Transactions of the Korean Nuclear Society Virtual Autumn Meeting
December 17-18

Extraction of an axis of a bent pipe from 3D scanned data

Junghyun Ryu[a], Sungmoon Joo[a], Jinbok Choi[a]
[a]*Korea Atomic Energy Research Institute*
jhryu80@kaeri.re.kr, *smjoo@kaeri.re.kr*, *jbchoi95@kaeri.re.kr*

1. Introduction

3D CAD model, which is based on the as-built dimensions, is essential to check the structural integrity of a manufactured component in advance although it is hard to get in the case of the complex geometry. 3D scanning is an effective dimensional inspection scheme for the complex geometry cases, however, additional reverse-engineering is required in general because the basic result of the 3D scanning is point cloud on the surface. In this study, the 3D CAD model which is based on 3D scanned data for a pipe with three-dimensional curvature, which is the part of the cold neutron source in-pool assembly, is constructed by extracting the pipe axis. If the point cloud data includes only surface points, geodesic algorithm[1] could be a solution to extract the pipe axis. However, in this study, the pipe axis could be extracted by minimizing the root mean square of the inner product between the pipe axis and the normal vectors on 3D scanned data effectively because not only surface points but also normal vectors on the surface points are available.

2. Method and Results

The target shape of this study is a bent pipe with 3D curvature and scanned points data is illustrated in Figure 1.

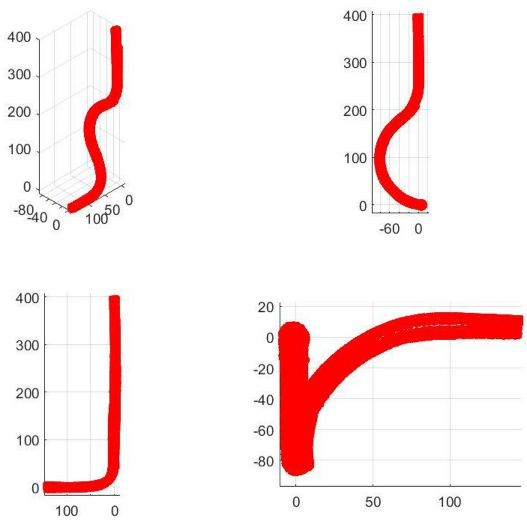

Figure 1. Scanned points data of the bent pipe

Thus, reverse engineering could be categorized into the following three steps.

1. Extracting the points of the axis
2. Reconstructing the axis using the spline with the above points.
3. Reconstructing the 3D model using the sweep method with the known cross-section information and reconstructed axis spline line.

In general, Step 1 is usually not supported command of the 3D scanning software whereas Step 2 and Step 3 can be easily done in the typical commands, spline and sweep, of the typical CAD software. Thus, the more detailed explanation needs for the step. It should be noted that 3D scanned data used in this study includes not only the coordinate of the surface points but also the normal vectors at each point.

The average coordinate of points in the region of interest (ROI) could be regarded as a point of axis because points in the ROI are surface points of a short straight pipe if the length of the) is short enough although it is a part of a bent pipe. Then, the other points on the axis can be calculated by changing repetitively the relative position between scanned points and the ROI along the axis direction.

It should be noted that in the case of the straight pipe, the vector for the axis direction is orthogonal to the normal vectors on the pipe surface. Thus, the vector for the axis direction can be approximated by minimizing the square sum of the residuals, inner product between the vector for the axis direction, and each normal vector in ROI. Thus, the objective function for the minimization is described in equation (1)

$$f = v_k^T N_{km}^T N_{mn} v_n + \lambda \left(v_n^T v_n - 1 \right) \tag{1}$$

where N_{ij} is a group of normal vectors: index i indicates the index of the points and index j indicates the index of the coordinates. v_i is components of the v, vector for the axis direction.

It should be noted that Lagrange multiplier [2], λ, is introduced to satisfy the constraint because the vector for the axis direction should be normalized.

The objective function is minimized by using the Newton-Raphson method. The 1st and 2nd derivatives of the objective function for Newton-Raphson method the are summarized in the equation (2) and (3)

$$\begin{aligned} \frac{\partial f}{\partial v_i} &= 2N_{im}^T N_{mn} v_n + 2\lambda v_i = 0 \\ \frac{\partial^2 f}{\partial \lambda^2} &= v_n^T v_n - 1 = 0 \end{aligned} \tag{2}$$

$$\begin{aligned} &\frac{\partial^2 f}{\partial v_i \partial v_j} = 2N_{im}^T N_{mj} + 2\lambda\delta_{ij} \\ &\frac{\partial^2 f}{\partial v_i \partial \lambda} = 2v_i \\ &\frac{\partial^2 f}{\partial \lambda \partial v_j} = 2v_j \\ &\frac{\partial^2 f}{\partial \lambda^2} = 0 \end{aligned} \tag{3}$$

After calculating the vector for the axis direction, the relative position between ROI and scanned points can be updated in a systematic manner. The examples for the transition state are described in Figure 2. ROI is illustrated in a rectangular parallelepiped in each step. It should be noted that the width and depth of the ROI wider than that of the pipe diameter to absorb the uncertainty whereas the height of the ROI is small to minimize the effect of the curvature.

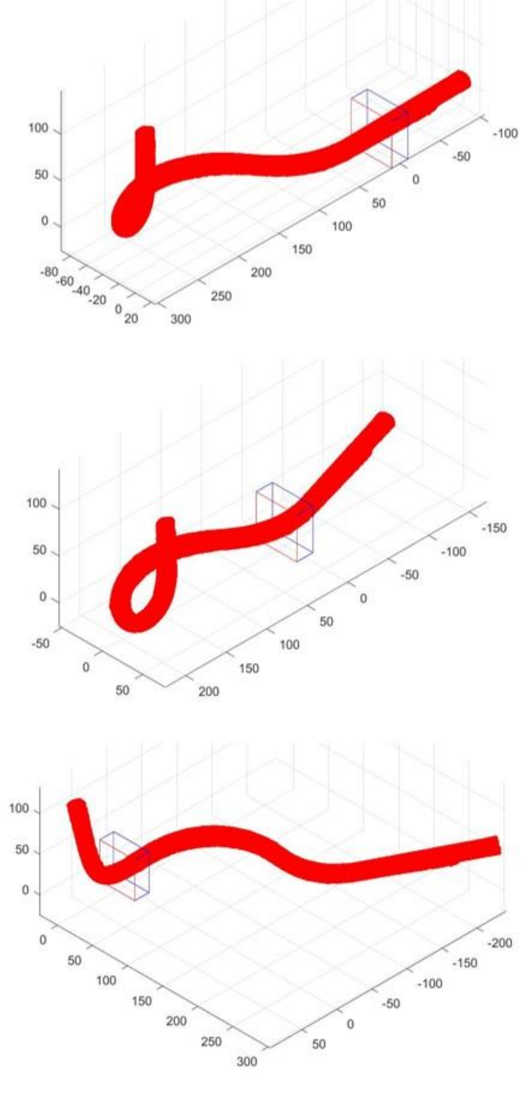

Figure 2. Updating procedure of ROI

The result of the repetition to find the points in the pipe axis is illustrated in Figure 3. It clearly shows that axis of the centerline is extracted successfully.

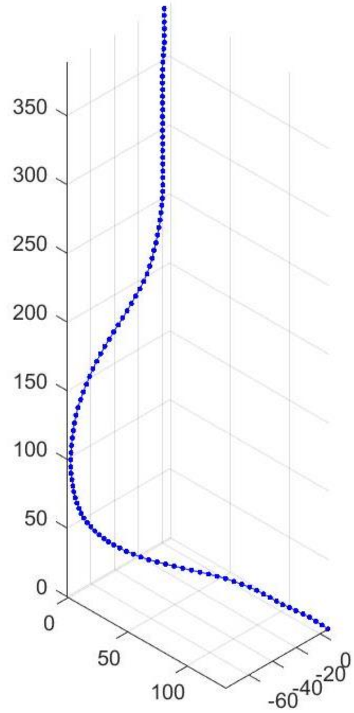

Figure 3. Center line of the bent pipe

3. Conclusions

Points on the pipe axis are successfully extracted from the scanned data. Short height of ROI is adopted to minimize the effect of the curvature and the relative position between ROI and scanned data is updated systematically using the information for the axis direction. The axis directions are calculated by minimizing the square sum of the inner product between the vector for the axis direction and normal vectors on the scanned points.

ACKNOWLEDGMENT

The authors acknowledge the financial support provided by the Ministry of Science and ICT of Korea.

REFERENCES

[1] Anne Verroust, Extracting Skeletal Curves from 3D Scattered Data, The Visual Computer Vol.16. pp. 15-25.

[2] Stephen Boyd, Lieven Vandenberghe, Convex Optimization, Cambridge University Press, Cambridge, pp.215, 2004.