

AUTOMATING POST-PROCESSING OF TERRESTRIAL LASER SCANNING POINT CLOUDS FOR ROAD FEATURE SURVEYS

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ABSTRACT:

Terrestrial Laser Scanner (TLS) have seen increasing use in survey practices as a means of fast capturing large volumes of point data, with one such practice being the surveying of as-built features for roads. This paper presents methods to automate some of the processing of road scenes. The method focuses primarily on the automation of the identification and extraction process of kerbs and surrounding discrete geometric features, such as signage. The process is done in multiple stages. The first stage is to isolate the road surface and ground points using simple local classification and segmentation techniques. From this, it allows the locality of the points sampled from the kerb and road features to be approximated. For defining the kerb feature, the orientation of the kerb is found locally, and a 2D cross-section is extracted and examined to find the profile. The adjacent kerb profiles can then be joined to define a line representation along the kerb. For features adjacent to the road, points defined off the road surface are selected as candidate points. A region growing method is applied to group adjacent candidate points together to form group of points sampled from the same feature. This allows for the extraction of features such as signage, lights and poles from the scene.

1. INTRODUCTION

Terrestrial Laser Scanners (TLS) are not a new innovation within the surveying industry. While they are not widely utilised yet, they are seeing increasing adoption in use for tradition surveying and photogrammetric applications. This increase is due to the continuing development in terms of data capture speed, accuracy and density of point data obtained from TLS technology. One such area that is starting to see increasing use of TLS is on road surveys. There are several benefits of using TLS that makes it attractive for surveying of assets and infrastructure, such there is no direct contact required with a feature of interest during data capture, which reduces the interaction time between the surveyor and a busy road, and the large volume of point data that can be captured from a single setup.

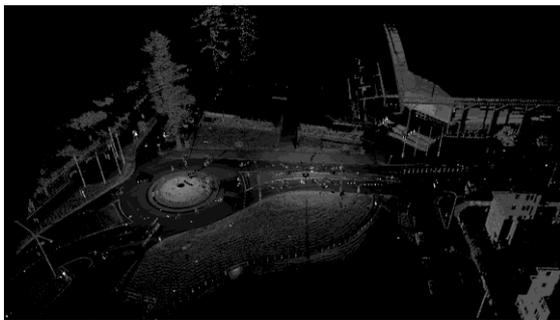


Figure 1. 3D Point cloud of a road and surrounding structures

Some examples of utilising laser scanning for the surveying and recording the data from roads and adjacent structures such as buildings are presented in Kretschmer et al. (2004), while Lichti et al. (2005) presents a comparison of accuracy between TLS and traditional methods, with respect to Australian survey standards for such jobs. Initially, extracting data to the required accuracy was a problem; however recent scanners provide the

required resolution and accuracy of position to make road surveys of all features by TLS viable.

The capture of data can be done several methods such as by stationary TLS, stop and go methods, and vehicle mounted LiDAR or line scanning systems. The benefit of a line scanning system is that the vehicle position is known and can be used for information on the roads location and orientation, as well as scan-line processing techniques can be applied to simplify some of the processing (Jiang and Bunke, 1994). Stop and go is similar to TLS, but with the benefit that the vehicles position may give addition information, as with line scanning systems. As such, stationary TLS can be more difficult to automatically process. The difficulties in automating the extraction of salient features comes from the complex data captured in the point data, combination of multiple data sources, unorganised point nature, inconsistent sampling, occlusion of road features by the very features of importance (such as kerbs), and no prior information of the position and orientation of the road. General problems come from finding non-geometrical features (line-markings) that require additional spectral information to solve, sparser sampling at the extents of the scan and the large volumes of points that need to be examined and dealt with.

The post-processing stage normally includes steps such as removing unwanted information and noise, identifying and isolating the salient features of a scene, and calculating and/or modelling the properties of each feature. Because of the length of post-processing time compared to the fast acquisition time, a large focus of the research in the area of TLS has been aimed at automating these processes to reduce cost involved at this stage and increase the overall efficiency of utilising TLS (Belton, 2008; Bae, 2007; Lichti et al., 2005).

This paper aims at automating some of the processing of road scenes. Specifically, it deals with automating the process of cleaning up the data, defining the road and isolating geometric

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features of the kerbs and surrounding nearby salient features. It will also be assumed that the data was captured by stationary TLS setups (although other capturing methods can be used, it is the one of primary use and focus of the project). In addition, the road scenes used in this paper of the type that have clearly define extents at the edges of the road in terms of geometric properties.

This processing of the point cloud is performed in the following steps:

- Finding candidate ground points
- Segmenting the ground points into common regions.
- Determining the road and its scanned extents.
- Extracting kerb profiles to sections where they exist.
- Isolating common groups of points into common features present in the road scene.

This paper does not look at features such as line markings and covers, as they require spectral information, and are often better extracted from 2D imagery, and overlaid onto the 3D point data.

2. DATA STORAGE

One of the biggest difficulties in post-processing of 3D point clouds is dealing with the large volume of unorganised point data, with common applications resulting in billions of points being sampled. Due to the amount of the data to be processed, there has been much research emphasis on the development of automation procedures for 3D point clouds. One of obstacles for these effort, in most cases, exhaustive search and local-calculation processes are required to interrogate every data point to evaluate which (geometric) properties it exhibits and which feature it was sampled from. Because of this, the method for storing the point data is important to ensure low processing costs, by balancing fast access times of points and its surrounding information, with initialisation time and memory space. Some common methods include kd-trees, oct-trees or voxels (Vosselman and Maas, 2010).

Fortunately, 3D point clouds for road scenes have some advantages over general point clouds, which help us to develop new storage and processing methods. The first is that most of the salient features are related to the scene and each other in primarily 2D, such as kerbs will be adjacent to the road, a footpath/verge will be next to the road, and a sign will mainly connect to one of these, but not the road. This provides a huge benefit of accessing each point in the horizontal plane, i.e. well-estimated ground, which provides a possibility of dealing 3D point in a 2D domain.

Also re-enforcing this concept is that most of the important information, such as the road, the base of poles and signs, and kerbing, is located at ground level. Additional, the majority of the targeted salient features are consistent over large area, such as roads, walls, poles, and signs. Locally, points sampled from these features will have very similar properties with little to no change in structure.

Taking in the aforementioned considerations, it was determined that the point cloud would be ordered and stored into a 2D grid structure. The spacing of the grids is set large enough to contain a significant number of points, but small enough the only a very small number of salient features would be present. Each point is then assigned a grid number such that:

$$\begin{aligned} grid_num_x_i &= \frac{x_i - \text{mod}(x_i - \min(x), s)}{s} \\ grid_num_y_i &= \frac{y_i - \text{mod}(y_i - \min(y), s)}{s} \end{aligned} \quad (1)$$

with x_i and y_i denoting the x and y values of point i , $\min(x)$ and $\min(y)$ denoting the respective minimum values of the x and y coordinates, mod being the modulus operator and s is the grid spacing. The points are then ordered using the sorted by the firstly $grid_num_x$, then $grid_num_y$, and finally by point heights. All points in the same cell are located together in the array in sequence of height. The count-sort algorithm is used for sorting the grid numbers because of their integer nature, and the speed of the algorithm when used on such values (Knuth, 1999, vol. 3). The index of the start of each cell, and the numbers of points contained within are then stored to allow for fast retrieval of the points

Once this is done, each grid cell can be examined independently to reduce the examining of the point cloud into smaller sub-examinations. Depending on the spacing of the grid, each cell should only contain a few features of interest, and can be easily separated. Additional information from neighbouring grid cells can be compared and incorporated to see if common features or properties exist across the cell, or if points are deemed to belong to a feature in a neighbouring cell. This also highlights the reason for the 2D horizontal grid, since salient features will be either contained in primarily one cell (such as poles and signs), or be related to each other by the horizontal position (roads, kerbs, verges and footpaths).

Furthermore, because of the ordering method, not only can individual cells and their points be access directly, but the nearest neighbourhood method can be approximated easily, if not with as much efficiency as a dedicated structure (i.e. kd-tree). The benefits of storing the points in this way for this application will be further highlighted in the following sections.

3. FINDING THE POINTS ON THE GROUND

The first step in the process is, for each cell, finding those points that are deemed have been sampled from the ground. Ground points are defined in this case as the points on the lowest, smooth, nominally horizontal surface. Methods for extracting DSM from ALS can be applied, and is part of the reason for storing data into a 2D grid (Vosselman and Maas, 2010). One such simple method is to define the lowest point in the data set as the ground. The cell that belongs to and any adjacent cells whose lowest point is with a set height difference are then labelled as containing ground points. The ground can then be interpolated between the lowest points in these ground cells, and any points that nominally agreed with the interpolated surface are then labelled as belonging to the ground. This method, while useful to eliminate a cast majority of non-ground points, will not necessarily filter out points belonging to small non horizontal changes, such as the step from the road up a kerb.

Another option is to examine each individual cell for the lowest horizontal surface. This can be achieved by separating the surface features in each individual cell by RANSAC (Fischler and Bolles, 1981), Hough transform (Shapiro and Stockman, 2001) or variational surfaces techniques (Wu and Kobbelt, 2005), and isolating the one that is most likely representing the ground. In a similar manner, since the focus is in lowest nominally horizontal surface, a planar can be fitting through the

lowest points in the cell and then iteratively adjusted by adding or removing points that are determined inliers or outliers based on statistical testing. The method outline in this paper is similar to this, but the initial point selection is based on the changes of sampling density of the points through the vertical axes in the cell.

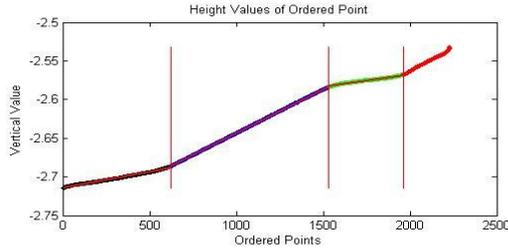


Figure 2. Ordered vertical point values. The red vertical lines denote where a change in vertical density is observed.

First step in this method is to order the points in a cell from the lowest to highest, as shown in Figure 2. Linear regression is used to fit a line through these ordered points. Where the point that exhibits the greatest residual occurs (excluding those points at the extremes of the data set), the set of points are divided, and a new linear regression model is fitted to both. This dividing method is then repeated on the section of points with the greatest residual until the ordered points are divided into regions of continuous sampling density and the largest residual is no longer significant, as seen in Figure 2. The result of this subdividing with respect to the 3D points is displayed in Figure 3.

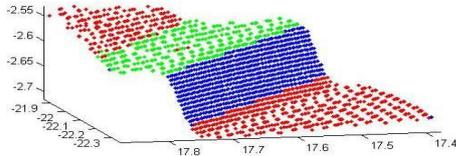


Figure 3. Points split base on the changes vertical point density.

These sets of points are examined (from the lowest to highest) to find the lowest one that contains the flattest or most horizontal trend and is chosen as the one contain points sampled from the ground. This is due to it containing the points which are the lowest, has the least change of sampling density in the vertical direction, and has a significant presence within the cell, which reflects the specified properties of the ground in this instant. A planar surface is then fitted through the selected points, and additional points are added, ore removed based on whether they are determined to be either inliers or outliers. The final result for a single cell is presented in Figure 4. Figure 5 displays the shows the results for the entire point cloud.

There are a couple of limitations to this method. The first is that it only works for finding nominally horizontal surfaces, which is not an important factor in this case since the since this is not the focus of the problem and the method can excel for eliminating point noise caused by traffic for cells containing the road. Another limitation is that the method does not take into account concave surfaces. For this application, the majority of this occurs where the road cambers off and meets a kerb, where the selected points of the lowest region will include a small section up to the face of the kerb (since it only looks at the change in vertical). This can be reduced by having a small grid size, and can be handled by fitting a plane though the selected points (under the assumption that the point on the ground will be locally planar), and then refining the point section to those that

does not belong to the plane (such as those points mistakenly selected from the kerb).

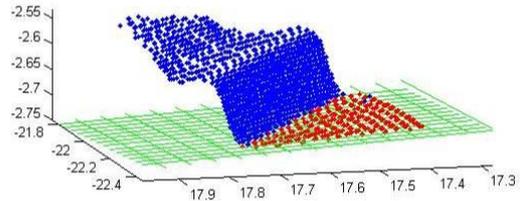


Figure 4. Points in red are chosen as the lowest ground points.

And finally, this method will only target the lowest ground surface, which is not a significant problem for 3D road-scene point clouds. If there are two or more ground surfaces (such as on a kerb or stairs), then either more than one surface can be selected, or the planar surface from surrounding adjacent cells can be use to see if any of the remaining points agree with their surface definition. The following section on segmentation will highlight the last option when the ground points are segmented into continuous and smooth surface regions.

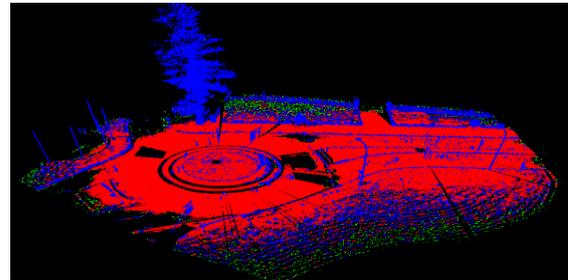


Figure 5. Red points denote the lowest ground points found in the point cloud.

4. SEGMENTING THE POINTS INTO REGIONS

Once the majority of ground points have been identified, these points are segmented into continuous ground regions. To do this, a simple region growing method is applied with respect to the grid cells. The first step is to identify all grid cells that contain ground points. Adjacent grid cells that contain ground points are compared to each other in an iterative manner in order to see if the ground pints are likely to have been sampled from the same ground surface. The comparison is performed by looking at the planar surface fitted to the ground points in each cell, to see if they are nominally aligned. This means that no large difference between the normal directions and the distance between the planar surfaces are small

To look at the difference between the planar surfaces, the residuals between the mean ground point of a cell (μ_i) and the surface normal of an adjacent cell (\hat{n}_i) is examined, where the residuals for two adjacent cells i and j are defined by:

$$\begin{aligned} r_j &= (\mu_j - \mu_i) \bullet \hat{n}_i \\ r_i &= (\mu_i - \mu_j) \bullet \hat{n}_j \end{aligned} \quad (2)$$

These residuals are then examined, and both cells are labelled as containing ground points from the same ground surface segment if they pass the conditions that $|r_i|$ and $|r_j|$ are smaller than a tolerance. The tolerance comes from an user defined value, a global value for point deviation, or a t-test on the local surface

properties. Note that a tolerance of difference d between planar surfaces when there is a grid spacing of s will approximate to angular tolerance between the normal direction of $2\sin^{-1}(d/s)$. The process is repeated until all the cells have been examined with respect to their neighbours.

Once the cells are labelled, the other points in the cell can also be labelled in a similar manner. For every ground point in the labelled cell, the point is given the segment label as the cell it belongs to. Then for every point that is not labelled, they are examined with respect to the properties of the ground points in adjacent labelled cells. This is done again by examining the residual of the point to the fitted planar surface of the ground points in the adjacent labelled cell. If they are deemed inliers (either by the use of the t-test or a user specified tolerance), then they are labelled as belonging to the same surface segment as the adjacent labelled cell. If it is considered to belong to more than one adjacent fitted surface, it is labelled as the one for which it has the smallest residual.

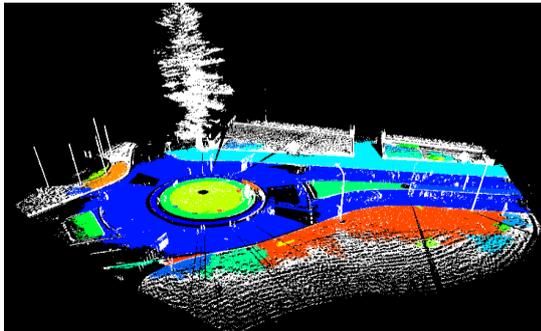


Figure 6. Segmented ground points, with each colour denoting a different segment.

In this way, the majority of the points that could be deemed to have been sampled for the nominally horizontal ground surface are labelled and segmented, as shown in Figure 6. Care must be taken in specifying tolerances, as areas such as driveways and footpaths that have a small change in slope may otherwise be missed. This can be helped by ensuring that the spacing is small enough and the tolerances tight enough to detect the slight change in surface orientation.

5. FINDING THE ROAD

Finding the road should be a straight forward process since the ground points has been determined and segmented. It is simply a matter of determining which segment(s) contains points sampled from the road surface. In most cases, because the road is the focus of the scene and is one large continuous and smooth surface, it will be contained in the largest segment(s) in the middle of the point cloud. This is shown in Figure 7.

Problems arise if the road is contained in multiple segments, as is the case if the road is a dual carriage way, divided in half by a medium strip or divided due to some other reason such as occlusion. If the point cloud is large enough to encompass an intersection, then this will not be a problem, however, if this is not the case, then the largest segments need to be examined to see if more than one exhibits the properties of the road. These properties include:

- The segment extends through the complete point cloud (entering in one side and exiting out another).

- The segment is smooth and relatively flat (exhibiting a subtle convex surface produced from the chamber of the road).
- It is lower than neighbouring surface segments (especially if kerbing is present).

User interaction may also be required unless additional information can be provided. Such additional information includes if the scanner was mounted on a vehicle, or setup adjacent to the road, in which case the scan origins will help to determine the location of the road.

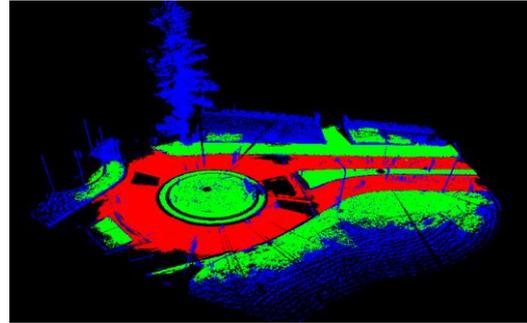


Figure 7. Isolated road (red) from the ground points (green).

6. FINDING AREAS OF THE ROAD NON ROAD KERBS COINCIDE TO FIND KERBS

After the road surface has been identified, the surrounding features can be extracted in relation to the information. On such feature that is closely related to the location of the road surface is the kerbing, which defines the extents of the road. To find this feature, the first step is to locate the cells which are likely to contain points sampled from a kerb. These cells can be found since they exhibit certain traits; they will be located on the edge of the road segment and have the difference in point heights will be nominally equivalent to the height of the kerb.

From this, the first step in finding the kerbs is to determine the cells that points sampled from the road segment. All cells which contain road points that are also adjacent to a cell which does not, will be labelled as containing the extent of the captured road. The difference in vertical values of the point in these cells and their surrounding cells are then looked at to see if these differences are nominally the same as the height of a kerb. As mentioned before, if these attributes are exhibited, then these cells are the ones likely to contain kerbs and can then be more rigorously examined individually.

For a target cell and its adjacent cells, the points are required to be partitioned such that the top and bottom of the sampled kerb is delineated. To achieve this, a plane is found which is parallel to the vertical direction, and that divide the points so that the most possible number of points on one side of the plane has a height greater than the most possible number of the points on the other side of the plane. The first step is to do this is to split the points into those above the mean vertical height, and those below such that:

$$b_i = \begin{cases} 1 & \text{if } z_i < \bar{z} \\ -1 & \text{if } z_i > \bar{z} \end{cases} \quad (3)$$

with z_i being the height of point i and \bar{z} being the mean height value. The best plane that divides the points above and below the mean that maximises:

$$\sum_{i=1}^n b_i ((p_i - c_i) \bullet \hat{n}) \quad (4)$$

given the constraints

$$\begin{aligned} [0,0,1] \bullet \hat{n} &= 0 \\ (\bar{p} - c_i) \bullet ([0,0,1] \times \hat{n}) &= 0 \end{aligned} \quad (5)$$

where \hat{n} is the normal direction of the plane, c_i is the centroid of the plane, \bar{p} is the mean position of the points, and \bullet and \times denote the dot and cross products, respectively. The direction along the kerb is specified as:

$$d = [0,0,1] \times \hat{n} \quad (6)$$

Once found, the plane will now also be parallel to the direction along the kerb. This direction can also be found by examining the normal directions of each point, as described in Jiang et al. (2005), or by looking in the direction which is parallel to the vertical direction, and the normal direction of the fitted plane to all the points. The problem with this method is that the first method requires a local surface fitted to the nearest neighbourhood of each point present, and the second method is easily contaminated by noise.

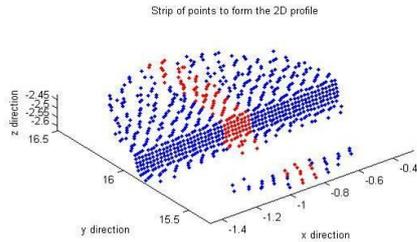


Figure 8. Selected points (red) that are used to form a local cross section.

Once this is achieved, a new plane is found orthogonal to the previous one, and parallel to the vertical direction through the centre of the points which will nominally bisect the kerb. All points with +/- small distance of this plane (as shown in Figure 8) are examined and projected onto the plane to create a 2D cross section.

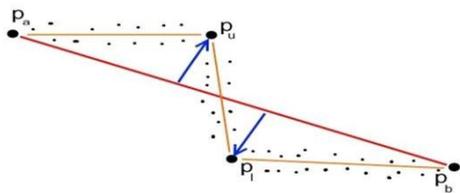


Figure 9. Isolated road (red) from the ground points (green).

The top and bottom point of the kerb is determined as depicted in Figure 9, by the following:

1. The two furthestmost points in the cross section are found and labelled as a and b, with a being the higher of the two.
2. A line is defined from a to b.
3. The point at the top of the kerb is defined as the point furthestmost above the line, labelled as u.
4. The point at the bottom of the kerb is defined as the point furthestmost below the line, labelled as l.

From here there are a few options. The first is that these points can then be translated back into the 3D locations to define the

kerb in this cell. These points can be connected to the corresponding kerb points found in adjacent cells to form a line model. The second is that the top, middle and bottom sections (points between a and u, u and l, and l and b respectively) of the kerbs can be modelled separately, and the location of the intersection between these models can be used as corrected location of the kerb. Lastly, if the profile is known beforehand, it can be fitted to the points in the 2D cross section, with the previous points used as an initial estimate.

The problem with the first option is that the points will not be truly sampled on the extent, and hence will be slightly biased away from the true location, based on sampling density. The problem with the second option is that the middle section of the kerb and parts of the lower section on the road are often occluded, meaning that they often can not be accurately modelled. Finally, the problem with the last is that the true profile is not always known. In the future work, a clustering/voting mechanism will hopefully be employed, so as to group profiles of similar attributes together and overlay them, so that the occlusion in one profile will hopefully be sampled in another, and can be overlaid on each other to make up for missing information.

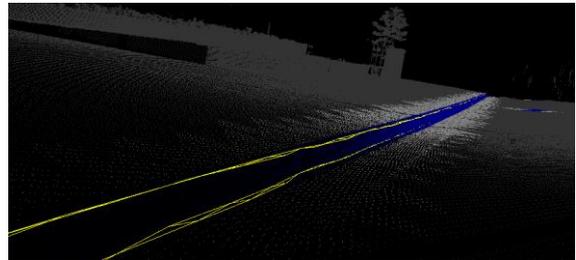


Figure 10. Defined kerb line (yellow) of a candidate kerb (blue).

Once the kerb points and profiles have been defined, they can be linked to form a line representation of the kerb. To do this, for a candidate cell, the closet kerb profile in the adjacent cells is defined as being the next in the line sequence (if it exists). Then from the remaining adjacent kerb cells, the one that contains the closest kerb profile that is nominally in the opposite direction is defined as being previous in the line sequence. By nominally opposite, in this case it is taken that the angle between the lines formed between the kerb profile in the current cell to the kerb profile in the previous and next cells is greater than 90 degrees. An example of the results of this is shown in Figure 10.

7. FINDING NEIGHBOURING FEATURES

Apart from the kerbs, there are also other features that can be delineated. The remaining features that will be extracted are specified as those that are disjoint from each other, or are only connect to other independent features by the surface of the ground. Examples of this are signs, poles, trees and buildings, which will be considered as one feature, even if it is made up of several primitive surface features. This definition is use because the features of high importance are things such as signs, light poles etc, which are only primarily connected to the ground and not with each others. Other features such as vegetation and buildings are often considered as a single entity, and either use primarily for collision detection.

To start the process, candidate seed points for a region growing process are selected based on if there are above the nearest road

cell by a certain tolerance (in this case half a metre), to ensure that they were sampled from non ground features. One of these seed points is then selected, and put in as the first element in a link-list data structure (Knuth, 1999). Surrounding points within a set distance of the first point in the list (less than the minimum distance between features) are added to the end of the list if:

- They are also candidate seed points.
- If they are not candidate points, then they are not classed as ground points previously, and their local surface normal is nominally orthogonal to the vertical direction (not having the same orientation of the ground).
- And they have not previously been labelled as belonging to a segment.

The point first in the list is then labelled as belonging to the current feature being extracted, and removed from the list. This process is continued, labelling the first point and adding points to the list, until the list is empty.

Once the list is empty, a new non-labelled candidate seed point is selected, and a new list is created for a new feature and the process is repeated.

As mentioned previously, the nearest neighbourhood selection can be simulated with the way the points are stored in the grid. For each adjacent cell, because the points are stored in order of vertical height, points within the specified distance, with respect to the vertical distance, will be grouped together in one continuous block. This means they can all be extracted in a group of points, and then quickly examined to remove those that fall outside distance threshold based on Euclidean distance.

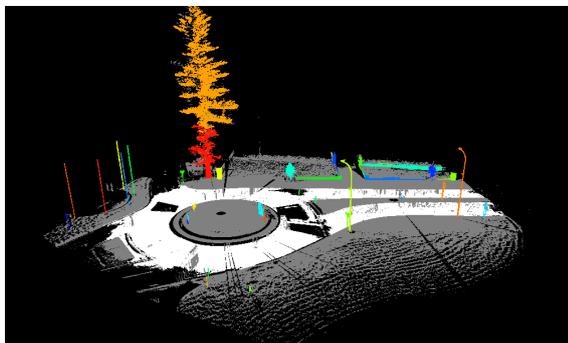


Figure 11. Isolated near road features. Road is depicted in white and the different features are denoted by different colours.

At the end, all disjoint features are delineated into common segments, as shown in Figure 11. Large features, such as buildings, that are made up of several smaller primitive surface features, can then be segmented further by methods, such as those referenced in Vosselman and Maas (2010), to further define features if needed, at the benefit of reduce the points needed be processed, and tailoring the process to the target feature (such as build facades, trees etc).

8. CONCLUSION

There are many advantages of utilising TLS for the surveying of roads, as previously indicated. The problem is that the processing of such data to extract information in a usable and productive format is costly when compare to the costs of capturing the data. This paper aimed to reduce this cost by automating part of the processing, namely the extraction of kerbs and isolating surrounding geometric features. The process was achieved by first isolating the road surface from identified

ground points, fitting a kerb profile and joining adjacent profiles to form a line representation, and segmenting above ground points into groups representing an adjacent feature to the road. Each step was presented in the paper, as applied to a real world dataset. Further research plans to be conducted to extend the automation process to delineate additional features using spectral information, such as road markings.

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