Title:
Identification of the Number of Overlapping Welded Thin Plates in an X-ray CT Volume

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Introduction:

Background

Reverse engineering is accelerated by digitizing the surface and internal shapes of parts. Optical 3-D scanners are often used nowadays for this purpose [4]. Optical scanners cannot inspect the internal shape of assembled parts; thus, users have to dismantle such parts. Applying an industrial X-ray CT in such cases would be useful because it facilitates non destructive, time-efficient digitization of assembled parts.

Problems and Goals

A 3-D X-ray CT volume represents the distribution of the attenuation coefficient in 3-D space. Because vehicle chassis almost always consists of single material, welded metal parts are contiguous on CT volume; simple thresholding is not sufficient to segment parts. A previous research has proposed extending regions on the basis of medial surfaces [3], which can handle two overlapping thin plates. We aim to provide information on the number of thin plates, even more than three, particularly in the near field of welding spots. Figure 1 shows overlapping thin plates and the result of our computation, visualized by coloring it.

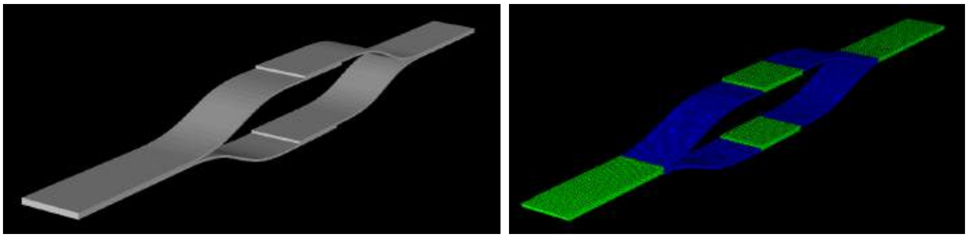

Fig. 1: A simple example of overlapping plates and the processing result.

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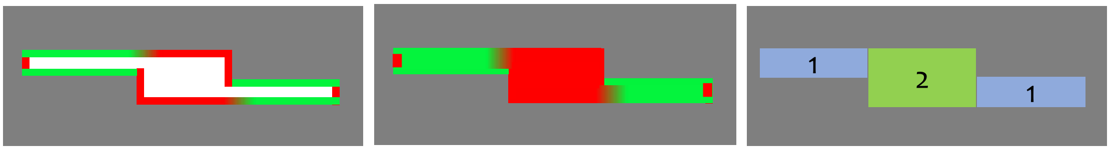
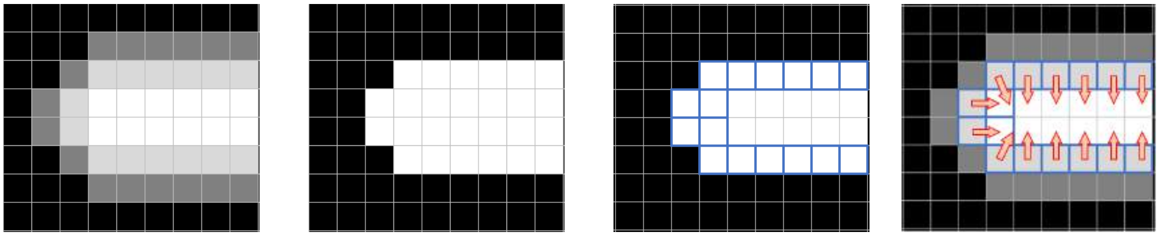


(a) Surface voxels have a thickness value (b) Foreground voxels have a thickness value (c) Regions labeled by the number of thin plates

Fig. 2: Simplified illustration of the computed results.



(a) CT volume (b) Binarized by thresholding (c) Defined surface voxels (d) Gradient vectors

Fig. 3: Steps to calculate the gradient vectors on the CT volume.

Algorithm:
Our algorithm considers and provides the following inputs/outputs.
Inputs:

- A 3-D X-ray CT volume containing the vehicle chassis
- A threshold value between the material and the air
- The thickness of the metal plates in the pressed part

Outputs:

- A 3-D point set with the thickness values.
- A 3-D point set with the number-of-plate labels.

Our algorithm can be briefly explained as follows. A simplified expression of a volume is shown in Figure 2.

1. The surface voxels on the CT volume are defined.
2. The thickness of the part on each surface voxel is calculated (Figure 2a).
3. The thickness values are propagated into the inner voxels (Figure 2b).
4. The number of plates on each foreground voxel are determined according to the thickness value (Figure 2c).

Definition of Surface Voxels
A CT volume (Figure 3a), is binarized by a threshold(Figure 3b). Voxels with a value above the threshold are marked as foreground voxels. After that, we define the surface voxels by the following condition: foreground voxels that have at least one background voxel among their 26 neighboring voxels. Other

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foreground voxels, other than surface voxels, are marked as inner voxels. In Figure 3c, surface voxels are marked with a blue border.

Measurement of Distance
After defining the surface voxels, for each surface voxel p_1, we search for another surface voxel p_2 in the direction of the gradient $G = \nabla I$, where I represents the intensity value of the CT volume. These vectors are shown as brown arrows in Figure 4. The distance between these two voxels represents the approximate (voxel-level) thickness of the chassis.

To achieve sub-voxel-level measurement, the approximate thickness refined by finding maxima and minima of differentiation of the intensity value on the line L(shown in Figure 4).

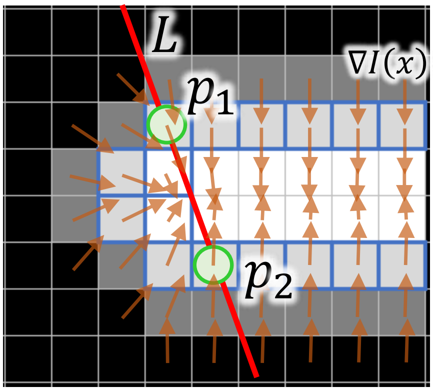


Fig. 4: Definition of the penetration L based on the voxels p_1 and p_2.

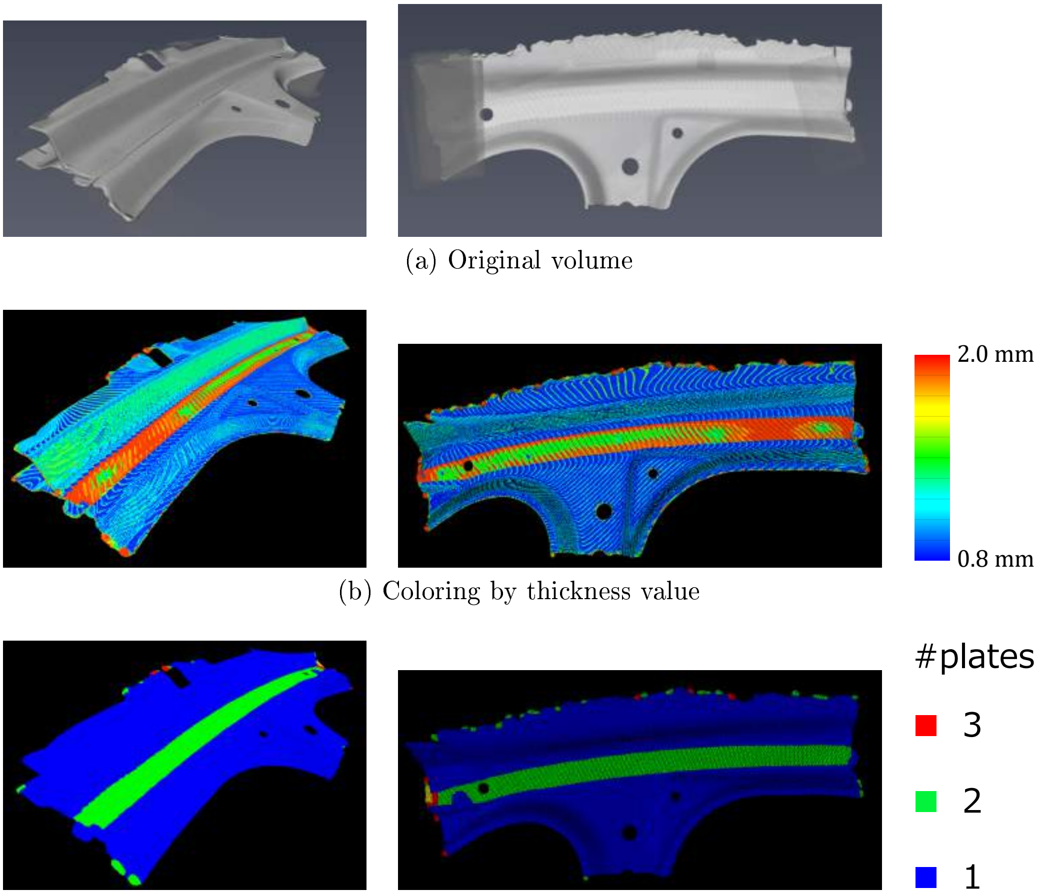
Propagating Values into Inner Voxels
It is preferred that all *foreground* voxels have some value in the segmentation of the volume. We want the inner voxels to have a value close to the nearest *surface* voxel. To satisfy this, existing voxels' thickness values are propagated among their neighboring voxels repeatedly.

Determining the Number of Plates
Let us consider a method to label the foreground voxels with the number of thin plates. We adopted the multi label graph cut algorithm, which can segment a graph into partial graphs with some labels [2].

The graph cut algorithm yields an optimized segmentation that minimizes an energy function E, which is configured with the data cost function D and the smooth cost coefficient λ. By setting up the cost function D as the "l-plateness" and optimizing the segmentation, we get the estimated number of thin plates on each foreground voxel.

Experiments and Results:
Sample A(Figure 5a) is part of a vehicle chassis. It includes several welding spots and an overlapping area of two plates at its center. The approximate thickness of a single thin plate is 1.0 mm. The calculation took approximately 2 min.

Sample B(Figure 6a) is also part of a vehicle chassis. It contains more complicated welding shapes and overlapping areas with three plates. The approximate thickness of a single thin plate is 1.5 mm. The calculation took approximately 20 min.



(a) Original volume

(b) Coloring by thickness value

(c) Coloring by segmented label

Fig. 5: Results for Sample A.

The results for sample A are shown in Figure 5. The overlapping area at the center of the images is properly colored as a two-plate region. The other areas without welding are colored as single-plate regions.

The results for sample B are shown in Figure 6. The welded region with three thin plates on the upper half of the left column is properly colored red. Areas with two plates are colored green.

Conclusions:

We succeeded in calculating the thickness of two 3-D CT volumes and segmented them into regions labeled by the number of thin plates. This type of imaging can lead to a more detailed analysis of the assembled vehicle parts.

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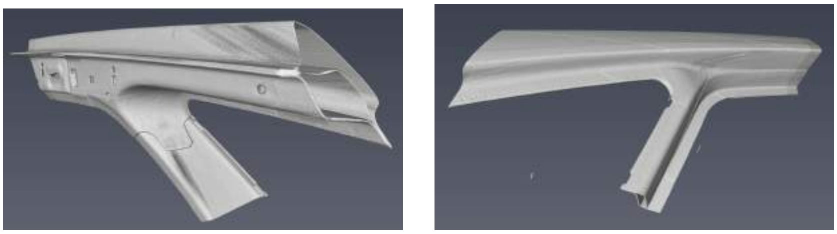
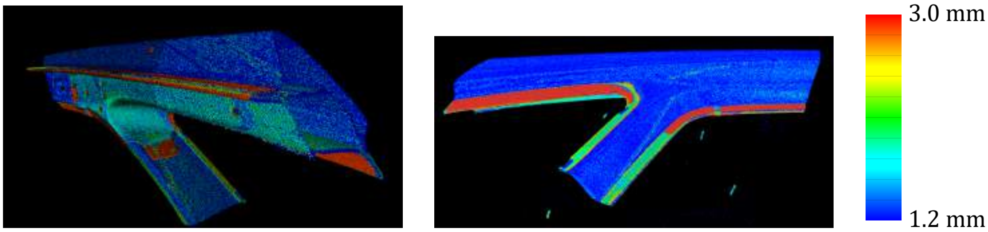
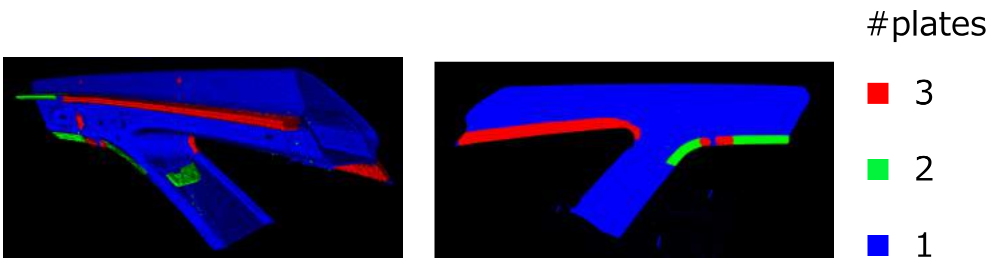


(a) Original volume



(b) Coloring by thickness value



(c) Coloring by segmented label

Fig. 6: Results for Sample B.

References:

[1] Boykov, Y.; Kolmogorov, V: An Experimental Comparison of Min-Cut/Max-Flow Algorithms for Energy Minimization in Vision, IEEE Transactions on Pattern Analysis and Machine Intelligence, 26(9), 2004, 1124–1137. https://doi.org/10.1109/TPAMI.2004.60

[2] Delong, A.; Osokin, A.; Isack, H.N.; Boykov, Y.: Fast approximate energy minimization with label costs. International Journal of Computer Vision, 96(1), 1–27, 2012. ISSN 1573–1405. http://doi.org/10.1007/s11263-011-0437-z

[3] Fujimori, T.; Kobayashi, Y.; Suzuki, H.: Separated medial surface extraction from ct data of machine parts. In M.S. Kim; K. Shimada, eds., Geometric Modeling and Processing - GMP 2006, 313–324. Springer Berlin Heidelberg, Berlin, Heidelberg, 2006.

[4] Sansoni, G.; Docchio, F.: In-field performance of an optical digitizer for the reverse engineering of free-form surfaces, The International Journal of Advanced Manufacturing Technology, 26(11), 2005, 1353–1361. https://doi.org/10.1007/s00170-004-2122-7