A manmade component (upper) in plant class, re-segmentation for manmade component (lower)

3 Plant component segmentation. The components already separate as non-plant components or plant components in the previous processes. The plant o components will be labeled as belonging to plant cover class. And there will contain individual tree segments, multi-tree segments and low-vegetation objects in the plant components. For individual tree components and low-vegetation components, they can directly regard as the final segmentation result, no need to segmentation for their interior. But for multi-tree components, they need further segmentation to derive individual tree

segments. So the segmentation for the plant segments mainly contains 2 steps, multi-tree segments detection and segmentation for multi-tree segments.

Multi-tree component detection. First, differentiate the low-vegetation components from tree components by the maximum height difference in a component. And then using maximum height difference divide by segment size as an index (i) to differentiate the individual tree segments and multi tree segments.

Multi-tree component re-segmentation. How to derive individual trees from multi-tree segmentation is not a new topic in point cloud processing field. There are many algorithms like mean shift, local max, can be used to achieve this purpose. In this thesis, a local maxima algorithm is used to derive individual trees from multi-tree component: a) Find the highest neighbor for each point at a certain radius in a multi-tree component. b) For each points go to its highest neighbor, and then go to the highest neighbor of its highest neighbor, go as this logic until the highest neighbor is not change, it will consider as reaching the top points of trees. c) The points which have the same final highest destination will group as an individual tree segment. (Figure 3-14)

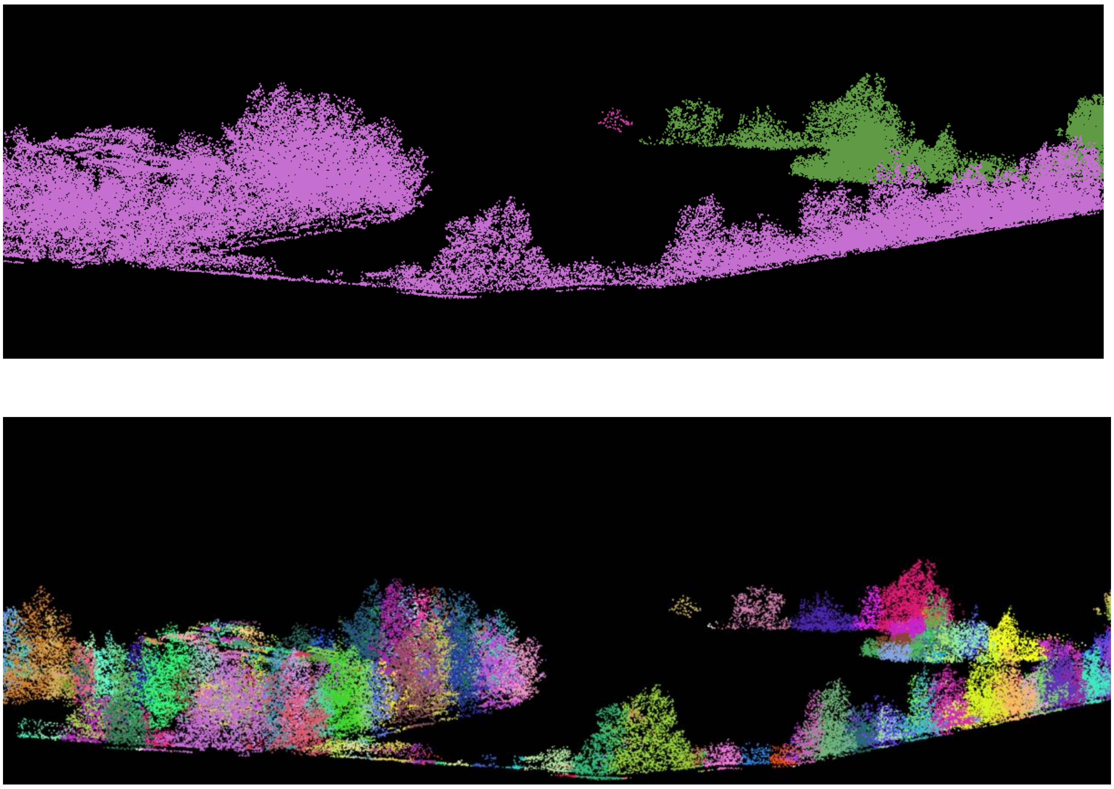


Figure 3-14 Multi-tree components (upper), result of multi-tree segmentation (lower)

4 Majority filtering. There will be some points which still do not have segmentation tag by now. Majority filtering will be done to label segment tag with the majority segment numbers in their neighbor points for unsegmented points.

D. Laser data combination. Combine the segmentation results of ground points and non-ground points.

3.4.3 Road class

Road is an important element of city. Roads mostly run through every corner of urban area. Segmentation of roads is the base of road modeling. The purpose of road segmentation is grouping points belong to an object into one segment (For road points, an object means a smooth surface of a road. For non-road points, an object means an individual physical object like a car or a street lamp) and labeling the points which actually belong to roads. The characteristics of road class are:

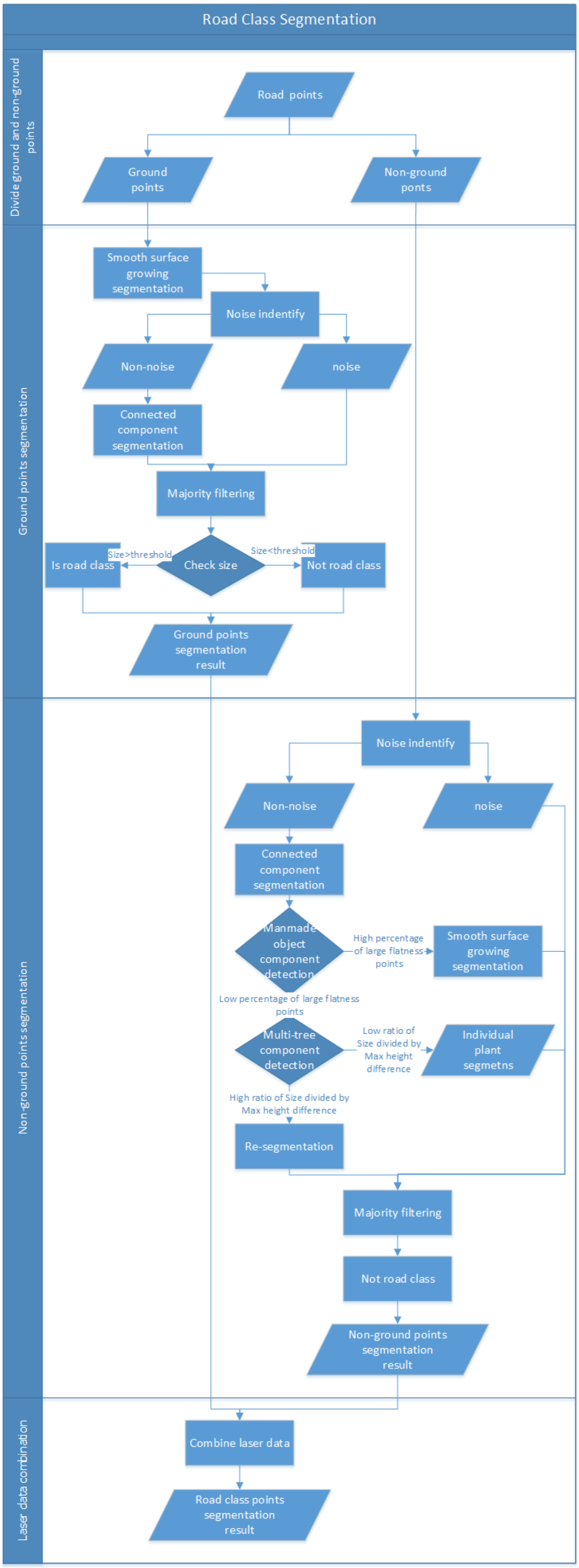
1 Roads are in ground points. Non-ground points are street furniture, cars and so on.

2 The surface of a road is smooth.

3 The area of a road is mostly large.

4 The objects on the road may contain manmade objects like cars, structures and street lamps, and also plants like trees and low-vegetation.

So according to these characteristics, the segmentation strategy (Figure 3-15) for road class is:



Road Class Segmentation
Divide ground and non-ground points
Road points
Ground points
Non-ground ponts
Ground points segmentation
Smooth surface growing segmentation
Noise indentify
Non-noise
noise
Connected component segmentation
Majority filtering
Is road class
Size>threshold
Check size
Size<threshold
Not road class
Ground points segmentation result
Non-ground points segmentation
Noise indentify
Non-noise
noise
Connected component segmentation
Manmade object component detection
High percentage of large flatness points
Smooth surface growing segmentation
Low percentage of large flatness points
Multi-tree component detection
Low ratio of Size divided by Max height difference
Individual plant segmetns
High ratio of Size divided by Max height difference
Re-segmentation
Majority filtering
Not road class
Non-ground points segmentation result
Laser data combination
Combine laser data
Road class points segmentation result

Figure 3-15 Workflow of road class segmentation

A. Divide ground and non-ground points form road class dataset and they will be segmented separately in the following processes.

B. Ground point segmentation. Like segmentation for ground points of previous classes, a smooth surface growing segmentation will first to be run polygon by polygon on the ground points. But unlike the plant cover class, the following process of ground points of roads is noise identification followed by connected component segmentation polygon by polygon for unsegmented points. Because the bodies of roads are in the ground points, and the segmentation purpose of road ground points is identify each road as a segment, so some more details in the ground points should be identified. At last, majority filtering is used to label segment tag for still unsegmented points. As road segments are mostly large, so the segments which their size larger than a threshold will treat as road segments, and be labeled as belonging to road class.

C. Non-ground point segmentation. As the objects in road class non-ground points are similar to plant cover class. The main idea of segmentation is the same as plant cover class. First, the connected component segmentation polygon by polygon will be implemented on non-ground points. And then detect the manmade object components and plant components, and re-segmentation for them separately. The methods used for regimentation are the same with the plant cover class. Obviously, non-ground points do not belong to road class, so after the segmentation they will label as not road class.

D. Combine the segmentation results of ground points and non-ground points as usual.

3.4.4 Water Class

Water bodies mostly existed in urban area, no matter it is a lake of a park or a river through the city. The first priority segmentation purpose of water class is group points from water body like a lake or a river into one segment and be labeled as belonging to water, because water bodies are the most important objects in this class. For other objects, I also segment them as one object one segment. The characteristics of water class are:

1 The surfaces of water bodies are large horizontal planes.

2 Water bodies could absorb laser beams, that will lead to blank areas of point cloud

3 The laser points of water bodies are in ground point dataset, but not all the ground points in this class are water bodies.

4 The objects existed in this class are both manmade objects and plants.

As previous, the segmentation strategy (Figure 3-16) is developed based on these characteristics, so it will be:

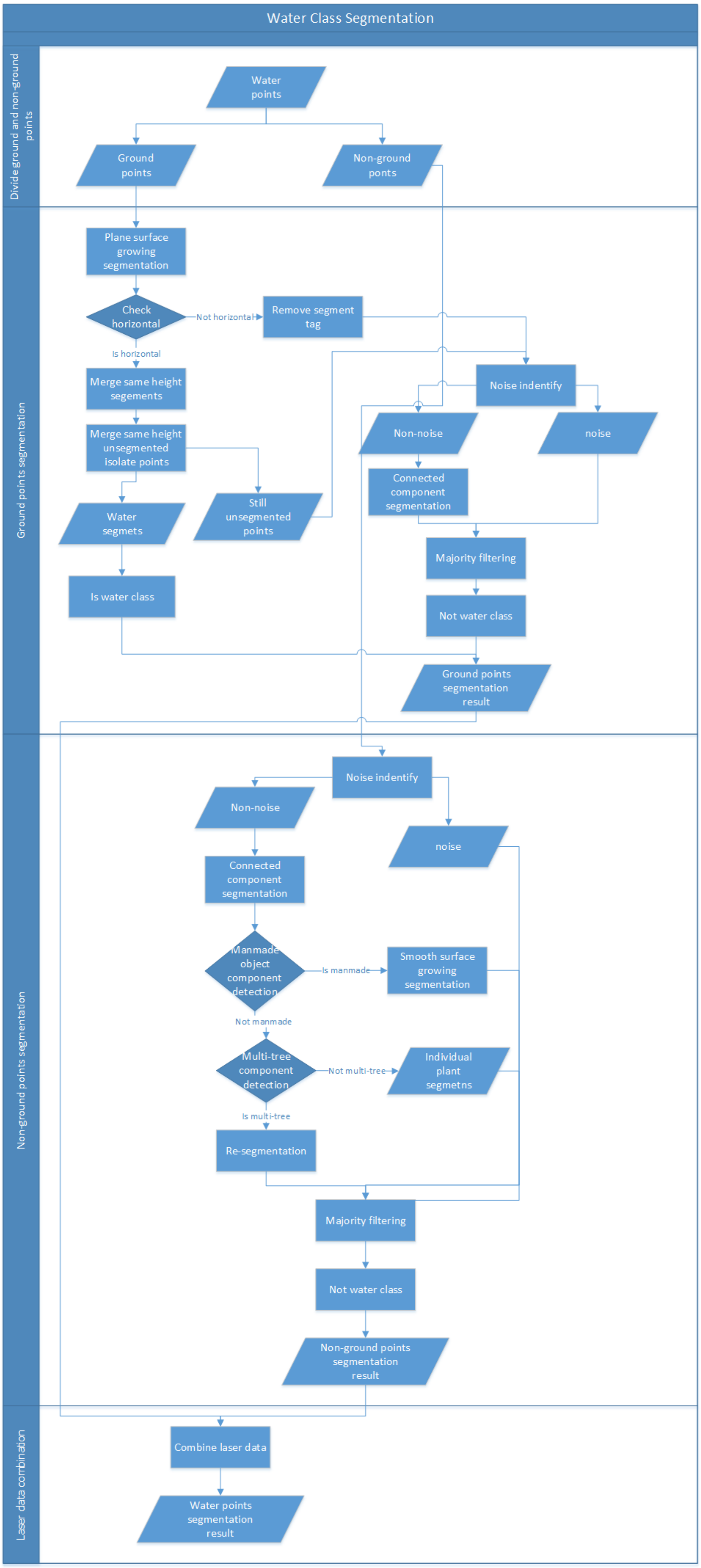

Water Class Segmentation
Divide ground and non-ground points
Water points
Ground points
Non-ground ponts
Ground points segmentation
Plane surface growing segmentation
Check horizontal
Not horizontal
Remove segment tag
Is horizontal
Merge same height segements
Merge same height unsegmented isolate points
Water segmets
Still unsegmented points
Is water class
Noise indentify
Non-noise
noise
Connected component segmentation
Majority filtering
Not water class
Ground points segmentation result
Non-ground points segmentation
Noise indentify
Non-noise
noise
Connected component segmentation
Manmade object component detection
Is manmade
Smooth surface growing segmentation
Not manmade
Multi-tree component detection
Not multi-tree
Individual plant segmetns
Is multi-tree
Re-segmentation
Majority filtering
Not water class
Non-ground points segmentation result
Laser data combination
Combine laser data
Water points segmentation result

Figure 3-16 Workflow of water class segmentation

A. Derive ground points and non-ground points from water class point cloud dataset.

B. Ground point Segmentation. A plane surface growing segmentation algorithm first to be implemented polygon per polygon on the ground points. As some blank area existed, that will lead to an over-segmentation for water bodies. So I need to merge the segments belonging to one water body into one segment. In order to achieve this function, I need to detect the segments belong to one water body. According to the characteristics of water body, for each map polygon area, I detect the horizontal segments and merge the horizontal segments which have a same height in one map polygon. And these horizontal segments will be labeled as belonging to water class. Also merge the isolate unsegmented points with its same height horizontal segment. After that, the water bodies are segmented. The parameters need to be set in this step are max angle (a) of horizontal segment to 0 degree, max height difference (h) between accepted ready to merge segments and the minimum size (n) of water segments. Removing the segment tag of non-water segments, and re-segmentation them using smooth surface growing and majority filtering. The segments which produced after water bodies segmented will label as not belong to water class.

C. Non-ground point segmentation. The non-ground objects in water class are similar to plant cover class. So the segmentation method is identical to plant cover class's method. And obviously, the non-ground segments do not belong to water class.

D. Combine the segmentation results of ground points and non-ground points. The still unsegmented points will keep as non-segment points.

3.4 Quality Assessment

The segmentation model is built class by class, so it's better to assess the quality of the segmentation model class by class. In order to see how good the segmentation model is. I will run the segmentation model step by step to insight the results of segmentation step by step and class by class.

4 Implementation and results

4.1 Data Statement

The laser dataset used to test the segmentation algorithm comes from the AHN2 which is a file with all detailed and precise elevation data of the Netherlands. The density of the laser points is approximate 8 points per square meter. The map used for this thesis comes from BGT (Registration Large Scale Topography) which is a uniform topographic base file with objects throughout the Netherlands. The center of study area of these dataset located at 51°43'30.4"N, 5°15'18.5"E near Den Bosch.

After the combination of laser data and map data, the combination laser dataset will contain the information of 3D coordinates (column1, 2, 3), class number (column 4), polygon number (column 5) and either the point belongs to ground points or not (column 6). (Figure 4-1)

There are 6 different class number in this dataset, and they will be classified into 4 different kinds of land cover classes, which 1001 and 1101 are building class, 2001 and 2101 are road class, 5501 is plant class, 6001 is water class.

```
145356.92 414966.14 3.37 100000006 5501 1
145357.06 414966.61 3.35 100000006 5501 1
145356.77 414966.5 3.36 100000006 5501 1
145356.5 414966.41 3.33 100000006 5501 1
145356.24 414966.31 3.37 100000006 5501 1
145356.87 414966.97 3.32 100000006 5501 1
145356.62 414966.87 3.33 100000006 5501 1
145356.33 414966.77 3.35 100000006 5501 1
```

Figure 4-1 Combination dataset

4.2 Implementation and Results

As the methods mentioned in section 3, the segmentations are implemented class by class, so the results will be presented class by class.

4.2.1 Building class segmentation

The Building class tag value are 1001 and 1101 in this dataset, select the building points and do the segmentation follow the method which proposed in chapter 3.

Re-assignment

In order to insure the integrity of building class point cloud, the re-assignment is implemented with parameters of a radius (r) which is the radius to outward extending the building borders. And a percentage (p) which is the lowest percentage building points occupied in a building segment.

(Figure 4-2)

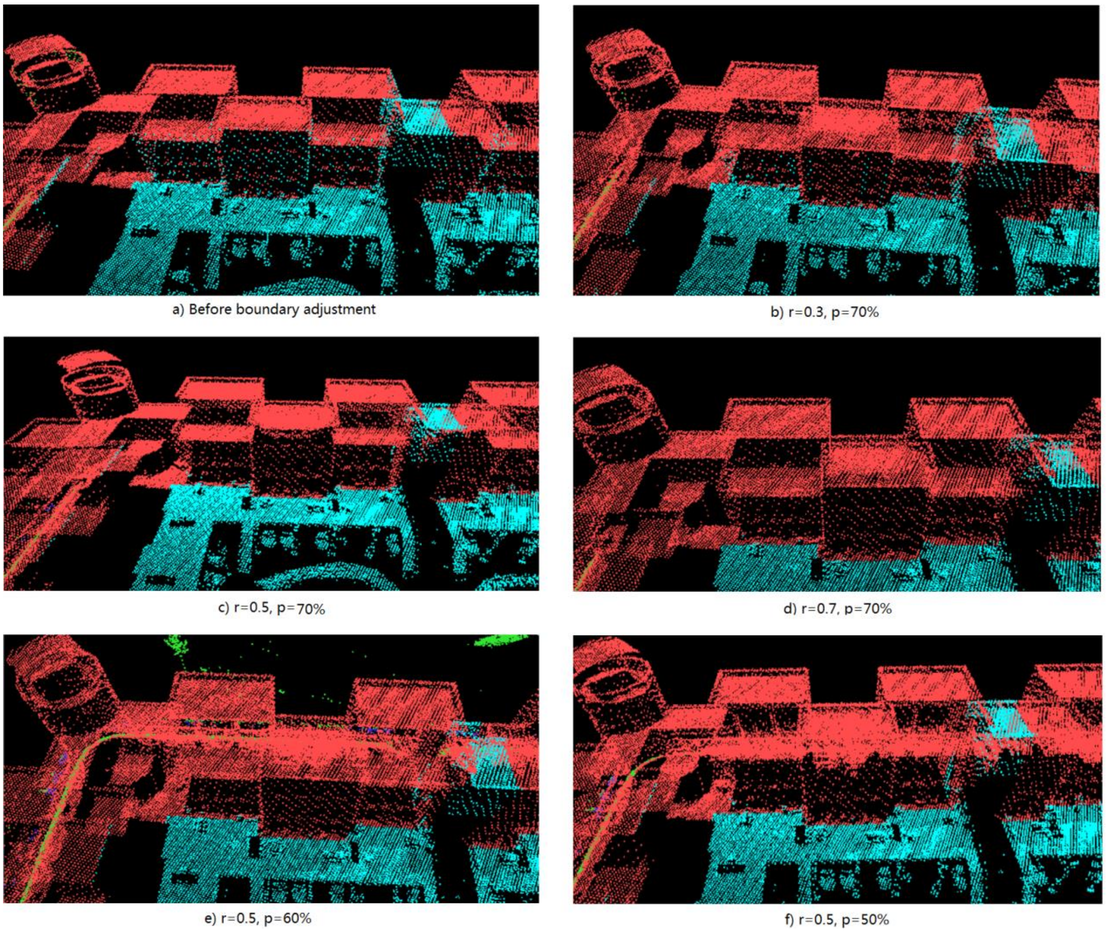


Figure 4-2 Re-assignment results

As the results shown, when r=0.3m, there still some points on the walls do not included. And when r=0.7m there too many other class points included into building class, so the r=0.5 is the better. And the result is not sensitive to parameter p, because the segments show a highly polarization distribution on parameter p. (Figure 4-3).

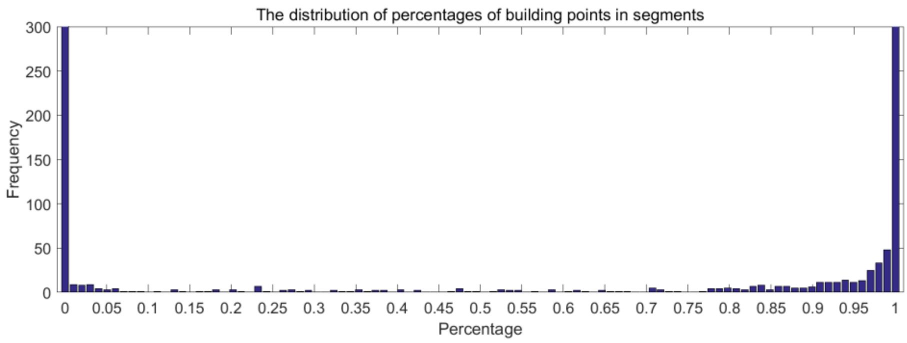


Figure 4-3 Distribution of percentages of building points occupied in segments

Segmentation Strategy

The parameters are determined according to the real scene and the purpose of each step (Table 4-1). For example, in the large plane detection step, as the purpose of this step is to detect the large plane surfaces, the minimum size of plane surfaces should be set to a bit large, and in the surfaces of building are mostly normative planes, so the thresholds for plane surfaces growing should be strict.

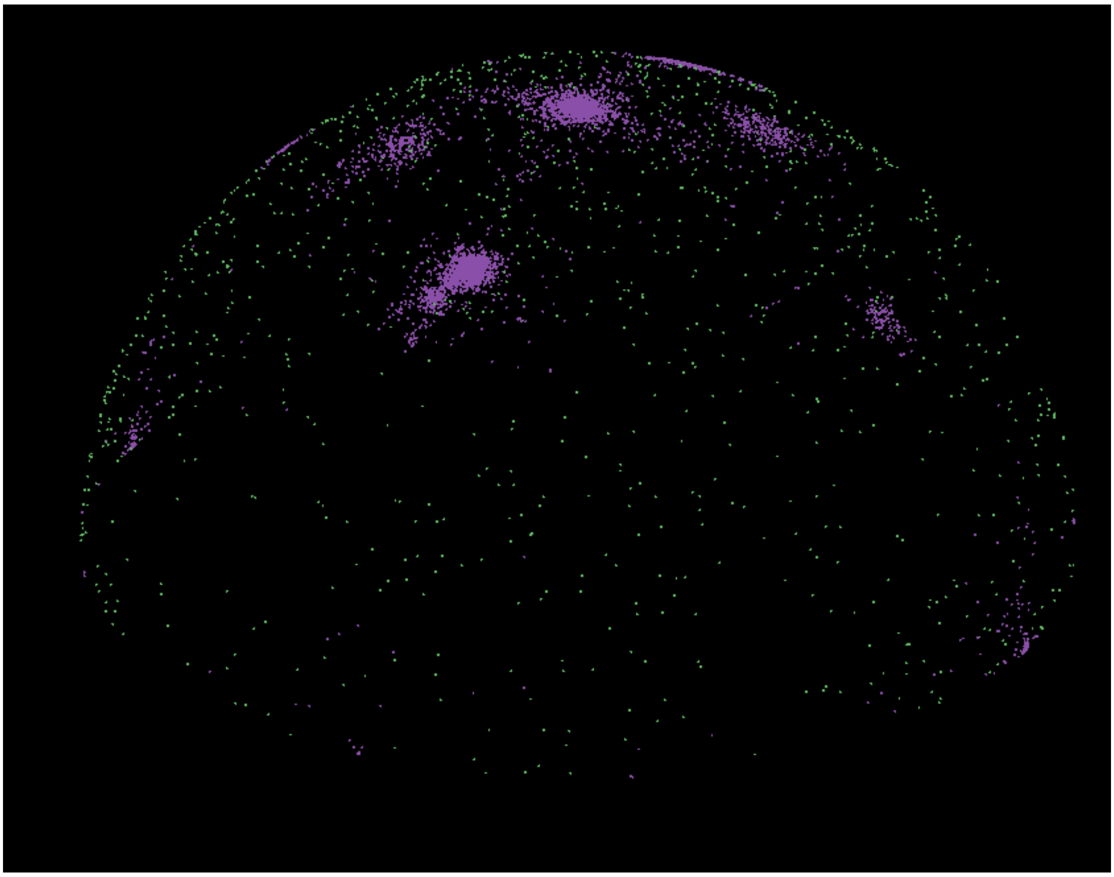
Stages	Parameters	Value	Description
Non-ground points extraction	Minimum size	20 pts	Minimum size of ground segment
	seed radius	1 m	The radius of searching neighbors in seed selection step
	Accepted max distance to plane	0.5m	The max accepted distance from candidate points to local plane
	Growing radius	2 m	The radius of searching neighbors in growing step
Large planes detection	Minimum size	100 pts	Minimum size of large plane segment
	seed radius	1 m	The radius of searching neighbors in seed selection step

	Accepted max distance to plane	0.2 m	The max accepted distance from candidate points to seed plane
	Growing radius	1 m	The radius of searching neighbors in growing step
Connectivity grouping	Max noise neighbor number	6 pts	The max number of noise neighbors in a certain area
	Radius of neighbors	1 m	The radius of the area of neighbors searching
	Knn	10	The number of the nearest neighbors involved to compute flatness
	* Threshold of flatness	0.8	The threshold of flat local surface and non-flat local surface
	* Threshold of percentage	70%	The threshold percentage of flat points occupied between manmade object and non-manmade object
Wall points re-segmentation	Minimum size	10 pts	Minimum size of segment
	seed radius	3 m	The radius of searching neighbors in seed selection step
	Accepted max distance to plane	0.5 m	The max accepted distance from candidate points to seed plane
	Growing radius	3 m	The radius of searching neighbors in growing step

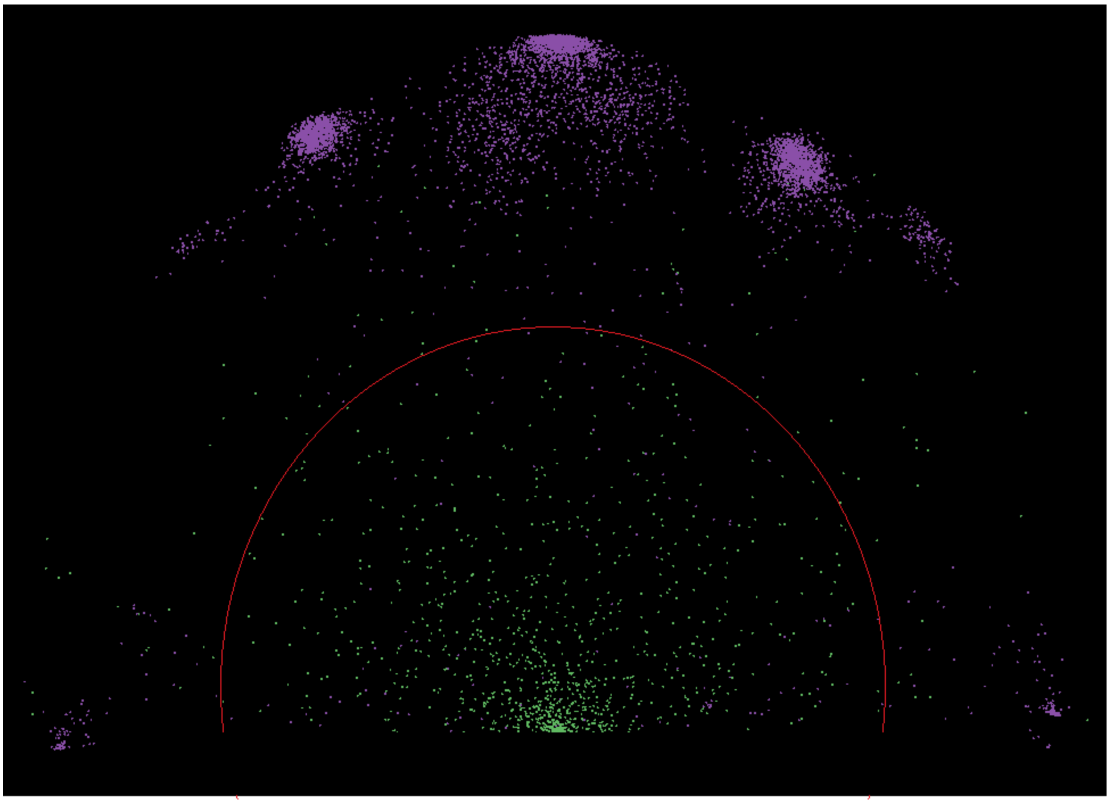
Majority filtering	Neighbor radius	2 m	The radius of searching neighbors take into count
	Knn	20	K nearest neighbor points

Table 4-1 Parameters of building segmentation strategy (* means crucial parameter)

The determination of threshold of flatness and threshold of percentage are based on the dataset. For this dataset, first manually select some obviously plane segments and some obviously non-plane segments, compute the flatness for each point of these segments, the flatness of points could be visualize as its square multiple by normal vector of the points (Figure 4-4), not a very clear crisp threshold shown on the distribution, but an approximate position of threshold can be found. As well as for each segment, the threshold of percentage is computed, and the distribution of percentages of high flatness points occupied in segments is shown in Figure 4-5. As we can see from the bar chart, the threshold of percentage of high flatness points is approximate 70%.



a) Visualization of points' normal (purple points are from plane segments, green points are from non-plant segments)



b) Visualization of scaled normal (flatness * flatness *normal) (red curve is threshold of flatness)

Figure 4-4 Distribution of normalized local normal and scaled local normal

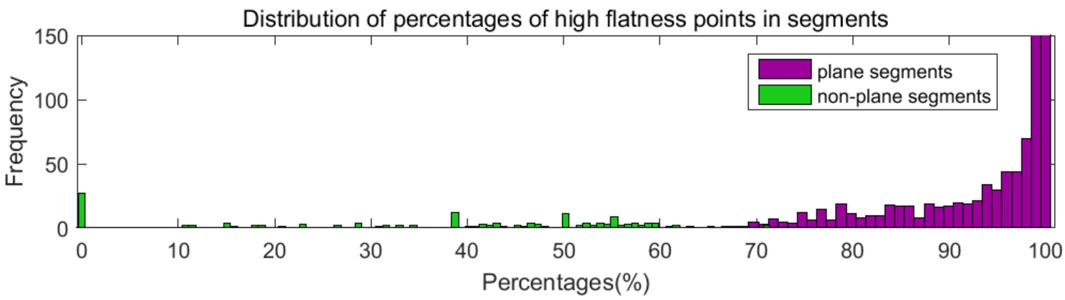
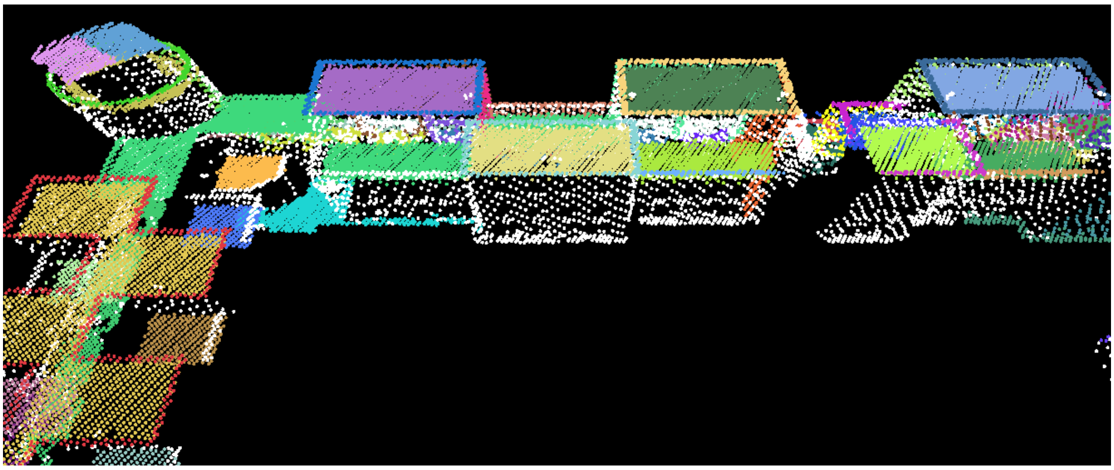
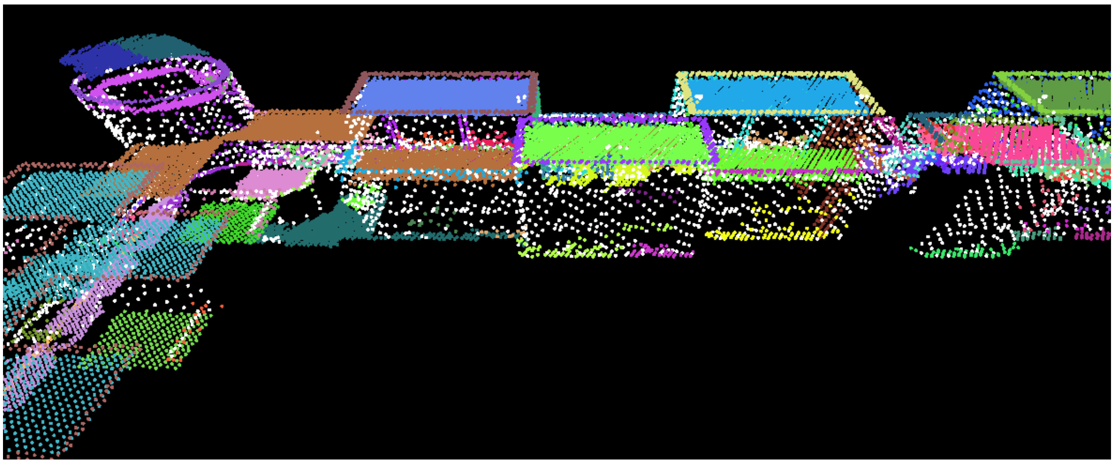


Figure 4-5 Distribution of percentages of high flatness points in segments

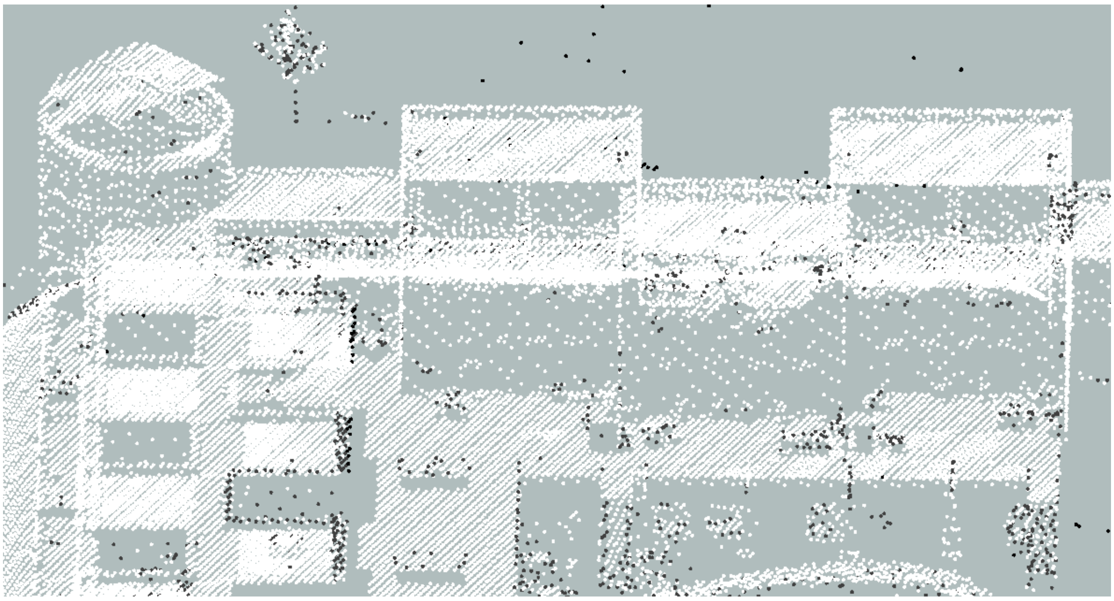
The results of building class segmentation: (Figure 4-6):



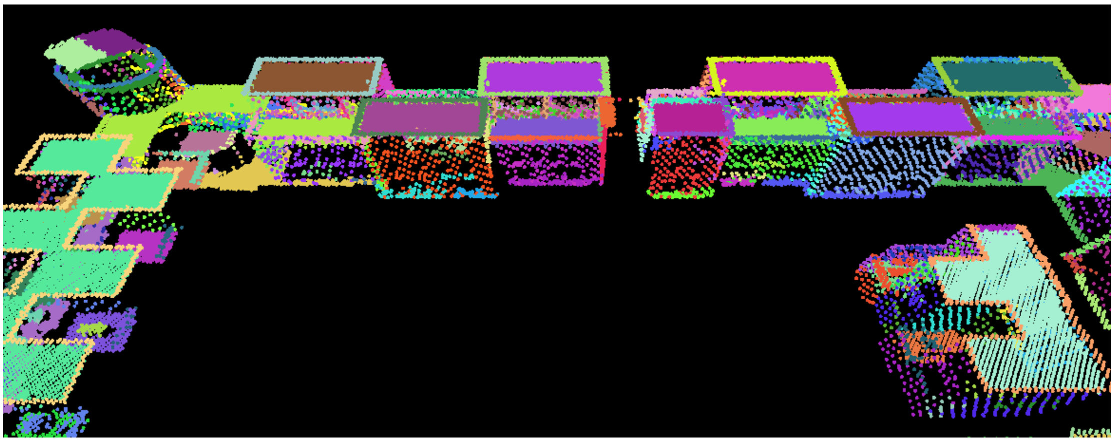
a) Result of large plane segmentation



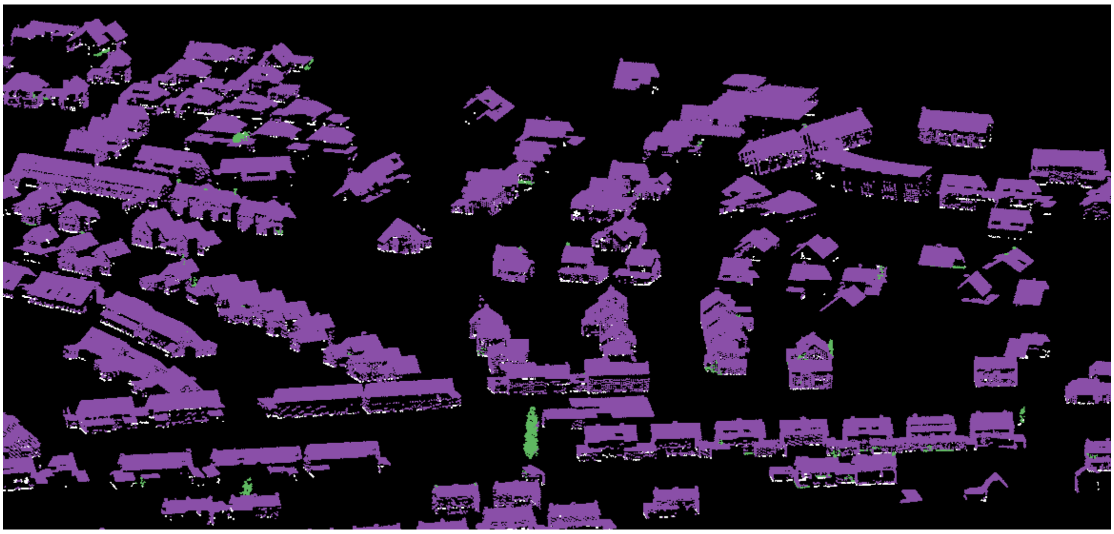
b) Result of connectivity grouping



c) Majority filtering segmented points (black points are segmented by majority filtering, white points are segmented be previous process)



d) Result of non-ground points segmentation



e) Result of classification (purple points are building points, green points are non-building points, white points are non-segment points)

Figure 4-6 Results of building point segmentation

After the large plane detection, the large roof surfaces are almost segmented, but the points on the wall are unsegmented, that because the wall points has lower point density than roof points and the real scenes of walls are different from roofs which as may some windows existed on the wall, so wall surfaces are not so normative plane as roofs. That leads to the parameters of roof surface segmentation are not suitable for wall points, so the result show a bad segmentation on walls.

After the wall points re-segmentation, the wall points are almost segmented, but some over segmentation case existed, that's because the wall segment are not normative vertical plane, so after the connected component segmentation, when the manmade object component detection is done, some component segment are incorrect classified into non-manmade surfaces. As well as some component segments are detected as manmade surfaces but not detected as wall segment, because they are not so vertical. Both these two cases, the component segments will not join the step of wall re-segmentation. That leads to some over segmentation existed on wall surfaces.

As explained in the previous chapters, some wall surfaces are not that normative plane, and some connected component segments which grouping the points at the corner of building surfaces, that will lead to several surfaces in a small segment, but as each surface is too small to be detected as a plane, so these connected component segments will recognized as non-manmade surfaces at final. That's why we can see some miss classification at the corner of building surfaces.

4.2.2 Plant Cover Class

The plant cover class tag value is 5501 in this dataset, select the plant cover points and do the segmentation follow the method which proposed in chapter 3.

Ground point segmentation

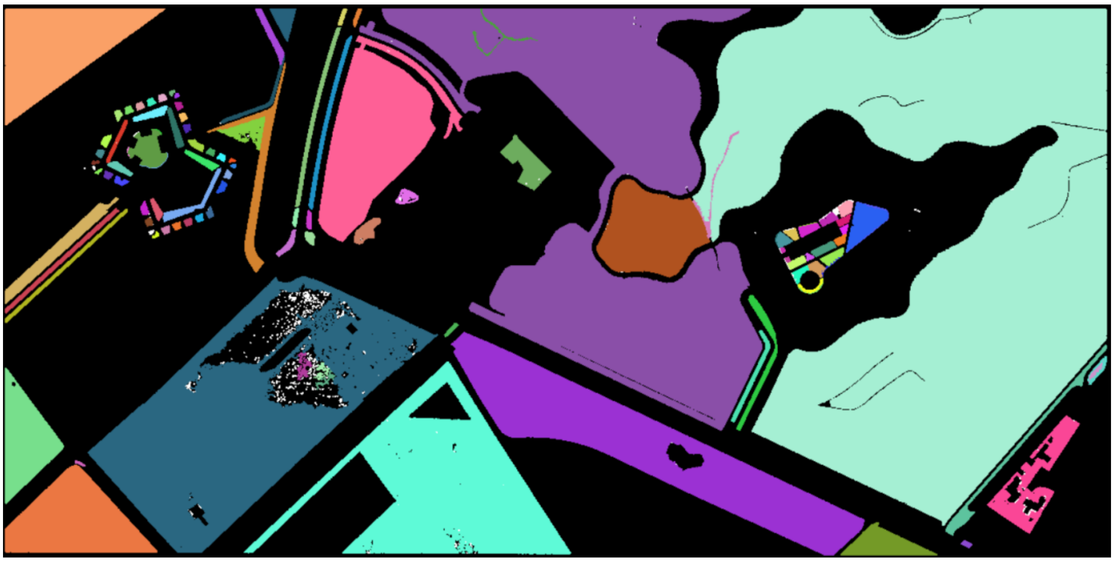
The ground of this class are mostly soil earth or grass, there will exist some height differences between ground points. According to the purpose of ground segmentation in this class, the ground segments should be pieces of smooth ground surfaces. So the parameters of ground point segmentation are: (Table 4-2)

Stages	Parameters	Value	Description
Ground point segmentation	Minimum size	100 pts	Minimum size of ground segment
	seed radius	1.5 m	The radius of searching neighbors in seed selection step
	Accepted max distance to plane	0.5 m	The max accepted distance from candidate points to local surface
	Growing radius	1.5 m	The radius of searching neighbors in growing step
Majority filtering	Neighbor radius	3 m	The radius of searching neighbors take into count

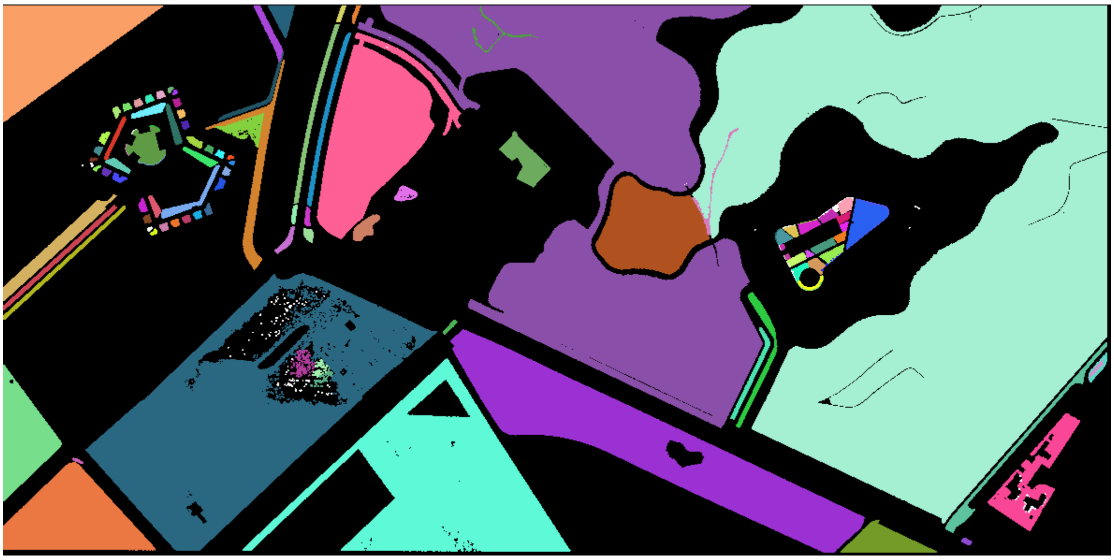
	Knn	20	K nearest neighbor points

Table 4-2 Parameters of ground point segmentation in plant cover class

The result of ground point segmentation (Figure 4-7):



a) Result of smooth surface growing



b) Result of majority filtering

c) Majority filtering segmented points (black points are segmented by majority filtering, white points are segmented be previous process)

Figure 4-7 Segmentation result of ground points in plant cover class

After the smooth surface growing segmentation, most points get a segment value, may be some water area existed in this class, leading to some sparse points existed which are not segmented because they get far away seeding points, and some points on the margin of segment do not have a segment value, that may because there are gradient changes in the border area. The following majority filtering will assign the most frequency segment number of their neighbors to them. Majority filtering will decrease the accuracy of segmentation result of smooth surface growing, because it will merge some noise and gradient difference points , so the points which segmented by majority filtering are labeled out. At final the white points are still unsegmented points.

Non-ground point segmentation

The parameters of non-ground point segmentation are (Table 4-3):

Stages	Parameters	Value	Description
Noise detection	Max noise neighbor number	6 pts	The max number of noise neighbors in a certain area
	Radius of neighbors	1 m	The radius of the area of neighbors searching
Connectivity grouping	Minimum size	10 pts	Minimum size of non-ground segment

	Radius of neighbors	1 m	The radius of searching neighbors in seed selection step
Manmade objects detection	knn	10	The number of the nearest neighbors involved to compute flatness
	Threshold of flatness	0.5	The threshold of flat local surface and non-flat local surface
	Threshold of percentage	60%	The threshold percentage of flat points occupied between manmade object and non-manmade object
Segmentation for manmade objects	Minimum size	10 pts	Minimum size of non-ground segment
	seed radius	1 m	The radius of searching neighbors in seed selection step
	Accepted max distance to plane	0.2 m	The max accepted distance from candidate points to seed plane
	Growing radius	1 m	The radius of searching neighbors in growing step
Multi-tree detection	*Ratio threshold	120	The threshold radio of segment size divided by max height difference
Segmentation for multi-tree segments	Minimum size	1 m	Minimum size of a tree
	Searching radius	2.5 m	The radius of searching highest neighbors

Majority filtering	Neighbor radius	2 m	The radius of searching neighbors take into count
	Knn	20	K nearest neighbor points

Table 4-3 Parameters of non-ground point segmentation in plant cover class

The ratio threshold of component size divided by max height difference is used to differentiate the multi-tree components from individual tree components. For this dataset, manually select some individual tree components and some double-tree components, calculating their ratios of size divided by max height difference. And find the suitable threshold from the distribution of the ratios. (Figure 4-8)

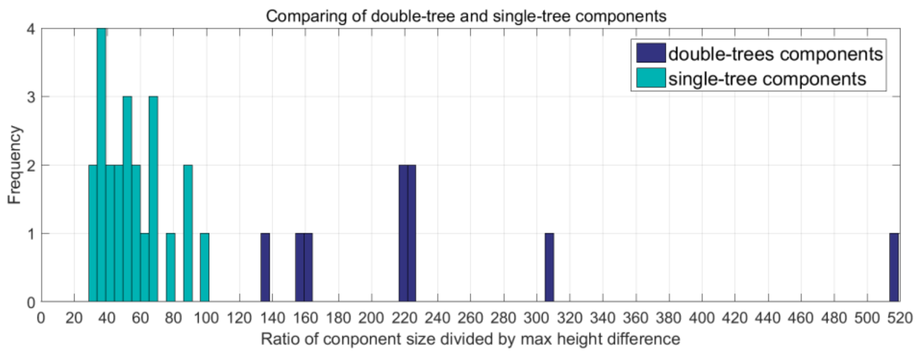
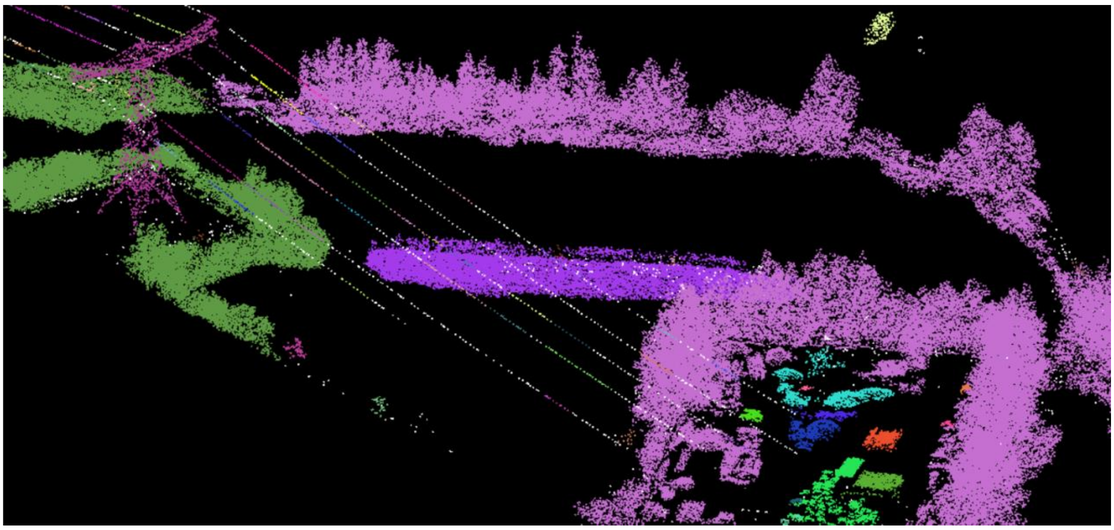
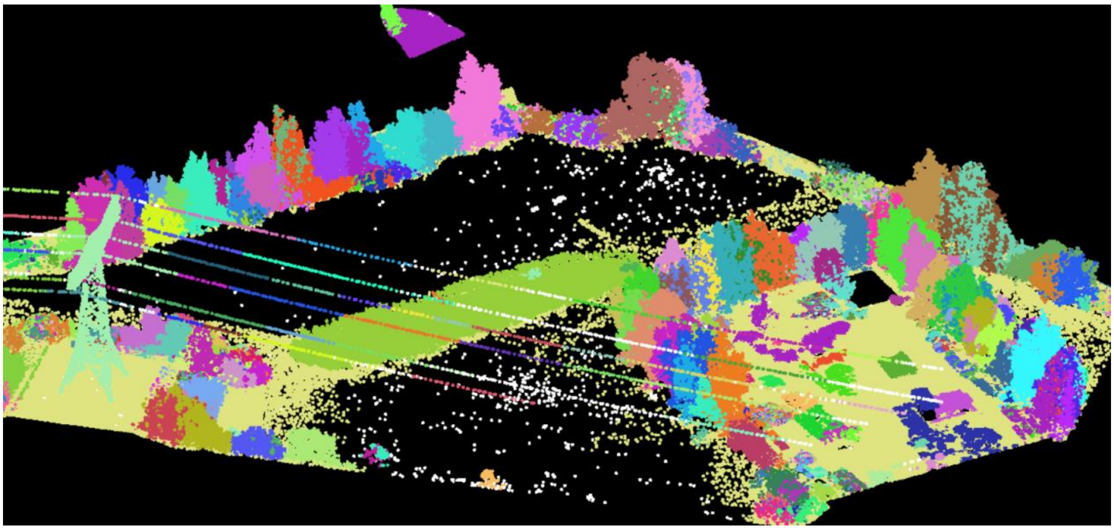


Figure 4-8 Ratio distribution of double-trees components and single-tree components

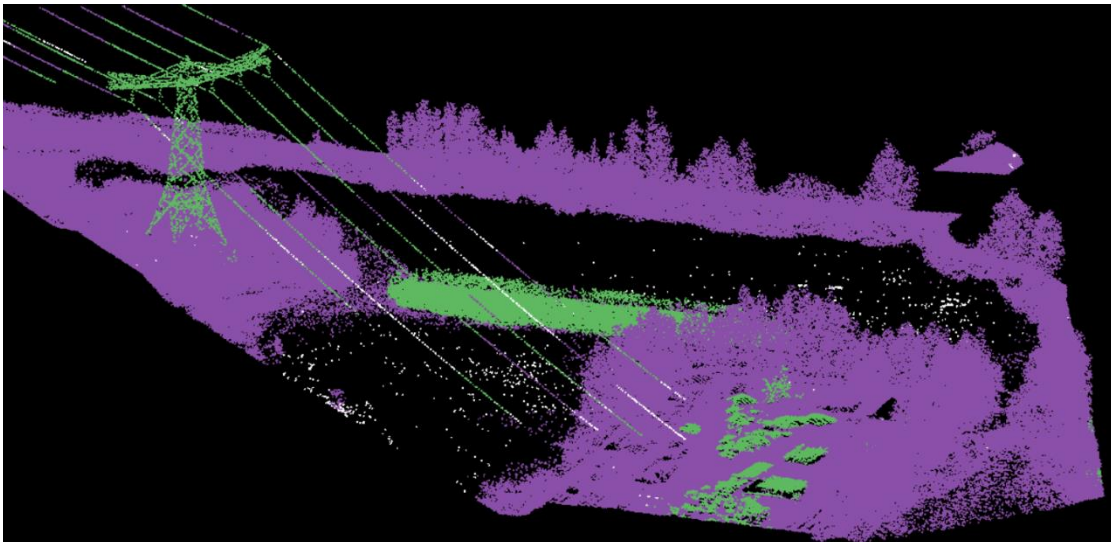
The results of the non-ground point segmentation in plant cover class are (Figure 4-9):



a) Result of connectivity grouping



b) Result of segmentation



c) Result of classification (purple points are plant points, green points are non-ground points, white points are non-segment points)

Figure 4-9 Results of non-ground point segmentation in plant cover class

In the result, one can see some manmade segments are incorrect classified and a large cluster of low vegetation is also incorrect classified. And some trees are over-segmented but some trees are under-segmented. The reasons for these cases are:

After the connectivity grouping, the non-ground points will group into component segments, and these segments will be test whether belong to manmade object or not. Some manmade objects are adjacent to plant objects, leading to mixed component segments in connectivity grouping result. The manmade objects in the mixed component segments are recognized as non-manmade objects, leading to wrong classification.

The area of the large classification is much higher than the height difference in this segment. At some scale, the shape of this segment is oblate flat, so in this case, the points in this segment will get large flatness values, leading to wrong classification.

The multi-tree segments are re-segmented by local maxima algorithm, the radius of searching the highest point is a fixed value, but the shape and size of trees are variance. So that leads to some trees over-segmented but some trees under-segmented.

4.2.3 Road class

The road class tag values are 2001 and 2101 in this dataset, select the road class points and do the segmentation for 2001 tagged point dataset and 2101 point dataset separately follow the method which proposed in chapter 3.

Ground point segmentation

The parameters involved in ground point segmentation are (Table 4-4):

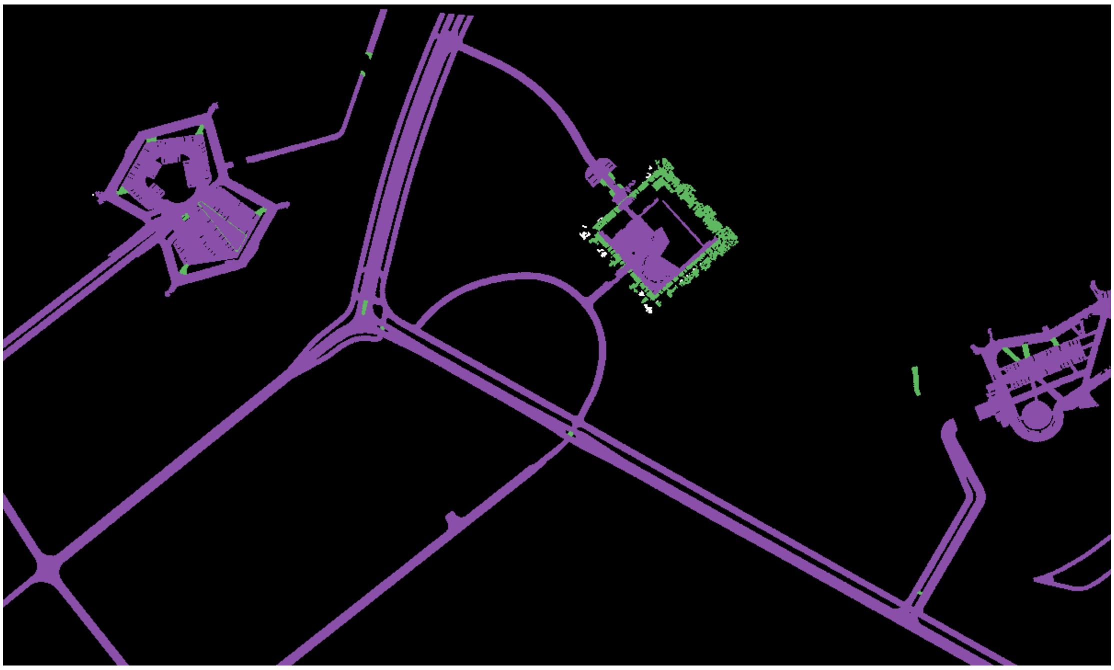
Stages	Parameters	Value	Description
Smooth surface growing	Minimum size	1000 pts	Minimum size of road segment
	seed radius	1 m	The radius of searching neighbors in seed selection step
	Accepted max distance to plane	0.5m	The max accepted distance from candidate points to local plane
	Growing radius	1 m	The radius of searching neighbors in growing step
Noise detection	Max noise neighbor number	6 pts	The max number of noise neighbors in a certain area
	Radius of neighbors	1 m	The radius of the area of neighbors searching
Connectivity grouping	Minimum size	30 pts	Minimum size of ground segment

	Radius of neighbors	2 m	The radius of searching neighbors in seed selection step
Majority filtering	Neighbor radius	2 m	The radius of searching neighbors take into count
	Knn	20	K nearest neighbor points

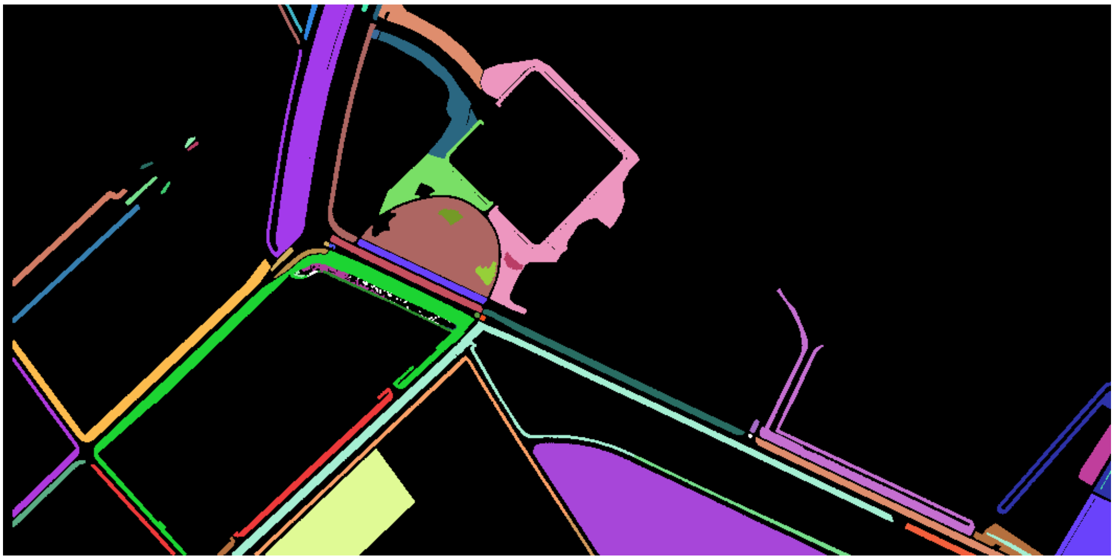
Table 4-4 Parameters of ground point segmentation in road class

The results of ground point segmentation are (Figure 4-10):

a) Result of 2001 ground point segmentation



b) Result of 2001 ground point classification



c) Result of 2101 ground point segmentation

d) Result of 2101 ground point classification

Figure 4-10 Segmentation result of ground points in road class

From the result one can see that some points still not be segmented as they are isolate to other points, the segment sizes are small than minimums segment size and get far from other segments, that leads to majority filtering can't segment them.

Some roads break into 2 or more segments, because they are in different map polygons, and the algorithms no matter connected component segmentation or smooth surface growing are implemented polygon by polygon, so the roads across several polygons will break into several segments.

Non-ground point segmentation

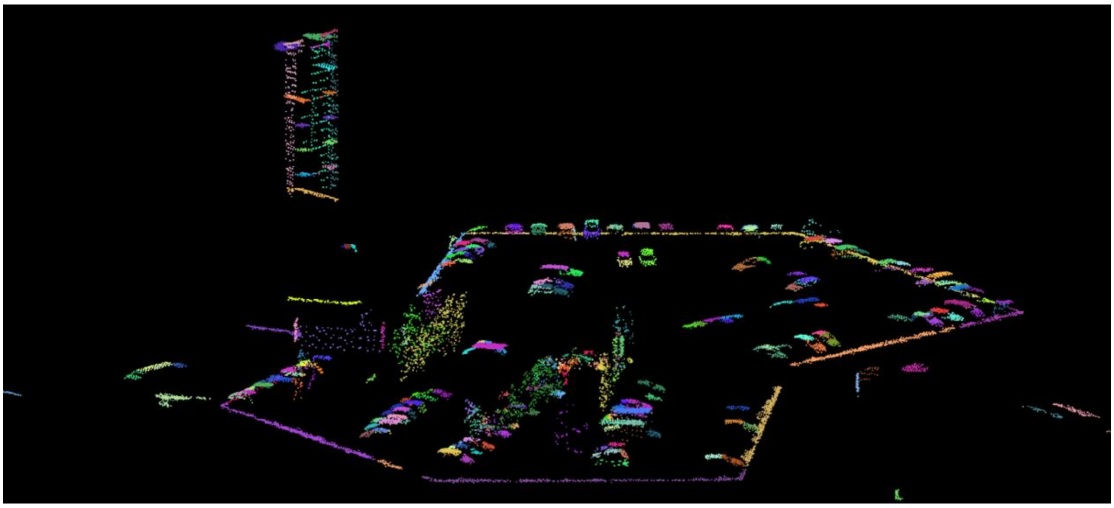
The parameters of non-ground point segmentation (Table 4-5):

Stages	Parameters	Value	Description
Noise detection	Max noise neighbor number	6 pts	The max number of noise neighbors in a certain area
	Radius of neighbors	1 m	The radius of the area of neighbors searching
Connectivity grouping	Minimum size	10 pts	Minimum size of non-ground segment
	Radius of neighbors	1 m	The radius of searching

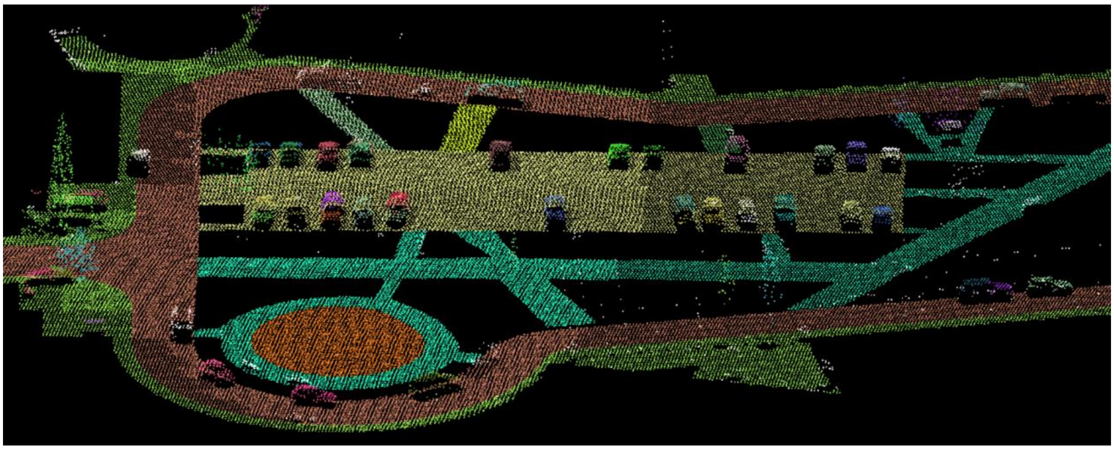
			neighbors in seed selection step
Manmade objects detection	knn	10	The number of the nearest neighbors involved to compute flatness
	Threshold of flatness	0.5	The threshold of flat local surface and non-flat local surface
	Threshold of percentage	60%	The threshold percentage of flat points occupied between manmade object and non-manmade object
Segmentation for manmade objects	Minimum size	10 pts	Minimum size of non-ground segment
	seed radius	1 m	The radius of searching neighbors in seed selection step
	Accepted max distance to plane	0.2 m	The max accepted distance from candidate points to seed plane
	Growing radius	1 m	The radius of searching neighbors in growing step
Multi-tree detection	Ratio threshold	120	The threshold radio of segment size divided by max height difference
Segmentation for multi-tree segments	Minimum size	1 m	Minimum size of a tree
	Searching radius	2.5 m	The radius of searching highest neighbors

Table 4-5 Parameters of non-ground point segmentation in road class

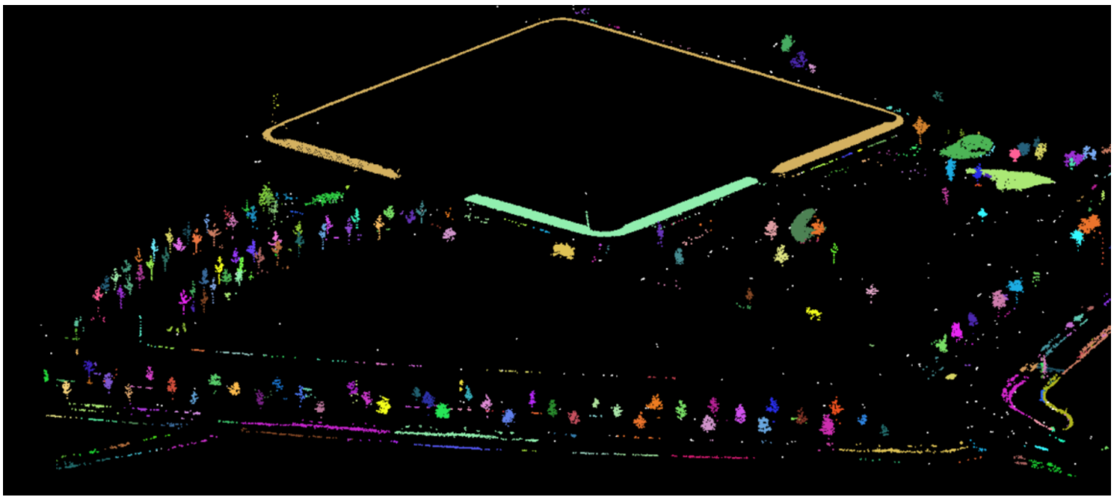
The results of ground point segmentation are (Figure 4-11):



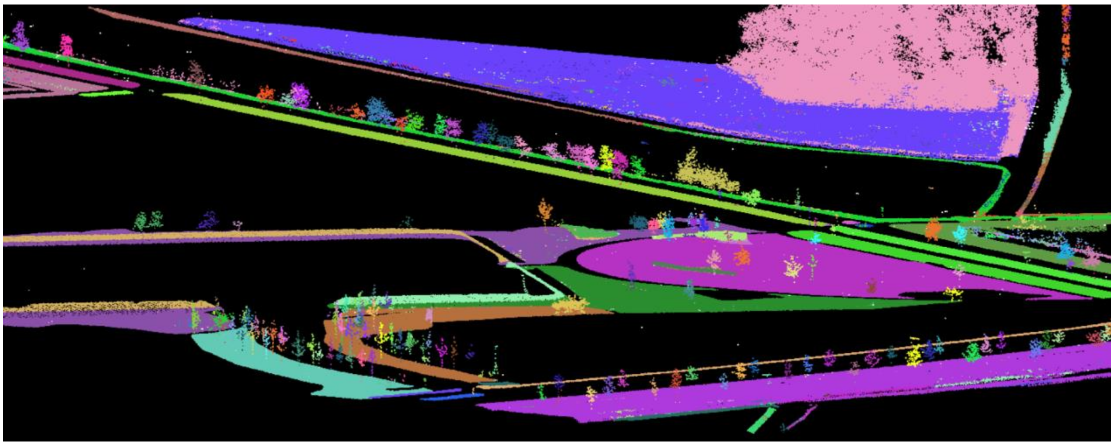
a) Result of 2001 manmade object component segmentation



b) Result of 2001 point segmentation (ground + non-ground)



c) Result of 2101 non-ground point segmentation



d) Result of 2101 point segmentation (ground + non-ground)

Figure 4-11 Result of non-ground point segmentation in road class

The road class non-ground point segmentation shows the same result as the plant cover class. Some mixed segments are wrong classification and large low vegetation segments recognized as manmade objects. And the reasons which leading to these cases I already explained in the previous chapters.

4.2.4 Water class

The water class tag values are 6001 in this dataset, select the water class points and do the segmentation for 6001 tagged point dataset follow the method which proposed in chapter 3.

Ground point Segmentation

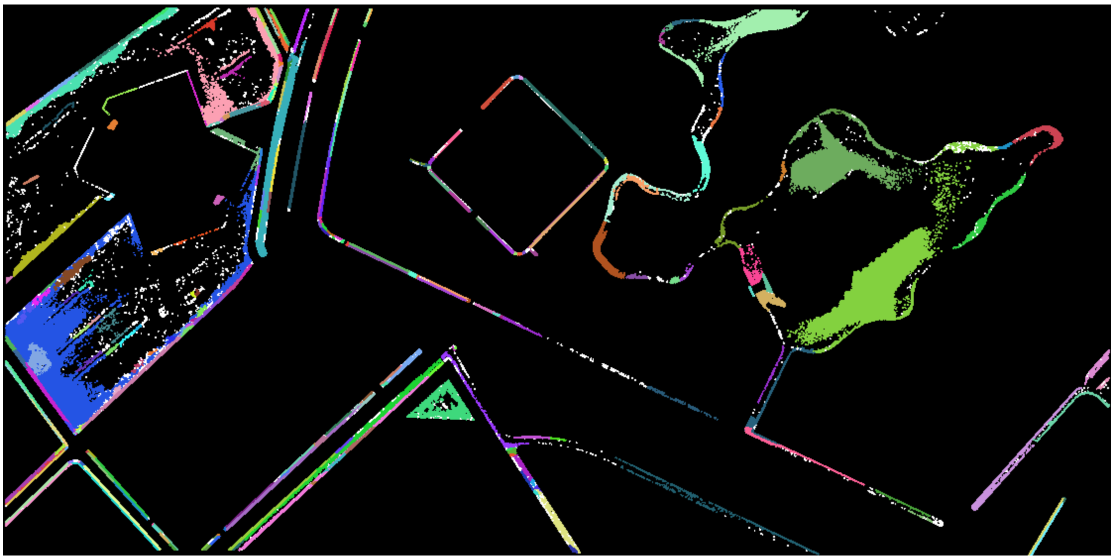
The main ground objects of this class are water bodies, but may contain soil earth, grass, roads as well. According to the purposes of ground segmentation in this class which are grouping points which belong to one water body to be a segment and recognize the water segments, the parameters of ground point segmentation are (Table 4-6):

Stages	Parameters	Value	Description
Plane surface growing	Minimum size	100 pts	Minimum size of water segment
	seed radius	3m	The radius of searching neighbors in seed selection step

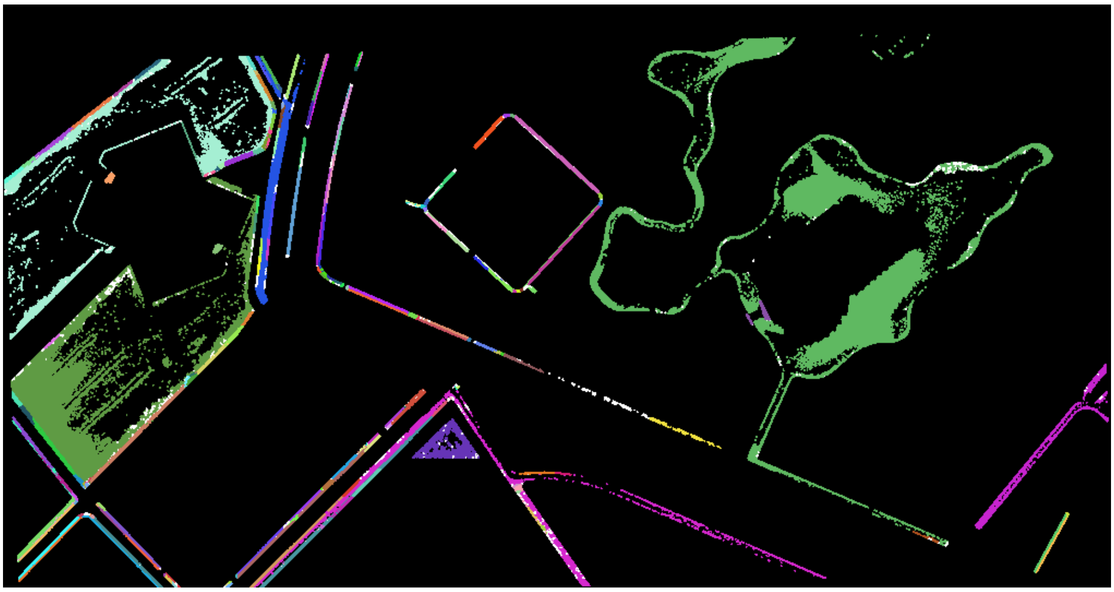
	Accepted max distance to plane	0.2m	The max accepted distance from candidate points to local plane
	Growing radius	5 m	The radius of searching neighbors in growing step
Water segment detection	Tolerance of horizontal angle	5°	The max tolerance angle of water segment to horizontal
	Tolerance of height difference	0.05 m	The max height difference between merging segments or isolate points and segments
	Minimum size	200 pts	The minimum size of final water segments
Noise detection	Max noise neighbor number	6 pts	The max number of noise neighbors in a certain area
	Radius of neighbors	1 m	The radius of the area of neighbors searching
Connectivity grouping	Minimum size	50 pts	Minimum size of ground segment
	Radius of neighbors	2 m	The radius of searching neighbors in seed selection step
Majority filtering	Neighbor radius	2 m	The radius of searching neighbors take into count
	Knn	20	K nearest neighbor points

Table 4-6 Parameters of ground point segmentation in water class

The result of water class ground point segmentation (Figure 4-12)

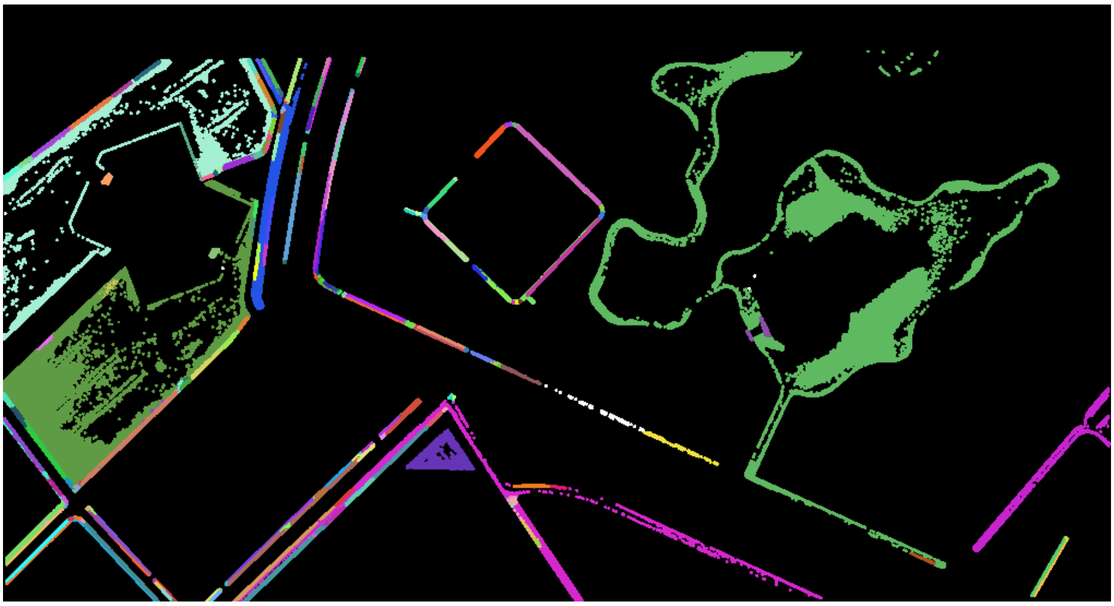


a) Result of 6001 ground point plane surface growing

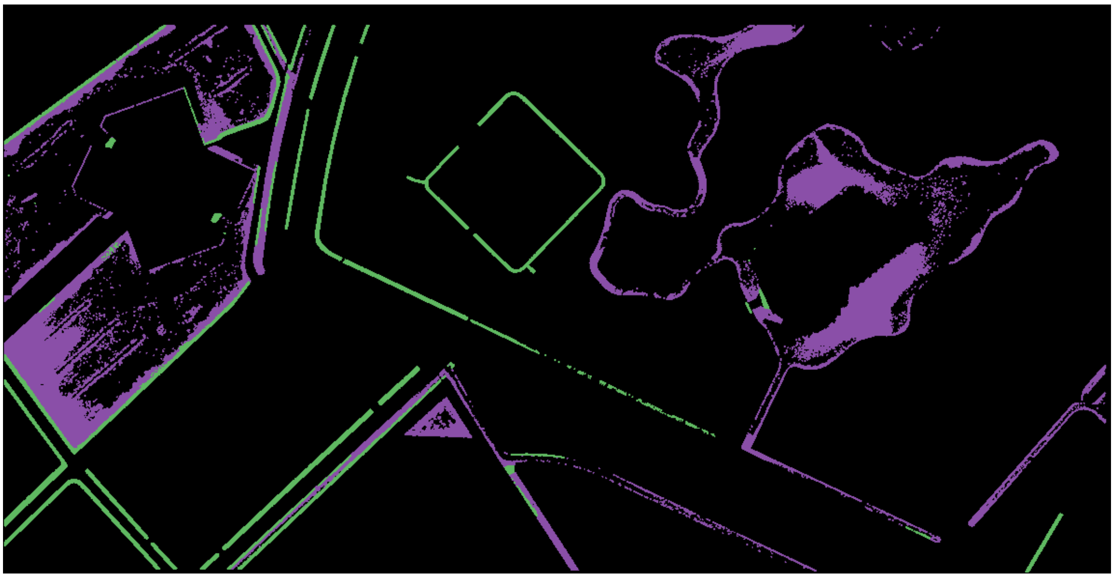


b) Result of water segment merge and isolate water point merge

c) Points which are segmented by majority filtering (black)



d) Result of 6001 ground point segmentation



e) Result of 6001 ground point classification

Figure 4-12 Result of ground point segmentation in water class

Some water bodies have been recognized as non-water segments, because they are over-segmented and that leads to their size smaller than the minimum size we used to identify water segments. The reasons which lead to the over-segment are the water body divided by polygons, but the surface growing segmentation is implemented polygon by polygon and some laser beams are absorbed by the water, so large blank area existed in the water body.

Non-ground point segmentation

The segmentation purpose of non-ground point segmentation is the same will plant cover class as well. According to the real scenes of this class, the parameters of non-ground point segmentation are (Table 4-7):

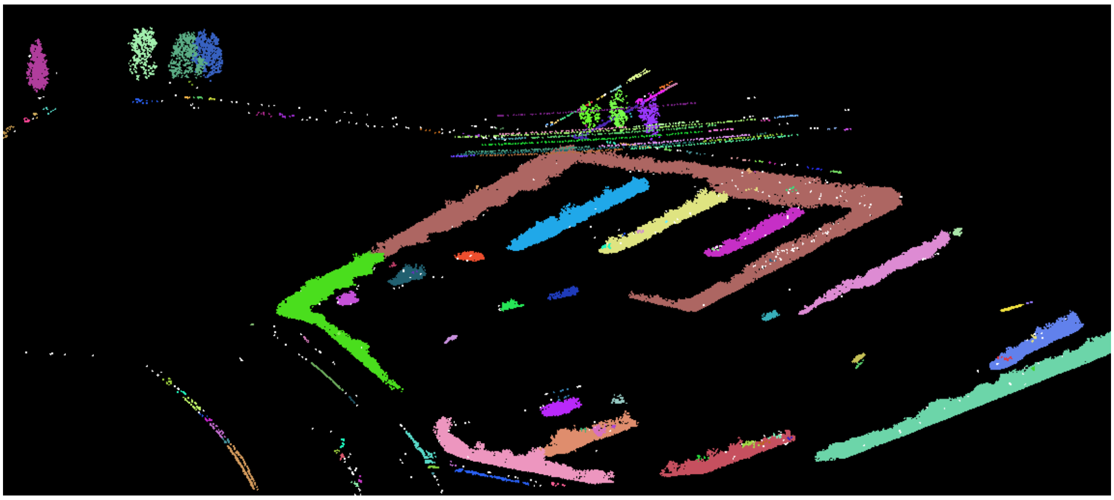
Stages	Parameters	Value	Description
Noise detection	Max noise neighbor number	6 pts	The max number of noise neighbors in a certain area
	Radius of neighbors	1 m	The radius of the area of neighbors searching
Connectivity grouping	Minimum size	10 pts	Minimum size of non-ground segment
	Radius of neighbors	1 m	The radius of searching

			neighbors in seed selection step
Manmade objects detection	knn	10	The number of the nearest neighbors involved to compute flatness
	Threshold of flatness	0.5	The threshold of flat local surface and non-flat local surface
	Threshold of percentage	60%	The threshold percentage of flat points occupied between manmade object and non-manmade object
Segmentation for manmade objects	Minimum size	10 pts	Minimum size of non-ground segment
	seed radius	1 m	The radius of searching neighbors in seed selection step
	Accepted max distance to plane	0.2 m	The max accepted distance from candidate points to seed plane
	Growing radius	1 m	The radius of searching neighbors in growing step
Multi-tree detection	Ratio threshold	120	The threshold radio of segment size divided by max height difference
Segmentation for multi-tree segments	Minimum size	1 m	Minimum size of a tree
	Searching radius	2.5 m	The radius of searching highest neighbors
Majority filtering	Neighbor radius	2 m	The radius of searching neighbors take into count

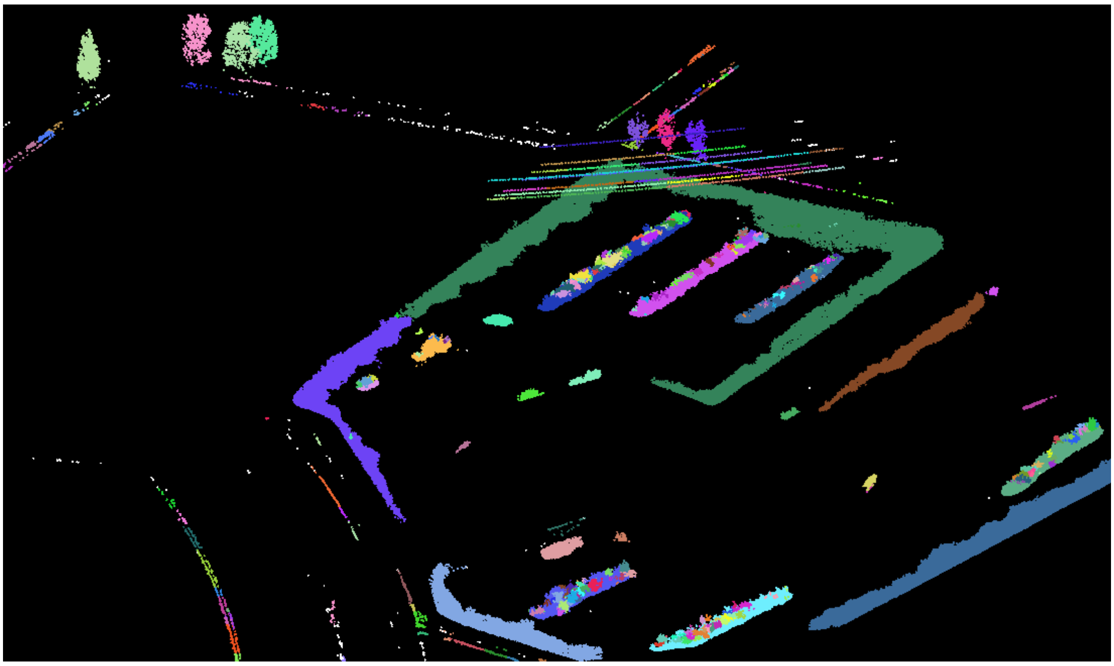
	Knn	20	K nearest neighbor points

Table 4-7 Parameters of non-ground point segmentation

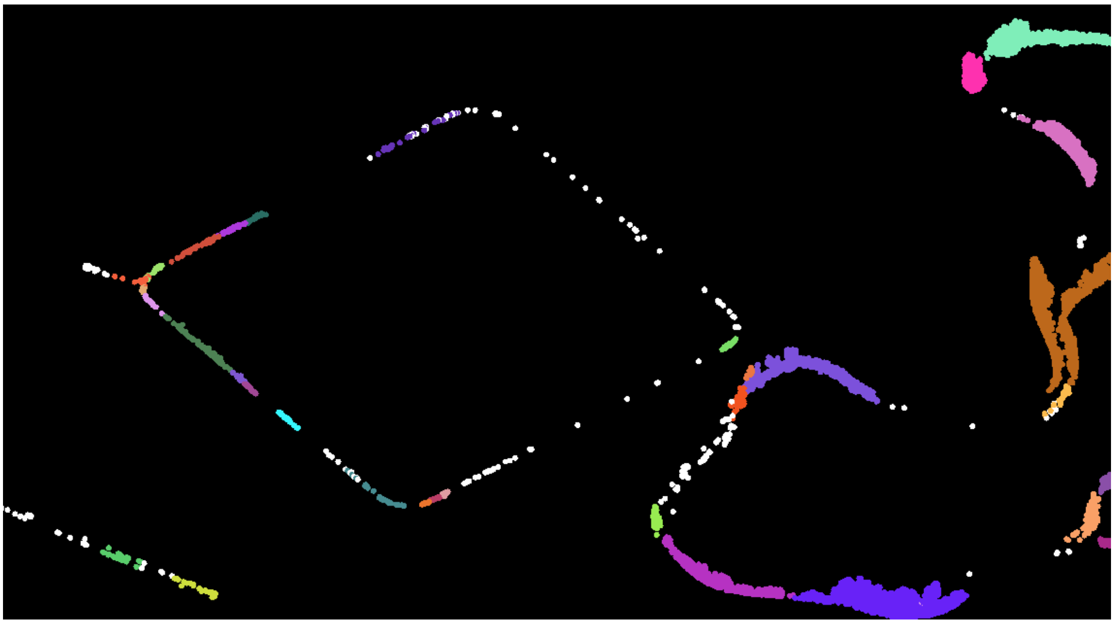
The result of the non-ground point segmentation (Figure 4-13):



a) Result of 6001 non-ground connectivity grouping



b) Result of 6001 non-ground point segmentation



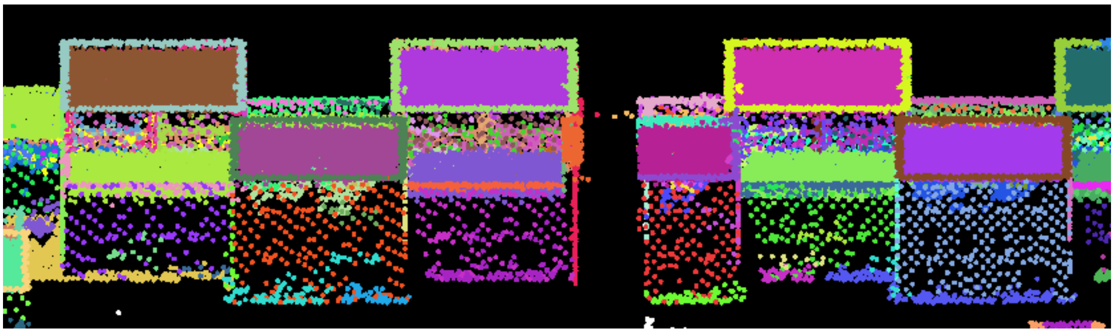
c) Unsegmented points of 6001 non-ground point segmentation

Figure 4-13 Results of 6001 non-ground point segmentation

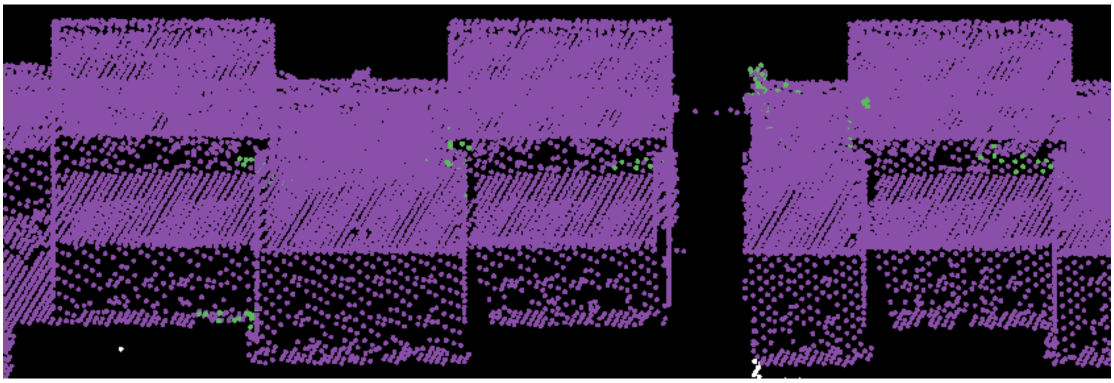
The points are group into large segments by connectivity grouping, then more detail segments are divided from the large segments by the following processes of manmade segmentation and multi-tree segmentation. At final there are some points still do not have segment tag, because they are sparse points, so in the manmade object re-segmentation step, they do not have enough neighbors to compute a surface or their segment size is lower than the minimum size parameter.

4.3 Over all

The segmentation model shows a good result for most points, but there still some wrong segmented points existed. In building class, the result shows a higher accuracy on the roofs surfaces than wall surfaces. At some corners of the building surfaces, the segmentation accuracy gets lower and some wrong classify existed. That is because some of them are noise, as well as the points at corner could group with points from other surfaces to build a small incorrect local plane, after majority filtering more noise points join them, and break its planarity, so they have been miss classified as non-building segments.(Figure 4-14)



a) Higher accuracy on roofs, lower accuracy on walls



a) Incorrect classification at the surface corners

Figure 4-14 Details of building non-ground segmentation and classification

In plant cover class, the largest problem of the segmentation result come from the multi-tree segment re-segmentation, over-segmentation and under-segmentation both existed. And the largest problem of classification result comes from the mix component segments (Figure 4-15).

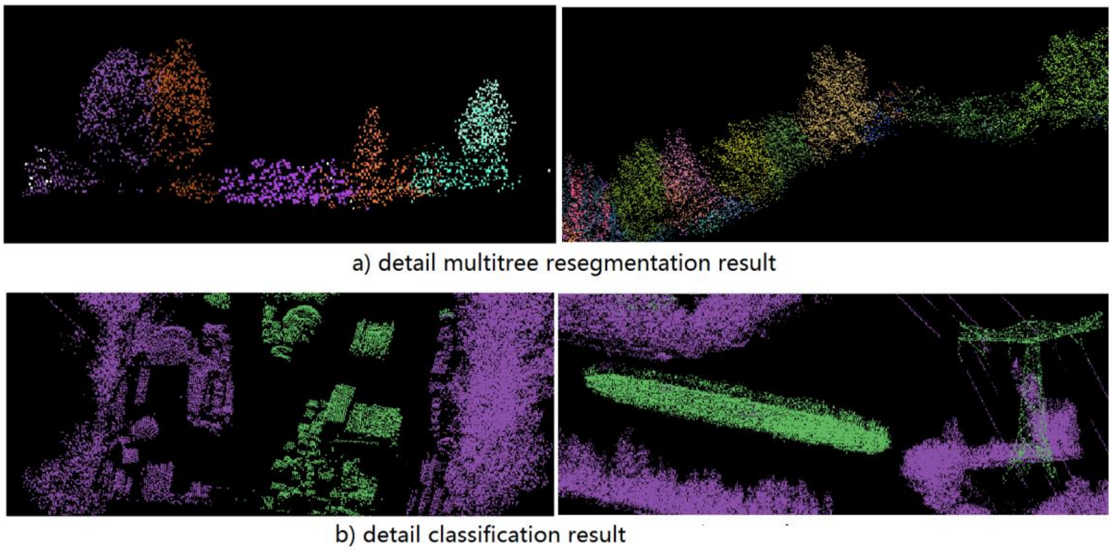


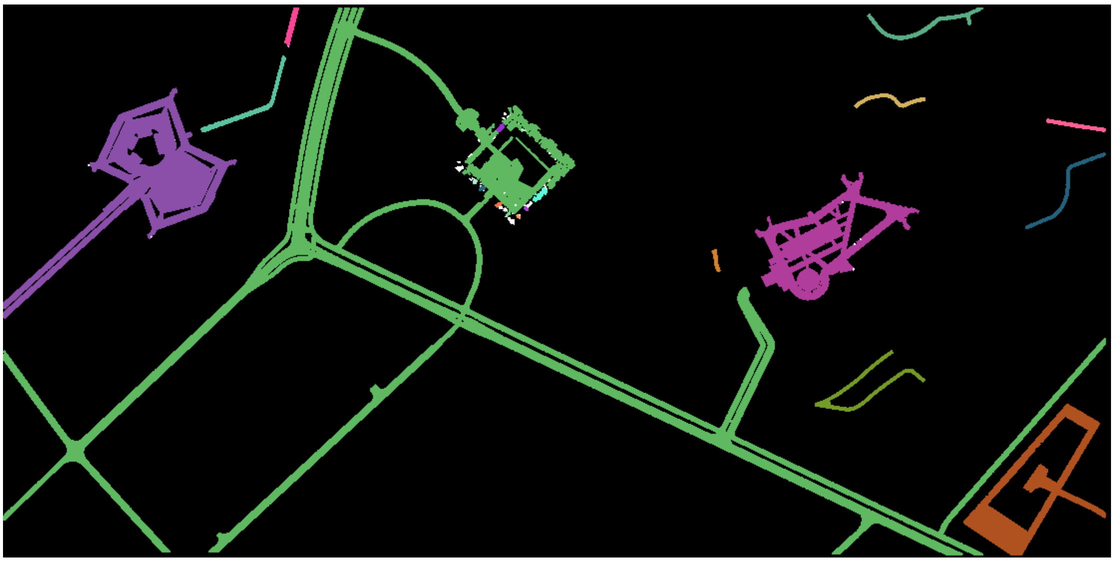
Figure 4-15 Detail plant cover segmentation result

In road class, the roads break into several segments by the map polygons, and in water class (Figure 4-10), a few water segments are wrong classified into non-water objects (Figure 4-12).

5 Evaluation and Discussion

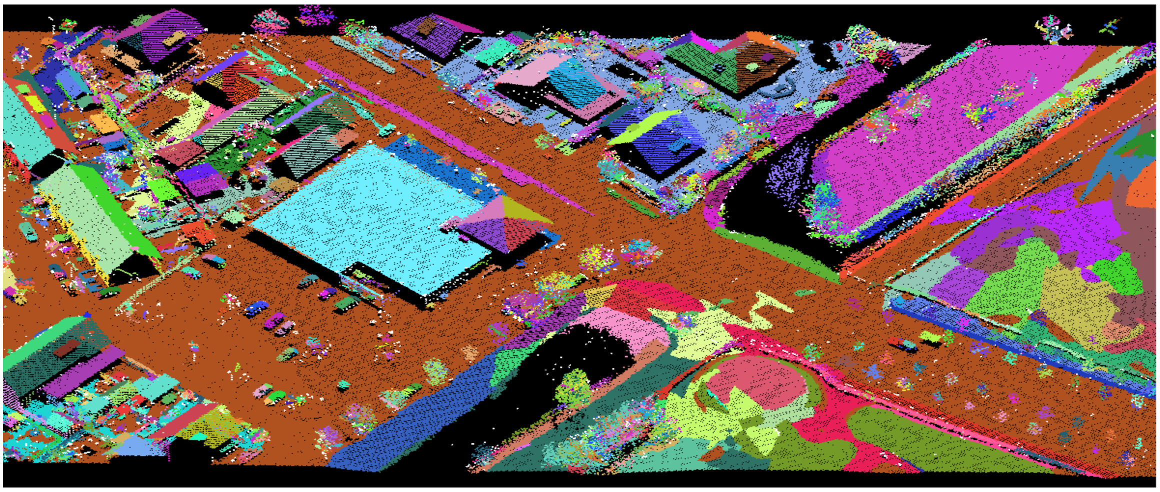
5.1 Evaluation

This thesis proposed a new map based segmentation structure for urban laser point dataset. With the help of maps, urban scenes are divided into 4 different land cover classes, and then according to the characteristics of each class, the segment strategy is developed separately and all the segmentation algorithms are implemented polygon by polygon. Through this segmentation model, the points will be grouped into different segment and the segments will be indicated to whether it actually belongs to its class or not. That will benefit for other researchers who may using the segmentation result to do further processing (like 3D modeling, space computation) to choose real useful points. Comparing with traditional segmentation which is no map involved segmentation. In this thesis, for the entire dataset the traditional segmentation which is surface growing segmentation followed by connected component segmentation and at last majority filtering is implemented. Map based segmentation shows a better result for the same dataset (Figure 5-1).

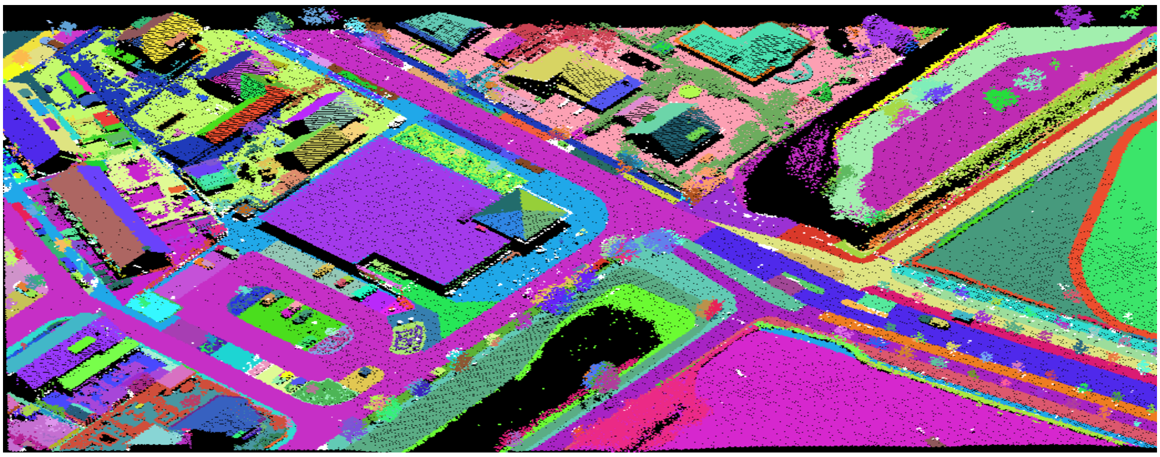


a) Result of traditional surface growing segmentation for road points

b) Result of map based surface growing segmentation for road points



b) Result of traditional segmentation for multi-land-cover landscape



c) Result of map based segmentation for multi-land-cover landscape

Figure 5-1 Comparing of traditional segmentation and map based segmentation

Map based segmentation using class and polygon information from maps to help segmentation for laser points. In most cases, it show a much better result than traditional segmentation, especially when the characteristics of classes are very different from others. Map based segmentation can use class information to separate them. Then according to the different characteristics of classes, the optimized segmentation strategy and optimized parameters are determined for each class. The map based segmentation methods are implemented polygon by polygon, so no cross polygon segment existed. But some objects like a tree may exist in different polygons, so it will cause over-segmentation for these objects (Figure 5-2).

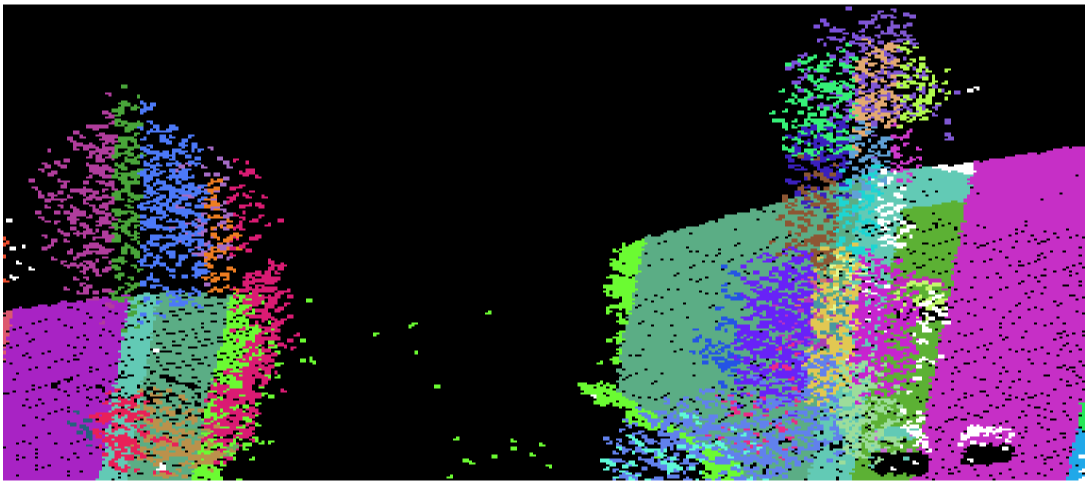


Figure 5-2 Over-segmentation of cross polygon objects

5.2 Discussion

As explained in the previous chapter, parameters of the segmentation hard to satisfy the complex real scene. For example, the result of re-segmentation for multi-tree component shows somewhere over-segmentation as well as somewhere under-segmentation. That's because the trees have no fixed size and shape, so the parameter of re-segmentation could not suitable for all trees. The result is sensitive to the segmentation parameters, that's mean the segmentation structures rely on the priori knowledge of the real scene to set the parameters, the further work of improving this segmentation model can be done from this aspect. For example, in multi-tree re-segmentation process, the parameter of radius of searching window can be set adaptive to the height. Higher the height is, smaller the searching window will be.

6 Conclusion

This thesis proposed a novel map based segmentation structure for multi-land-cover laser dataset. For different land covers, the segmentation strategies are different. In all different classes, the segmentation is done for ground points and non-ground points separately. For the non-ground point segmentation, in building class, the main objects are in the non-ground laser points. A re-label processed is first given to the laser dataset. Then large plane surfaces are segmented by plane surface growing. After that, connected component segmentation groups the remaining points into components, detect each component belong to building or not by local flatness. As different characteristics of different kinds of components have, so for different kinds of components, the methods of following re-segmentation of interior components are different. For plant cover class, the non-ground points are mostly vegetation, connected component segmentation first to group points into components, detect each component is manmade object or not by local flatness. For manmade objects, plane surface growing is used to re-segment the interior components. For plant objects, detect the multi-tree components by an index of component size divided by max height, and local maximum will re-segment the multi-tree components. The similar story will happened on the non-ground points of road and water classes, as the landscape are similar. For ground points segmentation, according to the segmentation purpose of different classes, in building and plant cover class, a smooth surface growing is used to segment points into smooth surface segments, in road class, a smooth surface growing is used to segment points into smooth surface segments and a following segmentation is used to group small land parcels. In water class, plane surface growing is used to group points into plane segments. Then the water surfaces in one polygon will be merged into one segments, isolated water points will also be merged into its water body segment, after water points segmented, smooth surface growing is used to segment the remaining points. The final result will is merged by the results of different class segmentation.

So features like flatness, normal, segment size, max height difference are used in this segmentation model. Flatness is used to differentiate regular manmade surfaces from irregular plant surfaces. Normal of the planes is used to identify wall surface and water surface which are vertical and horizontal respectively. Max height difference of segment is used in re-segmentation of multi-tree components and to differentiate the low vegetation components from tree components.

Points whether actually belong to that class or not are indicated during the segmentation processes. That will benefit for other researchers who may use the segmentation result to do further processing, for example 3D-modeling for buildings, researchers can select the points which really available from this segmentation result.

Through comparing the result of traditional segmentation with the result of map based segmentation on a common multi-land-cover dataset, a better result can be obviously seem from map based segmentation. For the further work, more intelligent method should be used to improve the accuracy of segmentation, like introduce adaptive parameters to replace fixed parameters.

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