ROAD TUNNEL DEFORMATION MONITORING USING TERRESTRIAL LIDAR DATA

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ABSTRACT:

Road tunnels, underground passages of roads going through or under some obstacles (e.g. rivers, hills, and even other roads), require adequate monitoring for detecting structure instability caused by any environmental impacts (e.g. settlement). Due to high data accuracy, high point density, and rapid data acquisition, terrestrial LiDAR has become a popular technique in deformation monitoring in the past several years. By using 3D point clouds from multiple scan stations, terrestrial LiDAR can provide a high-resolution perspective of the tunnel's inner dimensions, geometries, and shapes. In this paper, we propose a novel algorithm to explore the ability of terrestrial LiDAR point clouds collected using a RIEGL VZ-1000 system for tunnel deformation monitoring. The main steps include: (1) registration and pre-processing, (2) segmentation, (3) deformation analysis, and (4) quantitative evaluation of the experimental results.

To reconstruct the entire scene, we need to acquire multiple scans from different scan stations. In addition, tunnel data of at least two different epochs need to be collected to analyse deformations. All the scans from different epochs are transformed to a uniform coordinate system using the mark-based registration method. Since the process of tunnel deformation is very sluggish, here, we propose a simulated experiment (see Figure 1). In the experiment, a set of plastic boards with different thicknesses (i.e., 1 mm, 3 mm, 5 mm, 10 mm, and 15 mm) were placed on the tunnel walls to be measured. Due to the mechanism of LiDAR system, the surfaces may contain some outliers. To remove these outliers, we propose a spatial density filter, which calculates a spatial density for each point and removes the points whose densities are below a pre-defined threshold.

Due to the huge volumes of data points, we group a point cloud into some blocks. To this end, we make the y-axis of the dataset parallel to the route direction, the x-axis perpendicular to the route direction and parallel to the ground, and the z-axis perpendicular to the ground. This is achieved easily by applying the quaternion method. Consequently, each block is assigned a unique y value and a buffer size $\triangle$y. In each block, we classify the points into segments (e.g. ceiling, walls, and ground). A region growing approach is carried out to obtain the ground plane. Given a distance threshold, we extract the ceiling points. Through Euclidean distance clustering, we separate the wall from the others.

In each segment (e.g. ceiling and two walls), we compare the change of the points from different datasets obtained in different epochs to detect deformations. First, by constructing a covariance matrix of the segment points, we compute the normal vector v of this segment through eigenvalue decomposition. Then, all the points within the segment are projected onto the plane going through the origin and having a normal of v. Next, we rotate the projection plane to be parallel with the XoY-plane. Afterwards, the plane is partitioned into a grid structure with a fixed spacing in the XoY-plane. Finally, the point within the segment corresponding to its projection point is partitioned into some grid. By respectively computing the centroids of the corresponding grids in different epochs, we calculate the distance d between these two points in the normal vector direction. This distance d is the local deformation of a specific grid. Figure 2 shows the processing results in each step of the tunnel deformation monitoring algorithm. As seen from the detection results in Figure 2, we conclude that the proposed algorithm performs well in detecting tunnel deformations from terrestrial LiDAR point clouds.

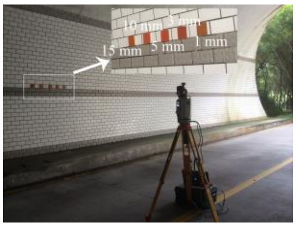

Figure 1.

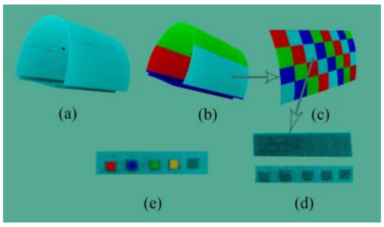

Figure 2.

Figure 1. Test scene of the simulated experiment. Figure 2. (a) A block point cloud of tunnel, (b) segments of a block, (c) partition grid of a sample segment, (d) a grid in different epochs, (e) defected deformation (red means a deformation between 14mm and 16mm, blue between 9-11mm, green between 4-6mm, yellow between 2-4mm, the last one is not detected).

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