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An Automatic Spherical Targets Detection Method with Multiple Geometrical Constraints

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Abstract. Spherical targets are used extensively in the registration and coordinate transformation of the railway point cloud. Thus, it is necessary to accurately detect the spherical targets from the railway point cloud. This paper proposes an automatic spherical targets detection method with multiple geometrical constraints. In this method, possible spherical points are extracted by the improved three points filter method. And possible spherical points are refined according to neighborhood height difference and curvature. Then, the refined possible spherical points are spatially clustered by the Euclidean clustering method and the potential target point clouds can be extracted by constructing the spherical neighborhood according to the cluster centroid. Finally, the ratio constrained random sample consensus (RC-RANSAC) method is proposed in this paper, based on the RANSAC method, to detect the spherical targets in the potential target point clouds. The point cloud scanned from the high-speed railway is taken as experimental data. The spherical targets in the point cloud are detected by this method. The experimental results show that the proposed method can detect the spherical target with and without the background in radial direction.

Keywords. Railway point cloud, spherical targets, random sample consensus

1. Introduction

At present, the spherical target [1] are widely used to achieve the registration and coordinate transformation of the railway point cloud. And the spherical target detection is a basic task for many practical railway engineering applications.

Method based on geometric information. The method [2-5] extracts the possible spherical points in point cloud according to the curvature and normal direction, and then detects spherical targets in the possible spherical points. In this method, there are some problems such as large amount of calculation and low efficiency.

Method based on neighborhood distance. Wang et al. [6] extracts the occluding edge points according to the depth difference between the center point p and the local eight neighborhoods, then the spherical targets are detected by the RANSAC method. Liu et al.[7] used the three points filter method to extract possible spherical points, and

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detected the spherical targets. The method assuming that the background of spherical targets in radial direction is always existing. However, in case of the scene of HSR, this assumption is not always true.

To save the problem, this paper proposes an automatic spherical targets detection method with multiple geometrical constraints, which takes into account the situation that the background of spherical targets in radial direction is missing. The experimental results based on the railway point cloud show that the proposed method can correctly detect the spherical targets with and without the background in radial direction in point cloud.

2. Technical Approaches

For the background of spherical target in radial direction is missing, the improved three points filter method is proposed to detect possible spherical points. In this method, its radial distance is set as a fixed value to meet the requirement of the three points filter method [7] if the neighborhood point is missing. This ensures that the spherical targets without the background in radial direction can be detected. Since some non-spherical objects in point cloud also meet the requirement of the improved three points filter method, the possible spherical points are refined by the neighborhood height difference and curvature. The potential target point clouds can be extracted from the refined possible spherical points. The ratio constrained random sample consensus (RC-RANSAC) method is proposed to detect spherical targets in the potential target point clouds.

The detailed steps are given as follows:

1) To detect the possible spherical points in point cloud by the improved three points filter method.

2) The possible spherical points are refined according to the neighborhood height difference and curvature, which can be given by geometric feature detection method.

3) For the detection results of the Step 2), the cluster results $\{c\}_i$ can be obtained by the Euclidean clustering method. The potential target point clouds $Sphere_i, i = 1, 2...g$ can be obtained in point cloud by constructing the spherical neighborhood according to the centroid $\overline{cp_i}$ of each cluster result.

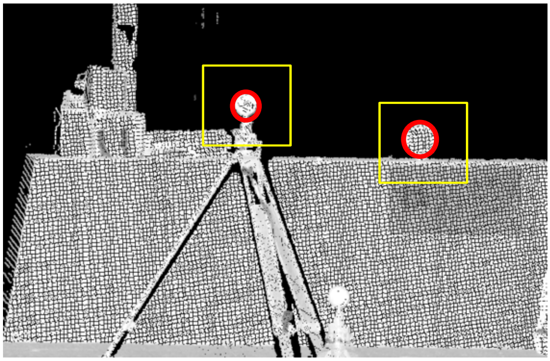
4) The spherical target in $Sphere_i$ is detected by the RC-RANSAC method.

5) Repeat Step 4) to detect the multiple spherical targets in $Sphere_i, i = 1, 2...g$.

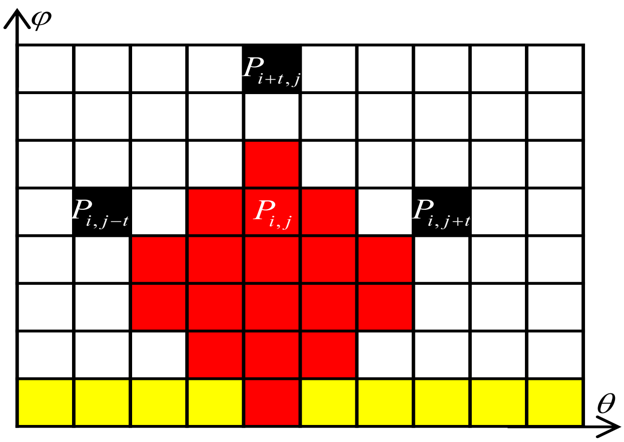
2.1. Improved Three Points Filter

The spherical projection [8] method is adopted to convert the point cloud from three-dimensional rectangular coordinate $p(X_i, Y_i, Z_i)$ to polar coordinate $P(\theta_i, \varphi_i, r_i)$. θ is the horizontal angle; φ is the vertical angle, and r is the radial distance. Therefore, a plane grid can be derived by taking θ and φ as the horizontal and vertical axis. It is a regular grid with the grid interval is $\overline{d}$ according to scanning process of TLS.

When the background of spherical targets in radial direction is missing (Figure 1 (a)), partial or all three neighborhood points $P_{i,j-t}$, $P_{i,j+t}$ and $P_{i+t,j}$ of $P_{i,j}$ will be missing (Figure 1(b)). In this case the three points filter method [7] is unable to get the all three radial distances $r_{i,j-t}$, $r_{i,j+t}$ and $r_{i+t,j}$, therefore, the spherical target will not be detected. To solve this problem, the radial distance is set to $2r_{i,j}$ if any of three neighborhood points is missing. This ensures that the spherical targets with and without the background in radial direction can be detected correctly.



(a)



(b)

Figure 1. Spherical targets: (a) the background of spherical targets in radial direction is missing, the red range indicates the spherical targets, (b) the plane grid of spherical target without the background in radial direction. The red grid represents the spherical target, the yellow grid represents the presence of points within the grid, the white grid represents the absence of points within the grid, and the black grids represent the three neighborhood grids that are detected in three points filter method.

The detailed steps of the improved three points filter method are given as follows:

1) The point cloud is expanded into plane grid by spherical projection [8].

2) For one point $P_{i,j}$ in the plane grid, the angular variation value γ and the grid span *t* can be calculated:

$$\gamma = 2\arcsin\left(\frac{R}{R + r_{i,j}}\right) \tag{1}$$

$$t = \left\lceil \frac{\gamma}{\overline{d}} \right\rceil \tag{2}$$

where $\lceil \ \rceil$ denotes round up to an integer. The three neighborhood points $P_{i,j-t}(\theta-\gamma,\varphi,r)$, $P_{i,j+t}(\theta+\gamma,\varphi,r)$ and $P_{i+t,j}(\theta,\varphi+\gamma,r)$ of $P_{i,j}$ can be obtained.

3) Find a point P_K in plane grid, which is the closest point to $P_{i,j-t}$. And d is the distance between $P_{i,j-t}$ and P_K . If $d \le \overline{d}$, $r_{i,j-t} = r_K$. If $d > \overline{d}$, $P_{i,j-t}$ is not existed in the plane grid and its radial distance $r_{i,j-t}$ is set to $2r_{i,j}$.

4) Repeat the Step 3) to obtain the radial distances $r_{i,j+t}$ and $r_{i+t,j}$ of the point $P_{i,j+t}$ and $P_{i+t,j}$.

5) If $r_{i,j-t}$, $r_{i,j+t}$ and $r_{i+t,j}$ are not in the range $(r_{i,j}, r_{i,j}+R)$, the point $p_{i,j}(X,Y,Z)$ in point cloud corresponding to point $P_{i,j}$ in plane grid is regarded as possible spherical point.

6) Repeat Step 2) to Step 5) to detect possible spherical points $\{p_i\}$ in point cloud.

2.2. Geometric Feature Detection

Some non-spherical targets meet the requirement of the improved three points filter method. The neighborhood height difference and curvature of some non-spherical targets are quite different from those of spherical targets. Therefore, some non-spherical points can be removed from the possible spherical points $\{p_i\}$ according to these two geometric features.

The specific steps of geometric feature detection method are as follows:

1) Neighborhood height difference detection: For one point p_i in $\{p_i\}$, a set of neighborhood points can be found, and then the neighborhood height difference dz can be calculated based on those neighborhood points. If dz less than the threshold, 1.5R in this paper, all neighborhood points of p_i will be removed from $\{p_i\}$.

2) Curvature detection: For one point p_i in $\{p_i\}$, if its curvature is not in the range of $[0.7C, 1.2C]$ ($C = 1/R$), it will be removed.

Thus, the possible spherical points $\{p_i\}$ can be refined.

2.3. Spherical Targets Detection

The potential target point clouds $Sphere_i, i = 1,2...g$ can be extracted from the refined possible spherical points. The spherical target in $Sphere_i$ can be extracted by the RANSAC method [3, 6, 7], which is less affected by noise. However, in some case, some false spherical targets are detected by the RANSAC method. For an example shown in Figure 2, the two knees of a person which the shape is close to the spherical target are regarded as the spherical targets.

In the real application, the radius R of the spherical target is known. Moreover, the point number of real spherical target must account for a high proportion, about 60% in usual case. Associated with these two characteristics, a ratio constrained RANASC (RC-RANSAC) method can avoid the false spherical targets.

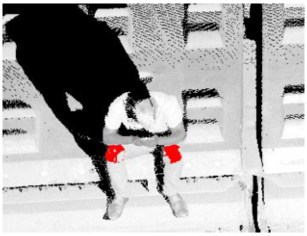


Figure 2. RANSAC false extraction (Denoted by red dots).

The detailed steps of RC-RANSAC method are given as follows:

1) Obtain the candidate spherical target by RANSAC method from $Sphere_i$, and its radius is R_{ransac} .

2) If the difference between the known radius R and R_{ransac} larger than the given threshold R_{th} , the candidate spherical target is considered as false one, and removed. Otherwise, it may be a real one.

3) Calculate the proportion Rat of points in spherical target

$$Rat = \frac{M}{N} \tag{3}$$

where N is the number of points in $Sphere_i$, and M is the number of points of the candidate spherical target.

If Rat is larger than the given threshold $Ratio_{th}$, the candidate spherical target is regarded as a real one.

3. Experiments

A real railway point cloud are used to test the performance of the proposed method, and compared with the current method. The experimental result of the two methods is evaluated by the two indexes, completeness and correctness [9].

3.1. Experimental Dataset

The point cloud S1 (Figure 3) are obtained from high-speed railway by a terrestrial laser scanner (FARO Focus S 150). There are 7 spherical targets (A1-A7), whose radius R is 0.07m. The background of spherical targets A3 in radial direction is missing, while the background of the other spherical targets are existing.

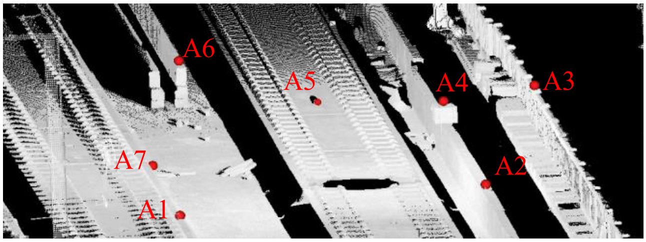
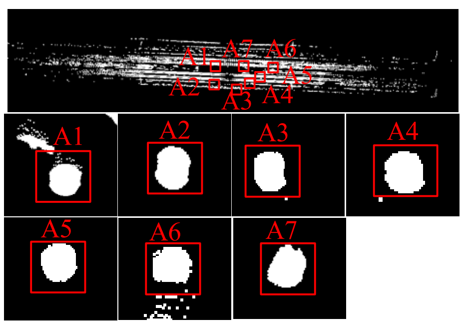


Figure 3. The point cloud S1.

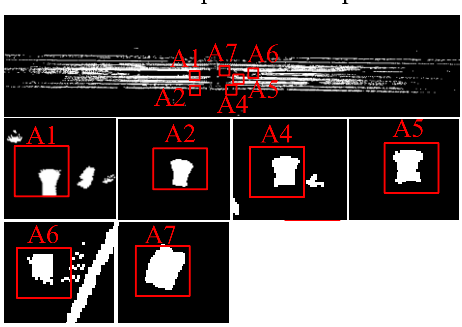
As to the proposed method, R_{th} is set to 0.01m and $Ratio_{th}$ is set to 0.6. As to the three points filter method [7], the inner radius $R_{\min}$ is set to 1.5R and the outer radius $R_{\max}$ is set to 2R in this paper.

3.2. Experimental Results

Possible spherical points in S1 are detected respectively by the improved three points filter method and three points filter method. There are 7 spherical targets (A1-A7) in the possible spherical points detected by the improved three points filter method in Figure 4(a). There are only 6 spherical targets in the possible spherical points detected by the three points filter method, and the spherical target A3 is not detected in Figure 4(b).



(a) detection result of the improved three points filter method



(b) detection result of the three points filter method.

Figure 4. Detection results of possible spherical points in S1

31 potential target point clouds (Figure 5) are extracted in S1 according to the possible spherical points detected by the improved three points filter method.

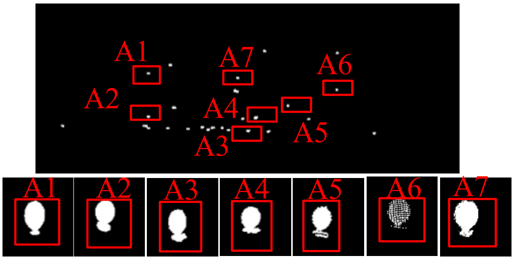
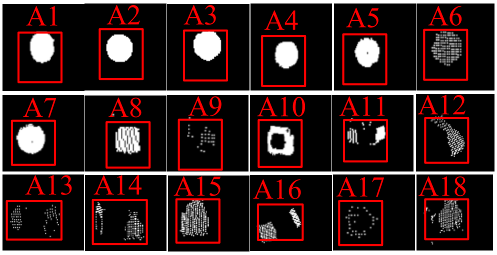
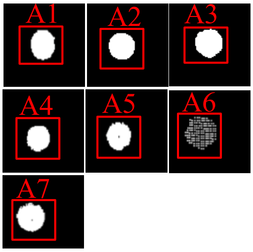


Figure 5. Extraction results of potential target point clouds.

RNASAC method detects a total of 18 spherical targets in Figure 6 (a) from the 31 potential target point clouds, while the RC-RANSAC method detects 7 spherical targets in Figure 6 (b).



(a) detection results of the RANSAC method



(b) detection results of the RC-RANSAC method.

Figure 6. Spherical target detection results in S1

3.3. Analysis of Experimental Results

The spherical target A3 is missing in the possible spherical points detected by the three points filter method in Figure 4(b), while there are 7 spherical targets in possible spherical points detected by the improved three points filter method in Figure 4(a). The experimental results show that the improved three points filter method can effectively detect the spherical target with and without the background in radial direction.

To evaluate the spherical target detection results of RANSAC and RC-RANSAC method, the correctness and completeness of the two methods are calculated and listed in Table 1. The completeness of the two methods is 100%. The correctness of RANSAC method is 38.9%, while the correctness of the RC-RANSAC method is 100%, the correctness increases by 61.1%.

Table 1.Analysis of spherical target detection results. (TP represents the number of correctly detected spherical targets, FP represents the number of extracted the non-spherical targets, FN is the number of spherical targets not extracted).

RC-RANSAC					RANSAC				
TP	FP	FN	Correctness	Completeness	TP	FP	FN	Correctness	Completeness
7	0	0	100%	100%	7	11	0	38.9%	100%

4. Conclusions

This paper proposes an automatic spherical targets detection method with multiple geometrical constraints. The improved three points filter method is proposed to detect possible spherical points in point cloud firstly, and then the ratio constrained RANSAC (RC-RANSAC) method is proposed to detect the spherical targets.

Experimental results show that the proposed method can correctly detect multiple spherical targets in point cloud, regardless of whether the background of spherical target in radial direction exists or not.

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