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DETECTION OF UNDERLYING SURFACE, HORIZONTAL AND VERTICAL EDGES OF THREE-DIMENSIONAL OBJECTS BASED ON LASER SCANNING DATA

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Introduction

Laser scanning technology is widely used in various industries and solves a lot of production problems. The result of applying this technology is a three-dimensional point cloud. There is a lot of different software for handling obtained laser scanning data. An overview of a number of such software products is given in [1]. Each of these software products has various implemented algorithms for detection objects in point cloud, which are distinguished by detection accuracy, computational complexity, input data, user parameters, etc. So each algorithm has its own approach for handling point cloud and could be applied to detection certain objects.

A lot of algorithms are based on the idea of Hough Transform [2,3]. The main problem of using Hough Transform for detection objects is high computational complexity, which depends on how compound the object is. Therefore, actual task is to develop more efficient detection algorithms for some type-object.

1. Point cloud structuring

The first step includes preparation of point cloud for further research. Proposed approach of point cloud structuring in [4] allows to reduce the computation complexity of most detection algorithms to a linear order $O(n)$.

The space of point cloud is divided on voxels which mean cells in three-dimension spaces with regular size *d*. Each point of cellular partition uniquely belongs to a certain voxel: the point coordinates (x_i, y_i, z_i) are divided on cell size *d* and obtained indexes define the voxel. The list of entered points with their quantity are formed for each voxel.

2. Detection of the underlying surface

Underlying surface includes all components referring to the earth`s surface. In a simple case the underlying surface means the terrain surface. So the points reflected from the terrain surface have the lowest *Z* coordinates. Using obtained data structure it is easy to detect dead-level underlying surface by scanning the low level voxels.

If the surface presents ambiguous terrain, then it is necessary to use algorithm from [5]. Succinctly describing of algorithm is demonstrated as follows:

- consistently searching for cells in point cloud structuring that have voxel on zero level and collect them into list;
- checking eight neighboring cells for each item from certain list. If a neighboring cell has a voxel whose lower level is not more than 1 from current cell, then it is added to the end of the list.

The model of detected surface is represented by flat triangulation on selected points (Fig. 1). Handled points are deleted or ignored from point cloud for further research.

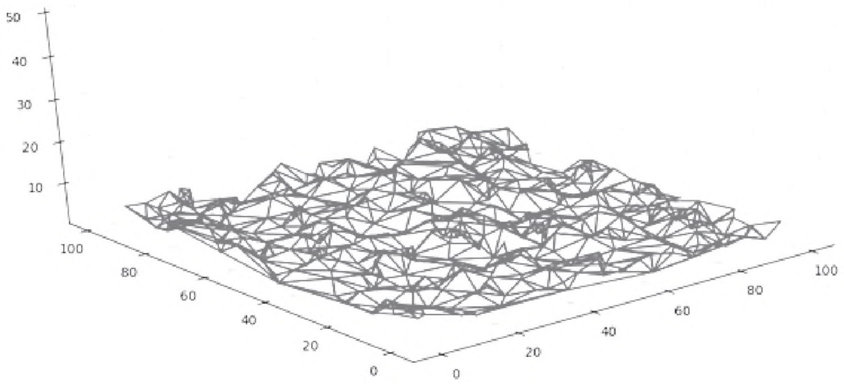

Fig. 1. The triangulated model of the underlying surface

3. Detection of horizontal edges of the objects

The algorithm for detection of horizontal edges is based on the idea of Hough Transform. This approach is effective since the horizontal edge is given by an equation with only one parameter: $z = D$, where D is a distance from origin to plane. So the accumulator array would be one-dimensional with regular size m and would be set to zero.

The voting process runs for each voxel where voxels` points vote for certain cell in accumulator A: $A[z_i/m]$, where z_i is coordinate of current point. Instead of using all the points it is possible to use only the average points in voxel to speed up the voting process.

The global maximum in the accumulator indicates the layer with one or several horizontal edges. Single edge could be separated from the layer by algorithm for finding connected components (Fig. 2). The model of detected edge is represented by triangulation in the edge of the plane and convex hull that illustrates boundaries of the edge.

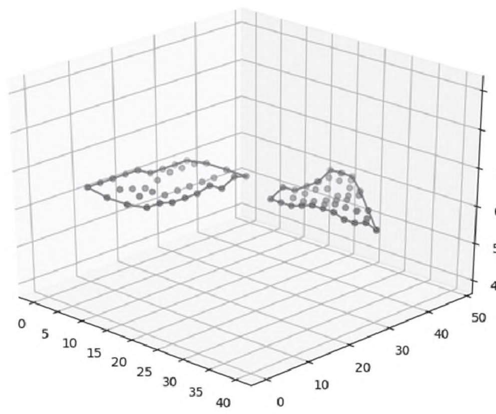

Fig. 2. Two horizontal edges of the same layer

After researching the global maximum the next one is found and the same operations are done with it.

4. Detection of vertical edges of the objects

The detection of vertical edges works more effective after detecting and deleting points belonging to the underlying surface, horizontal edges and single high objects. The vertical edges usually refer to objects such as buildings.

The vertical edge is represented as a projection on the xOy plane as a straight line segment. The algorithm for detection one is also based on the idea of Hough Transform. It is necessary to search for a part of the projection of the vertical edge that includes the maximum number of entered points.

The laser scanning data always has unpredictable nature, so it is rational to use a variable parameter such as length of the edge which consists of number of cells. Let`s pretend that minimum length of the searching part of the projection is probably passing through four cells. Then for each cell (i_1, j_1) of the cellular partition we have twelve unique positions for the other end of the segment (i_2, j_2).

The end of the segment (i_2, j_2) rotates clockwise from the initial position (Fig. 3) to the final position (Fig. 4).

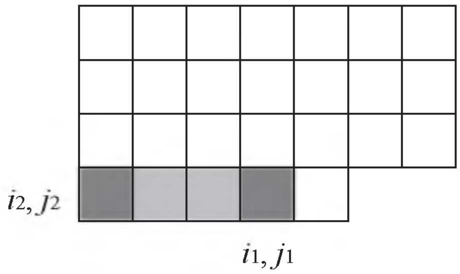

Fig. 3. Initial position

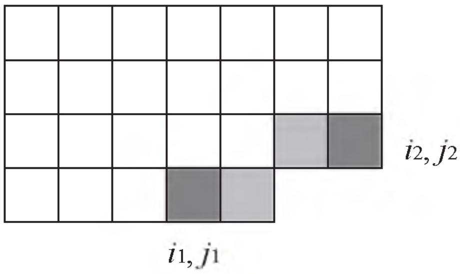

Fig. 4. Final position

The global maximum among fours of cells contains sought-for part of the projection. The detected segment is approximated by method of least squares. If the both ends of segment have neighbor cells, which continuous current segment and have enough points, then the segment would be extended and approximated again.

The equation of the approximated edge is $Ax + By + 1 = 0$, where coefficients A, B are calculated on the formulas [6]:

$$A = \frac{ce - bd}{c^2 - ab}, B = \frac{cd - ae}{c^2 - ab},$$

$$a = \sum_{i=1}^{n} x_i^2,\ b = \sum_{i=1}^{n} y_i^2,\ c = \sum_{i=1}^{n} x_i y_i,\ d = -\sum_{i=1}^{n} x_i,\ e = \sum_{i=1}^{n} y_i.$$

In order to build the model of the detected edge it is appropriate to do some transformations. Points with coordinates (x_i, y_i) that belongs to the edge are transformed to coordinate system *xOy* of the edge. Coordinates z_i stay without changes and become coordinates on *Y* axis on the edge plane.

There are three cases:

1. $A = 0$, coordinates x_i stay without changes, among them finding maximum and minimum.
2. $B = 0$, coordinates y_i become coordinates x_i, among them finding maximum and minimum.
3. $A \neq 0$ and $B \neq 0$, coordinates of the intersection point of the perpendicular from the current point (x_i, y_i) to the projection of the edge (x_{0i}, y_{0i}) are calculated in accordance with the formulas given in [6]:

$$x_{0i} = -\left(A + B\left(Ay_i - Bx_i\right)\right) / \left(A^2 + B^2\right),\ y_{0i} = \left(A\left(Ay_i - Bx_i\right) - B\right) / \left(A^2 + B^2\right).$$

On acquired coordinates (x_{0i}, y_{0i}) minimums (x_{min}, y_{min}) and maximums (x_{max}, y_{max}) are found. Point (x_{min}, y_{min}) become origin of *X* axis in the plane of the edge. Original coordinates (x_i, y_i) of point recalculated and become new coordinate $x_{\text{new } i}$ on X axis in the plane of the edge with formulas [6]: $x_{\text{new } i} = \sqrt{(x_{0i} - x_{\min})^2 + (y_{0i} - y_{\min})^2}$.

The model of detected edge is represented by triangulation in the edge of the plane and convex hull that illustrates boundaries of the edge (Fig. 5).

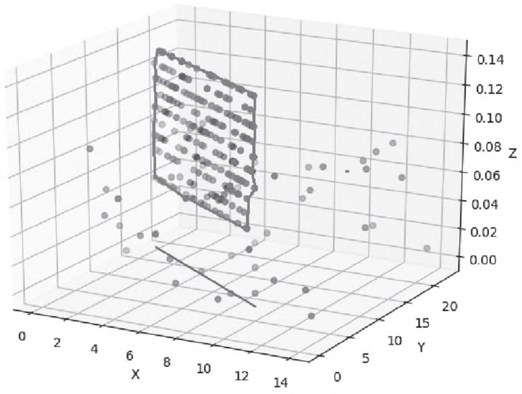

Fig. 5. The model of vertical edge with convex hull

Conclusion

The proposed point cloud structuring allows us to develop effective algorithms for detection different type-objects. The required memory capacity for such structure reaches $O(n)$. When applying an efficient sorting algorithms the computation complexity of creation this structure reaches $O(n \cdot \log n)$, where n is the number of points in the cloud. In this paper we propose several algorithms for detection the underlying surface, horizontal and vertical edges of three-dimensional objects. The previous two usually compose complex objects such as buildings or facilities.

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