Title:
Detection of Steel Materials of Large Structures Using Point-Clouds

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Introduction:

Since terrestrial Laser Scanner (TLS) can obtain dense point-clouds from a wide range of areas, it can be used for improving efficiency of maintenance tasks of large-scale facilities. In this research, we discuss methods to support maintenance of power transmission pylons using point-clouds.

Fig. 1(a) shows a typical power transmission pylon built in Japan. The height of this pylon is about 50 m. In maintenance of pylons, workers investigate deterioration of steel materials such as corrosion and deformation, and replace deteriorated steel materials. Since a pylon is assembled by connecting many steel materials with bolts, the measurement of steel material dimensions and bolt positions is important for accurately connecting new steel materials to existing ones. In the conventional method, steel material dimensions and bolt positions were measured manually, as shown in Fig. 1(b). However, such measurement tasks are dangerous, time-consuming and expensive, because several workers have to cooperatively measure steel materials in high and unstable places on a pylon.

Therefore, we develop methods to calculate steel material dimensions and bolt positions from point-clouds captured with a TLS placed on the ground, as shown in Fig. 1(c). In order to achieve this objective, it is necessary to detect steel materials and bolts from point-clouds and calculate their dimensions and positions.

Since shapes of steel materials and bolt heads are composed of planer surfaces, plane detection is useful for detecting them. Plane detection methods for point-clouds, such as the RANSAC method and the region growing method, have been intensively studied so far. However, there are the following problems to detect steel materials and bolts from pylon point-clouds measured on the ground using a TLS.

- In order to separate two steel materials joined by bolts, it is necessary to carefully specify the threshold value for plane detection. However, it is a difficult problem to determine an appropriate threshold value, because the threshold depends on the distance between the TLS and the steel material and the irradiation angle between the laser beam and the plane. In processing actual point-clouds of pylons, a single steel material is often divided to multiple planes, or combined with other steel materials, as shown in Fig. 1(d).
- The point-cloud of each bolt is only partially captured, because the position of a TLS is restricted to the ground, as shown in Fig. 1(e). Therefore, the center of the point-cloud of a bolt head often differs from the bolt position, as shown in Fig. 1(f). It is necessary to estimate the true bolt position using a partially captured point-cloud.

In this research, we discuss methods for solving these problems and accurately calculating the dimensions and positions of steel materials and bolts.

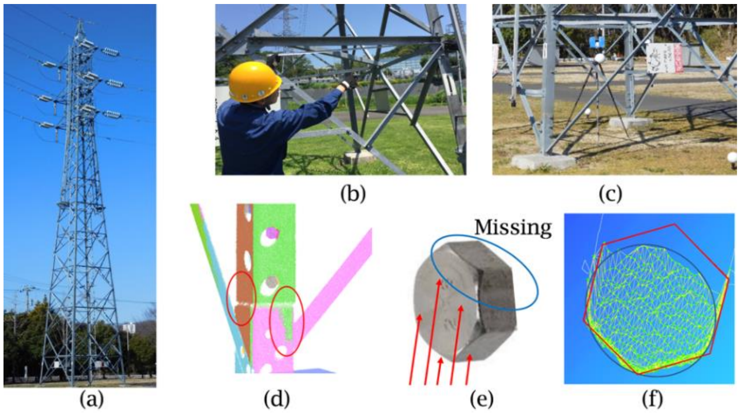


Fig. 1: Measurement of pylons: (a) Steel Tower, (b) Manual Measurement, (c) Laser Scanning on the Ground, (d) Detection of Planes of Steel Materials, (e) Laser Scanning of Bolt, and (f) Point-Cloud of Bolt.

Detection of Steel Materials:

Fig. 2 shows a method for detecting planes of steel materials. We extract initial planes using the method proposed by Masuda et al. [2]. In this method, planes are detected from points projected on the 2D lattice. Point-clouds can be mapped on a 2D lattice, as shown in Fig. 2(b), because points are sequentially measured by rotating laser beams in the azimuth and elevation angles. Then, the point-cloud is subdivided into continuous regions by examining continuity of neighboring points on the 2D lattice. When each plane is detected from a continuous region using the RANSAC method, points on the plane are removed and the remaining points are again subdivided into continuous regions. These subdivision and detection steps are recursively repeated until all planes are detected.

The RANSAC-based plane detection requires a threshold value for determining whether each point is on the plane. However, threshold values depend on the distances from the TLS and the irradiation angles of laser beams. In addition, steel materials may be bending and then residuals of plane fitting may become large. Therefore, it is difficult to stably separate each steel material using conventional plane detection. As shown in Fig.2(c), a rectangle plane of a steel material may be divided into multiple ones or different steel materials may be merged into a single plane.

To solve this problem, we introduce a plane detection method suitable for steel materials. After planes are detected using the method in [2], adjacent planes are merged when they have similar normal vectors. Then under-segmented planes are obtained, as shown in Fig. 2(d). In the next step, the center lines of steel materials are calculated, as shown in Fig. 3(a). In our method, holes on planar regions are filled, and the center lines are extracted by thinning planar regions using Hilditch's method [1]. Then, points are selected on each center line, as shown in Fig. 3(b), and a small plane is fitted to neighbors at each point for calculating a residual of plane fitting. Residuals are calculated for all selected points on the center line, and the minimum residual value σ_{min} is obtained for each center line. Then the threshold for plane fitting is determined as $\lambda\sigma_{min}$, where λ is a value close to 1.

To detect planes of bended steel materials, each under-segmented planar region is subdivided to small overlapping regions along the center line, as shown in Fig. 3(c). Then planes are detected using the region growing method in each small region. The seed region of region-growing is selected at the point with the minimum residual on the center line. When overlapping planes are detected from adjacent small regions, they are merged into a single plane. In our method, since the thresholds for plane detection are adaptively determined using the minimum residuals of actual points, small steps of bolted steel materials can be stably detected, as shown in Fig. 3(d) and Fig. 2(e).

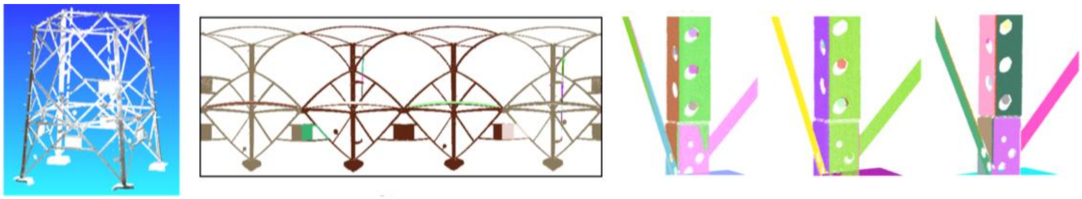


Fig. 2: Extraction of steel materials: (a) Point-Cloud, (b) Segmentation on 2D Lattice, (c) Initial Planes, (d) Merged Planes, and (e) Detected Planes of Steel Materials.

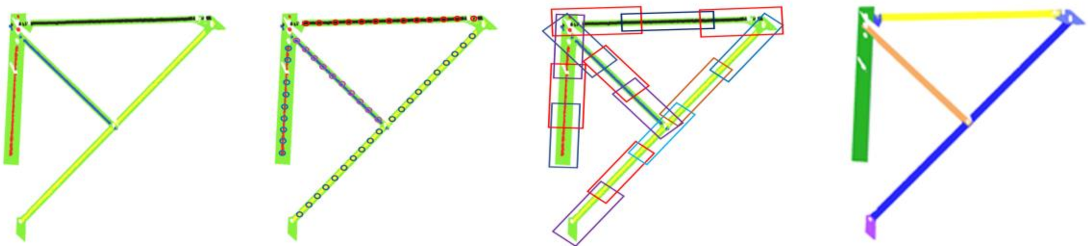


Fig. 3: Process of steel material detection: (a) Center Lines of Planar Regions, (b) Calculation of Residuals of Plane Fitting at Points on the Center Lines, (c) Small Regions along the Center Lines, and (d) Detected Planar Regions.

Detection of Bolts:

In plane detection, small planes of bolt heads are also detected, as shown in Fig. 2(c). However, these planes are extracted only partially due to occlusion, as shown in Fig. 1(e-f). Therefore, we develop methods to estimate the bolt centers from partially measured points. A plane is regarded as a candidate of a bolt head only when the plane size is equal or less than possible bolt diameters and a large parallel plane of a steel material exists under the bolt head plane. Then points between the bolt head plane and the steel material plane are regarded as bolt points. Fig. 4(a) shows bolt points with magenta.

Since the shape of a bolt is a hexagon, the width of a bolt varies depending on the rotation angle of the bolt, as shown in Fig. 4(b). Therefore, it is necessary to estimate the rotation angles of bolts for calculating the diameters. We introduce two methods for calculating diameters and positions of bolts.

One method is estimating the length of the longest hexagonal diagonal. In this method, bolt points are projected on a plane, and widths of points are measured in various directions. The maximum width, as shown in Fig. 4(c), is regarded as the diameter of a hexagon circumscribed circle. The bolt size and position are determined using the circumscribed circle.

In the other method, the bolt size and position are estimated by fitting a hexagon to bolt points projected on a plane (Fig. 4(d)). Fig. 5 shows the outline of this method. First, a cuboid is generated so that bolt points are included, as shown in Fig. 5(a). The orientation of the cuboid is specified so that two face of the cuboid is parallel to the steel material plane, and the laser beam intersects with the perpendicular face at the right angle as much as possible. Since points on the scanner side are densely measured without occlusion, a hexagon is fitted only to bolt points on the scanner side, as shown in Fig. 5(b). Bolt points are triangulated using the Delaunay triangulation, as shown in Fig. 5(c), and a hexagon is fitted to the boundary points on the scanner side, as shown in Fig. 5(d). Since bolt sizes are standardized, several standard values close to the width of bolt points are selected. All hexagons with selected standard bolt sizes are evaluated, and the hexagon that fits to the most boundary points is selected as the shape of the bolt. Fig. 6 shows bolts and a steel material extracted from a point-cloud.

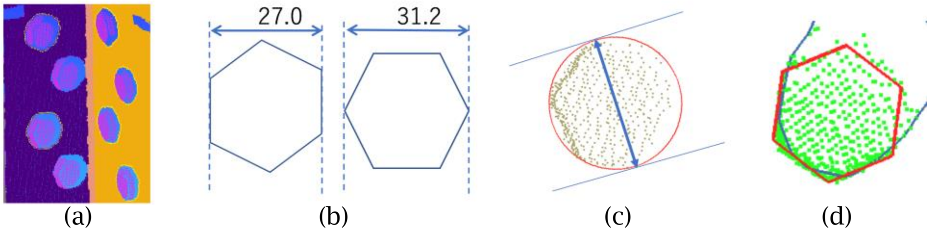


Fig. 4: Two methods for estimating the bolt size: (a) Bolt Points, (b) The Minimum and Maximum Lengths of Bolt, (c) Bolt Size Estimated by the Maximum Width Method, and (d) Bolt Size by the Hexagonal Fitting Method.

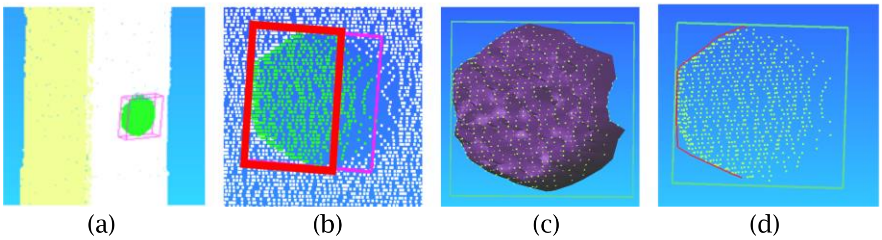


Fig. 5: Process of hexagonal fitting: (a) Cuboid for Bolt Points, (b) Points on the Scanner Side, (c) Triangulation of Bolt Points, and (d) Boundary Points on the Scanner Side.

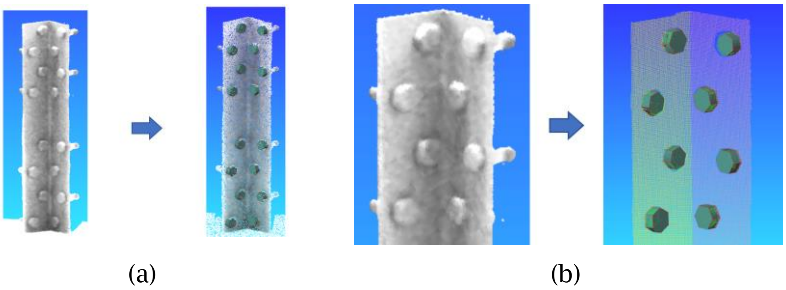
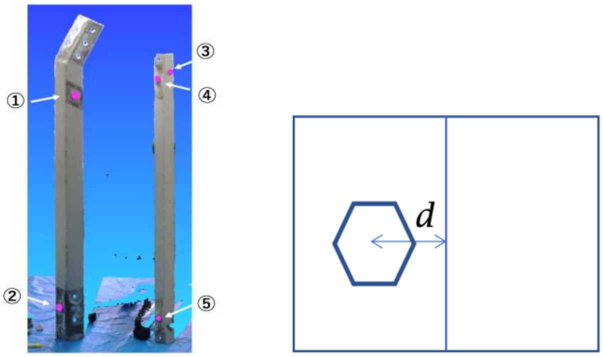


Fig. 6: Detected bolts from a point-cloud: (a) Detected Bolts, and (b) the Close-Up.

<u>Experimental results:</u>
The two bolt detection methods were evaluated using steel materials and bolts shown in in Fig. 7(a). In this evaluation, both methods could extract two steel materials and six bolts correctly. Then we evaluated the accuracy of bolt positions by measuring d, which is the distance between the bolt center and the intersection line of the angle steel planes, as shown in Fig. 7(b). We measured the distances using vernier calipers, and compared them to the distances calculated using the point-cloud. The results are shown in Tab. 1. In this experiment, the hexagon fitting method was better than the maximum width method in almost all cases.

We also detected steel materials and bolts from a point-cloud of an actual power transmission pylon. The pylon was measured at an angle interval of $\pi \times 10^{-4}$ radian. The number of measurements in a single laser scanning was about 170 million. Fig. 8 shows detected steel materials and bolts. Our method could successfully detect steel materials and bolts from actual point-clouds.

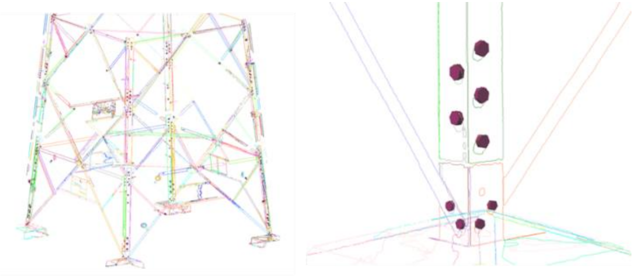


(a) (b)

Fig. 7: Steels materials and bolts: (a) Point-Cloud, and (b) Bolt Positions.

Bolt	*Measured by vernier calipers*	*Maximum width method*		*Hexagonal fitting method*	
		Calculated value	*Difference*	*Calculated value*	*Difference*
1	45.5 mm	46.8 mm	1.3 mm	47.0 mm	0.5 mm
2	44.2 mm	42.9 mm	1.3 mm	44.6 mm	0.4 mm
3	38.9 mm	37.8 mm	1.1 mm	38.8 mm	0.1 mm
4	30.6 mm	32.5 mm	1.9 mm	30.5 mm	0.1 mm
5	30.6 mm	30.5 mm	0.1 mm	30.4 mm	0.2 mm
Average	-	-	1.5 mm	-	0.8 mm

Tab. 1: Experimental results of the two bolt detection methods.



(a) (b)

Fig. 8: Detection of steel materials and bolts: (a) Detected Steel Materials and Bolts, and (b) the Close-Up.

Conclusions:

In this paper, we proposed methods to detect planes of steel materials and bolts from point-clouds of power transmission pylons. In our experiments, our method could successfully detect steel materials and bolts.

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[2] Masuda, H.; Niwa, T.; Tanaka, I.; Matsuoka, R.: Reconstruction of Polygonal Faces from Large-Scale Point-Clouds of Engineering Plants, Computer-Aided Design and Applications, 12(5), 2015, 555-563. http://dx.doi.org/10.1080/16864360.2015.101473