3D measurement and feature extraction for metal nuts

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Abstract. The metal nuts used to assemble bridges and buildings inevitably deteriorate over time, which makes it crucial to obtain various parameters related to their conditions during maintenance activities and then determine whether and when they should be replaced. However, since measuring the essential parameters such as height and minimum width of large numbers of nuts is a very time- and energy-consuming project, we developed a method that uses a laser measurement instrument to collect three-dimensional (3D) information on such nuts. We then combined it with a software application that can quickly and automatically calculate their 3D point cloud data and obtain their parameters. As a result, building and bridge inspections can now be conducted more quickly and efficiently, and with reduced manpower requirements.

1 Introduction

Large metal nuts, which are among the most common fastening parts used in the assembly of machines and buildings, typically have a center hole with a female thread and are used in combination with male threaded parts, such as bolts. Generally speaking, hexagonal-shaped nuts and bolts are used to fix steel bars together in buildings and bridges. However, in situations where they are installed exposed to outside environments, they corrode over time, and after 10 or 20 years, need to be replaced. Hence, such nuts need to be examined periodically. In conventional inspections, the examiner conducts an on-site survey and determines the condition of each nut based on his or her experience. However, due to the large number of nuts in a typical bridge or building, this procedure is often time-consuming and potentially dangerous [1].

In previous studies, nuts were measured in three dimensions, and their parameters were obtained by interactively manipulated on a personal computer (PC) using software such as MeshLab and CloudCompare. However, in these situations, the nuts were considered individually, and the parameters of each had to be manually calculated via numerous interactive mouse-based operations, which required significant amounts of time.

To solve the above problem, we developed a system that automatically performs a quick inspection study by using a laser scanner to obtain a three-dimensional (3D) image of a nut, along with an application that automatically calculates its 3D point cloud data to obtain its parameters. These data are used in combination with previously uploaded information on the bridge or building to determine whether the nut is still functional. Using this system, inspectors can determine which nuts are defective and need to be replaced via a simple, fast, easy, and safe operation.

2 Automatic measurement of 3D nut data parameters

3D measurements of metal nut. We have a lot of experience in 3D point cloud inspection. We have used 3D inspection technology to obtain 3D point cloud data of rocks and street in Miyako City [2] [3]. In this study, we used a 3D laser inspection device to obtain the 3D point cloud data of nuts installed in the Kanmon Kaikyo Bridge, which connects the Main Japanese Islands of Honshu and Kyushu. For the processing of 3D point clouds, we took inspiration from the literature [4] and [5]. We can calculate the parameters by obtaining the eigenvalues of the nuts. An example of the targeted nuts is shown in Fig.1. Image data were obtained using a 3DSL Rhino 01 laser imager (Seikowave Energy, Lexington, KY), as shown in Fig.2. Numerous point cloud data of 3D nut was captured via this system, such as the sample shown in Fig.3.

Fig.1: The nuts of Kanmon Kaikyo Bridge   Fig.2: 3DSL-Rhino-01 laser scanner

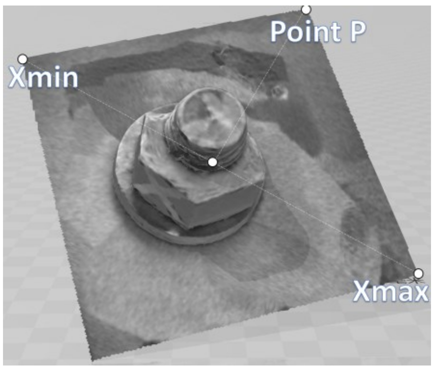

Fig.3: point cloud data of metal nut

Principle of the algorithm. To calculate nut parameters, we first need to know the plane below the nut, which means we need the coordinate values of three points on that plane in order to calculate the plane equation. In Fig 3, we see that the points corresponding to the maximum and minimum values on the X-axis of the nut point cloud are on the plane.

To prevent loopholes for the third point, we do not use the extreme point value and instead set the third point to point P (Xp, Yp, Zp). Point P is the farthest point from the midpoint of points Xmax and Xmin (Xmid, Ymid, and Zmid). We then use the Xmax, Xmin, and P points to obtain the plane equation (Ax + By + Cz + D = 0).

$$Xmid = \frac{(Xxmax + Xxmin)}{2}$$

$$Ymid = \frac{(Yxmax + Yxmin)}{2}$$

$$Zmid = \frac{(Zxmax + Zxmin)}{2}$$

$$Lmax = \sqrt{(Xmid - Xp)^2 + (Ymid - Yp)^2 + (Zmid - Zp)^2}$$

We can then find the point farthest from the plane (Xd, Yd, Zd). The distance from this point to the plane is the height of the nut called d.

$$d = \frac{|Ax + By + Cz + d - D|}{\sqrt{A^2 + B^2 + C^2}}$$

Next, we divide d into 200 equal parts and calculate the number of point clouds contained in each part of the space separately. As shown by Fig 4, the horizontal coordinates are d1 to d200, and the vertical coordinates are the number of point clouds contained in the interval.

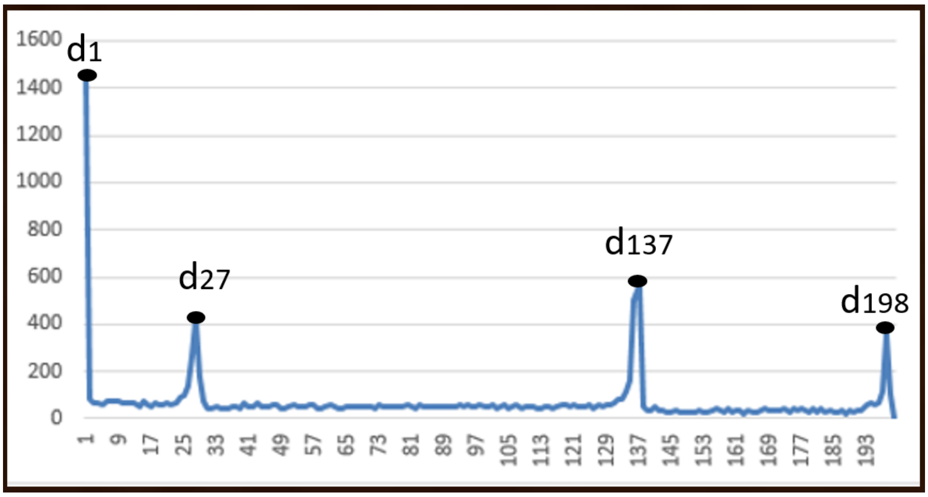

Fig 4 Correspondence table of the number of point clouds in different intervals.

In Fig 4, it can be seen that d1 has 1460 points, which is the highest number of all the parts surveyed, thus indicating that d1 is the plane (Ax + By + Cz + D = 0), while Fig 5 shows that d1, d27, d137, and d198 correspond to the four planes of the nut.

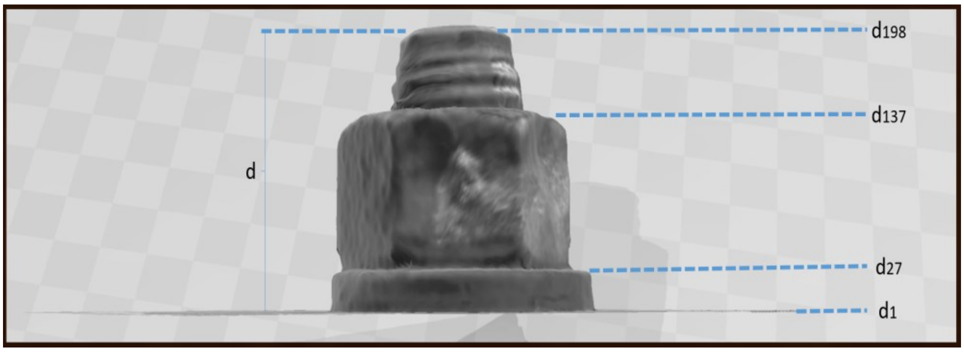

Fig 5 Side view of the nut

Next, we calculate the parameters of plane d137, which is hexagonal in shape, as shown in Fig 6. Since the Xmax, Xmin, Ymax, and Ymin points can be found in Fig 7, we need just two more vertices to obtain them all.

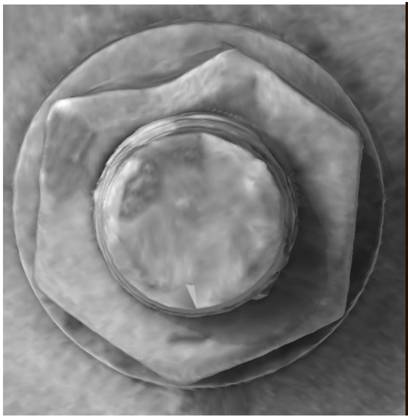

Fig 6: Top view of the nut

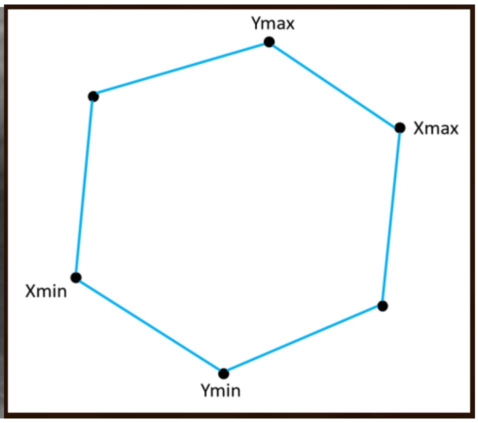

Fig 7: Four poles on the hexagonal plane

The other two vertices may exist at four different positions, as shown in Fig 8. We calculate the number of point clouds in intervals designated as 0, 1, 2, and 3. The two intervals with the highest number of point clouds are where the remaining vertices are located. Next, we find the point in this interval that is farthest from the line where the pole is located, from which we obtain the two points Pa and Pb. As a result, we now have six vertices and can calculate the hexagon parameters.

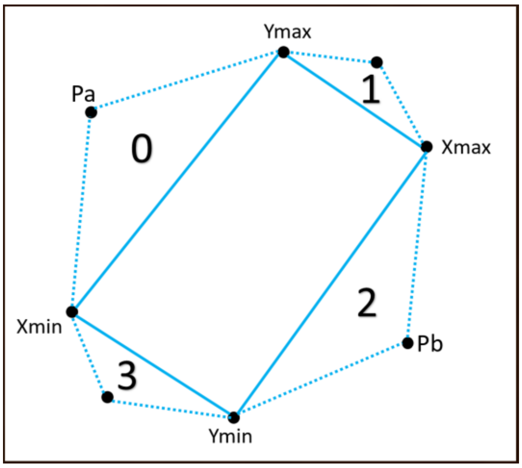

Fig 8 Four positions of two vertices

Study results. We developed an application to automatically calculate nut data parameters and tested it using the 3D model Ply_1. Figs 9 to 10 and table 1 show the results.

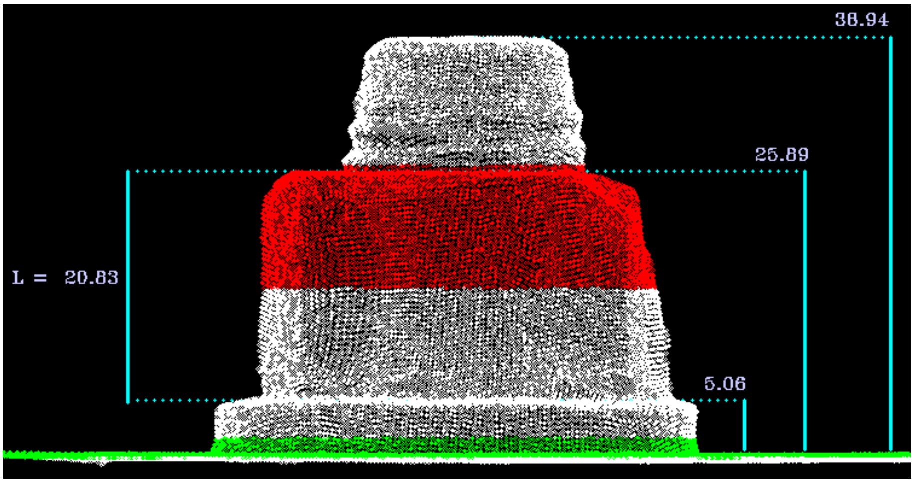

Fig 9 Nut height parameters

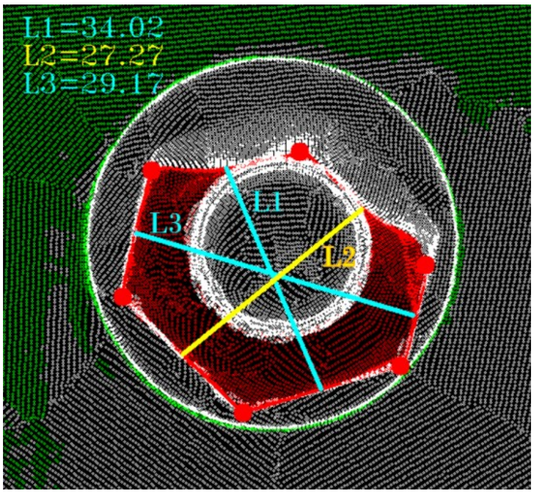

Fig 10 Nut hexagonal parameters

Table 1. Hexagonal parameter calculation results

Height of nut thinning	20.830475
L1	34.022653
L2	27.271394
L3	29.174537
Shortest line segment (yellow part)	L2 = 27.271394

In order to judge the accuracy of our algorithm, we tested the cross-sectional shortest distance parameters of five sets of data using the present method and the inch method, showed in Table 2. By comparison, the accuracy of the present method was proved to be high.

Table 2. Comparison table showing the true parameters of five nuts.

Data name	Shortest line segment by software	True value
Ply_1	27.27 mm	27.3 mm
Ply_2	33.54 mm	33.5 mm
Ply_3	33.83 mm	33.9 mm
Ply_4	31.14 mm	31.2 mm
Ply_5	33.79 mm	33.9 mm

3 Conclusion and future work

In this study, we showed how we could collect the 3D point cloud data of nuts installed on bridges, and reported on the development of a program to automatically calculate nut parameters. Then, using the 3D space conversion principle, we showed how we could obtain the equation of the lower plane of the nut, calculate the nut height by adjusting the value of d in the equation, and then obtain the hexagonal cross-section of the nut. These data allow us to find the point cloud coordinates of the six hexagon vertices using the polar method and calculate the minimum width value of the hexagonal cross-section.

The minimum width indicates the area worn out by external environment weathering and corrosion effects over the years. We then set a threshold value and determine if the minimum width of any nut is below this threshold. If so, that nut needs to be replaced. The program currently under study is only the first stage. Our ultimate goal is to create a program that can successively examine multiple nuts in succession, analyze the nut defects, and mark the nuts that need to be replaced. The final form of the program may be reduced to a cellphone application with which the inspector simply opens the phone camera, quickly scans the nut, obtains a 3D model, and calculates the nut parameters.

The 3DSL-Rhino-01 laser imager we use is only suitable for close range inspection, which is not really applicable to nuts on bridges with complex environment. In the future, we can use cell phone to control the aerial imager to get data, synthesize 3D point cloud by SfM algorithm [6], and then combine with nut calculation program to mark the broken nuts.

References

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