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Paper:

Machine Tool Assignment Realized by Automated NC Program Generation and Machining Time Prediction

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The present study proposed a method to automatically generate a numerical control (NC) program by referring to machining case data for each machine tool with only 3D-CAD models of a product and workpiece as the input data, and to select machine tools for machining the target removal region among several machine tools with different characteristics. The special features of the proposed method are described as follows. The removal volume can be automatically obtained from the total removal volume (TRV), which is extracted from the workpiece and product using a Boolean operation by dividing it on the XY plane. The removal region changed according to the determined machining sequence. The conditions for machining the removal region is automatically determined according to the machining case data, which is stored by linking the geometric properties of the removal region with the machining conditions determined by experienced operators. Furthermore, an NC program is automatically generated based on the machining conditions. The machine tools for machining the target region are selected according to the predicted machining time of each machine tool connected by a network. A case study was conducted to validate the effectiveness of the proposed system. The results confirm that machining can be conducted using only 3D-CAD models as input data. It was suggested that the makespan would be shortened by changing the machining sequence from the optimized machining sequence when machining a plurality of products.

Keywords: machine tool assignment, automated NC program generation, machining time prediction, CAD-CAM, autonomous manufacturing system

1. Introduction

Numerical control (NC) machine tools are widely used in industrial production. In particular, end milling is used in many factories because it is indispensable for machining complex parts. Because NC programming is essential for machining by NC machine tools, computer-aided design software (CAD) and computer-aided manufacturing software (CAM), which support the preparation of an NC program, have been rapidly developed. However, existing software cannot completely realize the automated generation of an NC program because operators have to manually determine the machining region, sequence, and conditions, and input them in the software. It is necessary for the autonomous manufacturing to automate these manual tasks. Previous studies have proposed computer-aided process planning systems, many of which are methods for recognizing machining features [1] that characterize the machining process. Two methods have been proposed for machining feature recognition: recognizing the target shape [2–6] and recognizing the removal volume [7–18]. However, a practical system has not been constructed, and thus fully automated manufacturing has yet to be realized. Since machining also depends on experienced operators, it is often a one-to-one relationship between a product and a machine. Therefore, it cannot be said that a flexible manufacturing system is realized.

In previous studies, the machine to be used for machining is selected before conducting process planning. In the present study, a method is proposed for selecting the machine to be used for machining among multiple machines according to the evaluation function (e.g., makespan). Furthermore, a system is developed to autonomously select the machine for machining from multiple machines connected via a network, and start machining using only a 3D-CAD model as input information.

This paper is organized as follows. The method to automatically extract the removal volumes from 3D-CAD models is described in Section 2. A flexible machining sequence can be selected by changing the shape of the removal volume depending on the machining sequence. In Section 3, the method to automatically generate an NC program by referring to machining case data is described. The specific machining conditions are automatically determined to generate the NC program by referring to different machining case databases stored in each machine. In Section 4, the method that predicts the machining time of all the machines connected to the network, and assigns work to the machine with the shortest machining time is described. Finally, case studies are conducted and the proposed system is validated in Section 5.

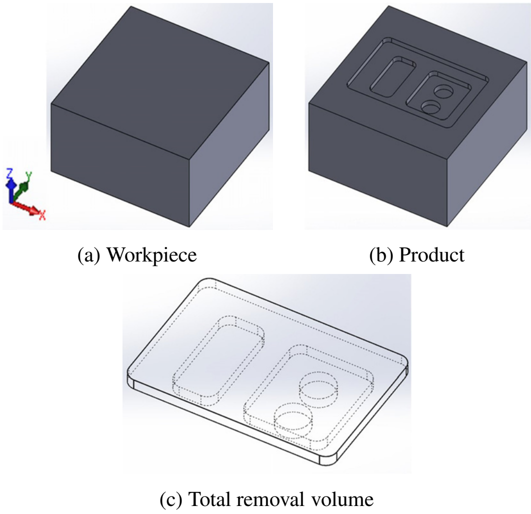


Fig. 1. Example of total removal volume extracted from workpiece and product shapes by Boolean operation.

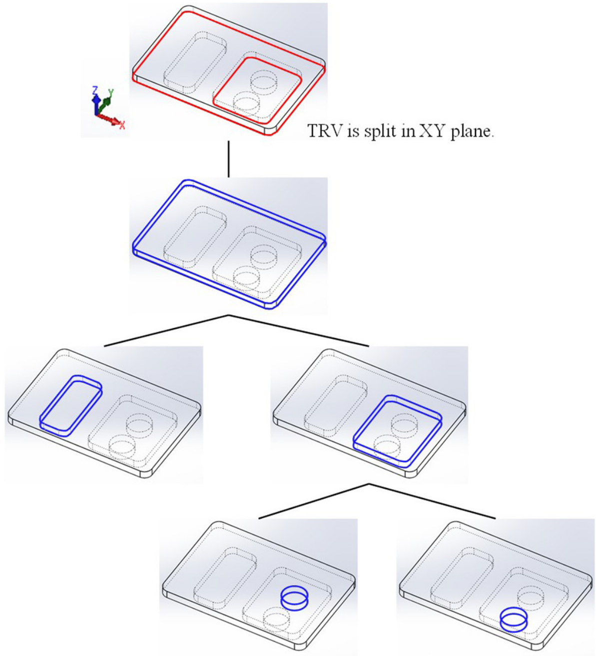


Fig. 2. Split removal volumes extracted by splitting the extracted total removal volume on the plane and association chart according to tool approach.

2. Extraction of Removal Volume and Expanded Removal Volume According to Machining Sequence

In this section, the method to automatically extract the removal volume from 3D-CAD models of a product and workpiece is described. The method to expand the removal volume according to the machining sequence by relaxing the constraint conditions is also described.

2.1. Machining Removal Volume and Geometric Constraints

Our previous study proposed a method for extracting the total removal volume (TRV) from the workpiece and product using a Boolean operation, and the split removal volume (SRV) was obtained by dividing the TRV into regions suitable for actual machining [16].

The reason for using the TRV is that the features of the machining removal volume are not always the same because the removal volume varies with the shape of the workpiece, even if the product shape is the same. Another reason for using the TRV is that common machining conditions can be used when the geometric features of the shape are similar, even if the product shape is completely different. For example, **Fig. 1** shows the TRV extracted from the workpiece model and product model by a Boolean operation.

When the shape of the product model is complex, it is difficult to analyze the extracted TRV because the shape of the TRV is also complex. In this case, the SRV obtained by dividing the TRV on the XY plane is extracted. The reason for dividing on the XY plane is that machining is generally performed from the region located in the Z-axis positive direction under the geometric constraint conditions for tool approach when the tool approach direction is the Z-axis positive direction. The reason for this is that the divided shape is simple, such as a cylinder or prism, even if the TRV is complex as shown in **Fig. 2**.

Some previous studies have proposed a method to determine the machining sequence for the extracted removal volume [19]. Our previous study also proposed a method to determine the machining sequence by considering the geometric constraints of the extracted SRVs [18]. In machining, since the tool can approach only the surface where the workpiece is in contact with the atmosphere, geometric constraints exist for the machining sequence of the SRV. Our previous study proposed a method for calculating the association chart, in which the geometric constraints are expressed in a hierarchical structure. The association chart, shown in **Fig. 2**, can be obtained by considering the geometric constraints (i.e., whether the tool can approach the SRV) [18]. The machining sequence can be limited from enormous candidate machining sequences according to the association chart. For example, when the association chart can be obtained as shown in **Fig. 2**, it is possible to limit the machining sequence from 120 (5!) to 8 ($1 \times {}_4C_1 \times 2!$).

2.2. Expansion of Removal Volume to Allow Flexible Machining Sequence

In previous studies, it was assumed that there is no case of machining the same overlapping region because the extracted SRV was obtained by dividing the TRV on the XY plane. For example, as shown in **Fig. 3**, when the extracted TRV is divided on the XY plane, the closed pocket and blind hole are extracted as SRV. Then, the machining sequence, in which the closed pocket is machined first and the blind hole is machined later, can be obtained ac-

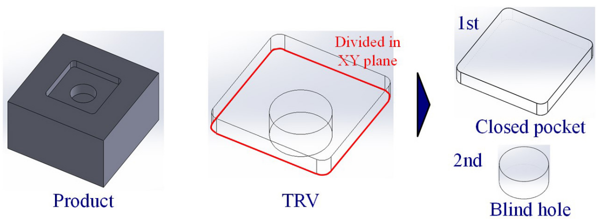


Fig. 3. Example of machining sequence according to the geometric constraints of SRV.

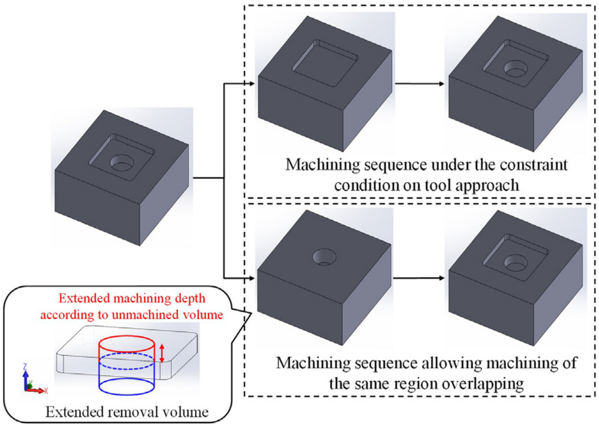


Fig. 4. Machining sequence for flexibility and expanded removal volume according to machining sequence.

cording to the association chart. However, when the same overlapping region is machined (allowing inefficient machining), the machining sequence, in which the blind hole is machined first and the closed pocket is machined later, can be used.

Actually, when machining with one multitasking machine tool, the machining efficiency decreases with the machining sequence, which allows machining of the same overlapping region. However, when machining multiple products with a single-task machine tool (e.g., milling or drilling), there is a possibility that the makespan will be shortened if the machining sequence can be flexibly changed despite the inefficient machining sequence. Therefore, the present study proposes a method to extract the SRV, which changes according to the machining sequence by allowing the machining of the same overlapping region.

For example, in **Fig. 3** which shows the SRVs extracted by dividing the TRV on the XY plane, the blind hole away from the tool-approach surface of the workpiece can be machined first. But the machining depth of the blind hole becomes longer. Therefore, when the surface in the tool-approach direction of the target SRV is not in contact with the workpiece, the depth of the SRV is expanded to the surface of the workpiece, as shown in **Fig. 4**. When the SRV existing in the upper hierarchy relative to the target SRV is not machined, the depth of the target SRV is automatically updated by adding the depth of the un-machined SRV.

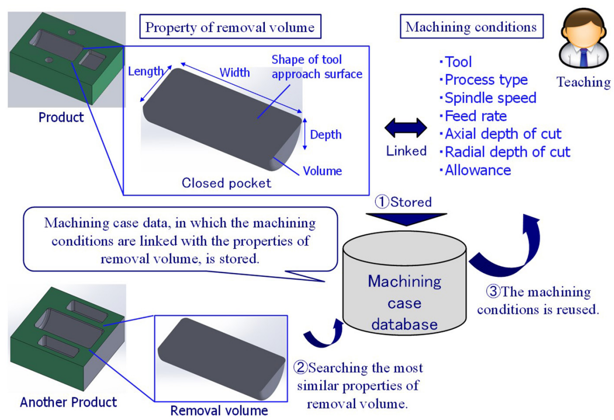


Fig. 5. Automated determination of machining conditions by reusing machining case data based on geometric properties of removal volume.

The processes of extracting the TRV from a product model and workpiece model, obtaining the SRV by dividing the TRV on the XY plane, and updating the SRV according to the machining sequence were realized using SolidWorks 2018 (via an Application Programming Interface: API).

3. Automated NC Program Generation Referring to Machining Case Data

3.1. Determination of Machining Conditions Referring to Machining Case Data

An NC program can be geometrically generated by calculating the tool path when machining conditions such as tool type, axial depth of cut, or radial depth of cut for each extracted SRV are determined. However, the machining conditions need to be carefully determined by considering the workpiece material and the shape of the product. Therefore, the determination of machining conditions requires the knowledge of an experienced operator. An autonomous manufacturing system cannot be realized if the experienced operator always determines the machining conditions for each product. Therefore, it is necessary to automate the determination of machining conditions. Our previous study proposed a method to automatically determine the machining conditions according to machining case data, as shown in **Fig. 5** [20]. Initially, the experienced operator interactively inputs the machining conditions into the SRV. Then, the SRV properties and machining conditions are linked and stored as machining case data (**Fig. 5**①). When machining a different product model, the SRV is extracted by the method described in the previous section. Then, it is possible to search the machining case data, i.e., the properties of the region most similar to that of the target SRV, because the shape of the extracted SRV is simple, such as a cylinder or prism (**Fig. 5**②). The machining conditions for the target SRV can be automatically determined by reusing the ma-

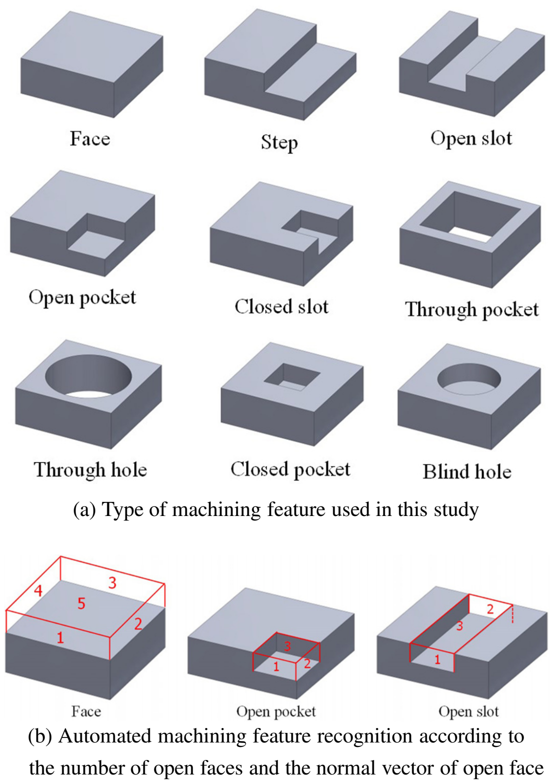


Fig. 6. The types of machining features that appear after removing the SRV from the workpiece.

chining conditions linked to the searched machining case data (**Fig. 5**③).

The properties of the SRV are the following.

1. Material of workpiece
2. Shape of tool approach surface
3. Aspect ratio and scale of tool approach surface
4. Machining depth
5. Volume
6. Type of machining feature

For item 1, when the workpiece materials are different, the machining conditions are greatly different even if the geometric properties of the SRV are the same. Therefore, the workpiece material is set by the user at the time of analysis. For items 2–5 which show the geometric properties, their information can be obtained from the SRV extracted by the method described in the previous section. **Fig. 6** shows the types of machining features that appear after removing the SRV from the workpiece. The type of machining feature can be calculated from the geometrical relationship between the processing workpiece and target SRV. The type of machining feature can be automatically calculated from the number of open faces, i.e., the surface in contact with the atmosphere and the shape of the tool-approach surface [17]. For example, in the case of face, it is possible to determine them according to the fact that the

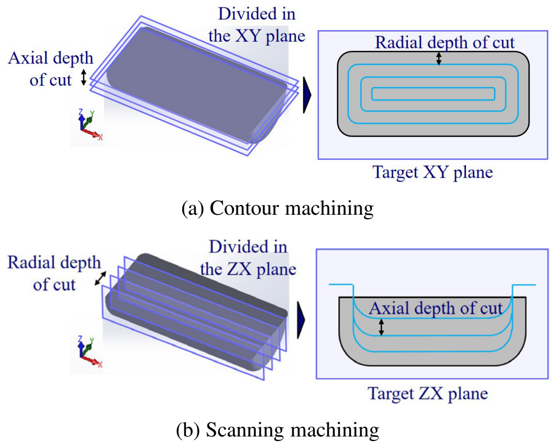


Fig. 7. Tool path geometrically calculated by the ridgeline of the split removal volume and automatically determined machining conditions.

number of open faces is five for the SRV and the workpiece before machining the SRV, as shown in **Fig. 6(b)**. When the number of open faces is same such as the Open pocket and Open slot shown in **Fig. 6(b)**, the machining feature is recognized from the normal vector of the open face. In the present study, the workpiece shape is assumed to be rectangular. Therefore, the extracted SRV is always considered to correspond to one of the machining features shown in **Fig. 6(a)**.

When there are several machine tools available for use, it is possible to automatically determine the machining conditions suitable for machining the target SRV on each machine by preparing a machining case database for each machine in advance.

3.2. NC Program Generation

Tool paths can be geometrically calculated when the machining conditions of the target SRV are determined. Here, the tool path was calculated by the originally developed program. Two types of machining patterns were realized: contour machining and scanning machining, as shown in **Fig. 7**. In contour machining, the tool path was calculated from the ridgeline obtained by dividing the target SRV on the *XY* plane. In scanning machining, the tool path was calculated from the ridgeline obtained by dividing the target SRV on the *ZX* plane. After the tool path is calculated, the NC program can be generated according to the feed rate of the machining conditions.

4. Machine Tool Assignment

Using the proposed system described above, the SRV can be automatically extracted from only 3D-CAD models of a product and workpiece, and the NC program can be automatically generated by referring to machining case data. The study also proposes a new method of allocating machine tools for machining the target SRV when machine tools with different characteristics are to

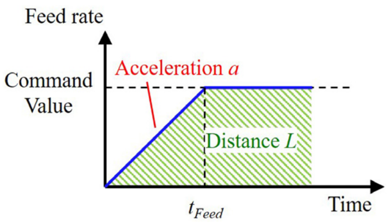


Fig. 8. Relationship between feed rate, acceleration, and distance of tool feed.

be used. Generally, different machining conditions suitable for each machine exist even when machining the same SRV. Then, the NC program is automatically generated for each machine tool using the machining case data stored for each machine tool. The generated NC program is different for each machine tool because the machining conditions determined for each machine tool are different even when the same product is machined. The present study selected machine tools for machining the target SRV by evaluating the machining time predicted by the NC program for each machine tool.

4.1. Machining Time Prediction

Machining time can be predicted by the generated NC program. It can be calculated by dividing the sum of the distances of the position command by the tool feed rate. However, when the tool feed direction changes finely, the actual tool feed speed depends on the acceleration of the tool feed axis. It takes time for the tool feed speed to reach the set value, as shown in **Fig. 8**. Therefore, the machining time predicted by simply dividing the distance by the tool feed rate differs from the actual time. The present study considered the acceleration of the tool feed axis and calculated the machining time. The tool travel time t can be calculated as following equation, where a is the acceleration of the tool feed axis, t_{Feed} is the time to reach the set tool feed speed, and L is the target distance.

$$t = \sqrt{\frac{2L}{a}} \quad (t \le t_{Feed}), \quad \dots \dots \dots \dots (1)$$

$$t = t_{Feed} + \frac{L - 0.5at_{Feed}^2}{at_{Feed}} \quad (t > t_{Feed}). \quad \dots (2)$$

4.2. Machine Tool Assignment for Machining from the Multiple Machine Tools Connected by Network

The machine tools to be used are connected by a network as shown in **Fig. 9**. A server manages product information, and transmits the information of the target SRV to each machine tool (client). Then, each machine tool automatically generates an NC program according to each machining case data, and the machining time is predicted. The machine tool for machining the target SRV is determined according to the machining time predicted for each machine tool. Naturally, it is technically possible to perform all the calculations on one computer without a server and client. However, in the proposed method, the prediction of the machining time requires the machining case data stored in each machine. This machining case data is highly confidential because it is the machining knowledge accumulated in the factory. Therefore, information-sharing will be difficult because the machining knowledge could be leaked. For practical reasons, the automated generation of an NC program and prediction of machining time are performed on the client side in order to exchange only a minimal amount information between related companies.

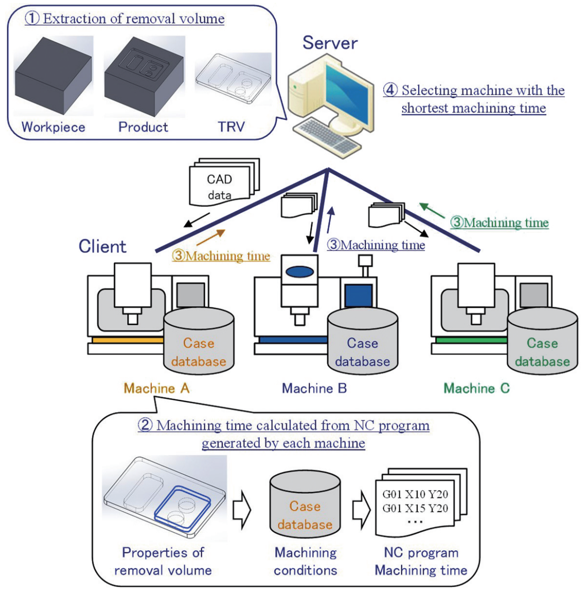


Fig. 9. Machining assignment of some machines connected by network.

First, the server calculates the extraction of the SRV from the 3D-CAD model of a product and workpiece, as described in Section 2 (**Fig. 9**①). After extracting the SRV, the server transmits the information of the 3D-CAD model of the product, workpiece, and extracted SRV to all clients. Each client calculates the geometric properties of each SRV and searches for the most similar machining case data in its database. Then, the NC program is generated using the machining conditions linked to the searched machining case data, and the machining time is predicted as described in Section 3 (**Fig. 9**②). Afterward, the client transmits the predicted machining time to the server (**Fig. 9**③). In the present study, communications between the server and client is conducted by TCP/IP protocol and the 3D-CAD data is transmitted in binary format. The server waits until it receives the results of the predicted machining time from all clients. After receiving all the results, the server assigns the machine tool with the shortest machining time to machine the target SRV (**Fig. 9**④). Although the evaluation function is the machining time in this study, it can be changed to machining cost, etc. The present study developed the system to realize the process described above using Visual Studio 2017 (C#).

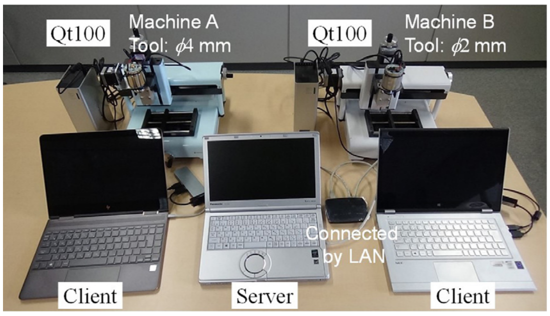


Fig. 10. Overview of the constructed system.

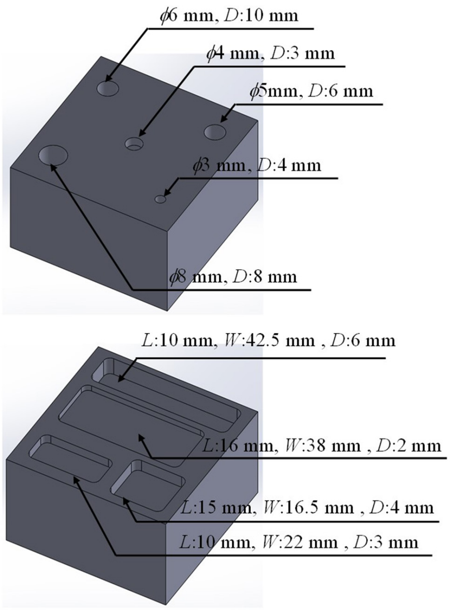


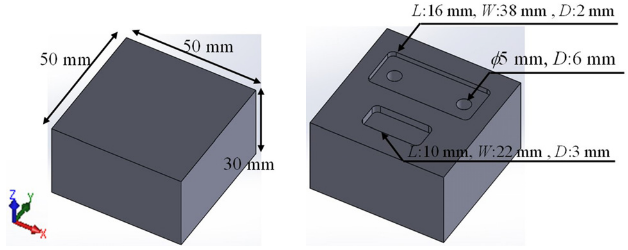
Fig. 11. Product model for machining case data.

5. Case Study

A case study was conducted to validate the effectiveness of the proposed system. The present study used two desktop NC machine tools (ORIGINALMIND INC., Qt100 (CNC: Eding CNC V4.02)) and constructed an environment in which the PCs attached to each machine were connected by a network, as shown in **Fig. 10**.

The first machine A is attached to a square end mill with diameter of 4 mm and spindle speed of 4800 rpm. The second machine B is attached to a square end mill with diameter of 2 mm and spindle speed of 7000 rpm. Each machine tool machined the product model as shown in **Fig. 11** beforehand, and the used machining conditions were stored as the machining case data.

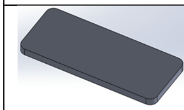
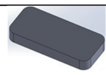
For this case study, the workpiece shown in **Fig. 12(a)** and product model shown in **Fig. 12(b)** were prepared. **Table 1** shows the extracted SRV from the workpiece and product. **Table 1** also lists the machining conditions determined according to the machining case data and the predicted machining time. According to the predicted machining time, machining for SRV1 and SRV2 was assigned to machine A because of the shorter machining



(a) Workpiece (b) Product

Fig. 12. 3D-CAD model for case study.

Table 1. Determined machining conditions and predicted machining time of each machine.

SRV	Machine A	Machine B
 SRV1	Ad: 1 mm Rd: 2 mm Fr: 600 mm/min Mt: 101 s	Ad: 1 mm Rd: 0.5 mm Fr: 600 mm/min Mt: 379 s
 SRV2	Ad: 1 mm Rd: 2 mm Fr: 600 mm/min Mt: 49 s	Ad: 1 mm Rd: 0.5 mm Fr: 600 mm/min Mt: 196 s
 SRV3	Ad: 0.4 mm Rd: 0.5 mm Fr: 600 mm/min Mt: 36 s	Ad: 1.5 mm Rd: 0.5 mm Fr: 600 mm/min Mt: 25 s
 SRV4	Ad: 0.4 mm Rd: 0.5 mm Fr: 600 mm/min Mt: 36 s	Ad: 1.5 mm Rd: 0.5 mm Fr: 600 mm/min Mt: 25 s

Ad: Axial Depth of cut, Rd: Radial depth of cut
Fr: Feed rate, Mt: Machining time

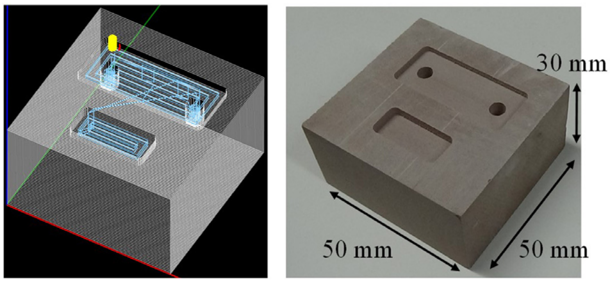
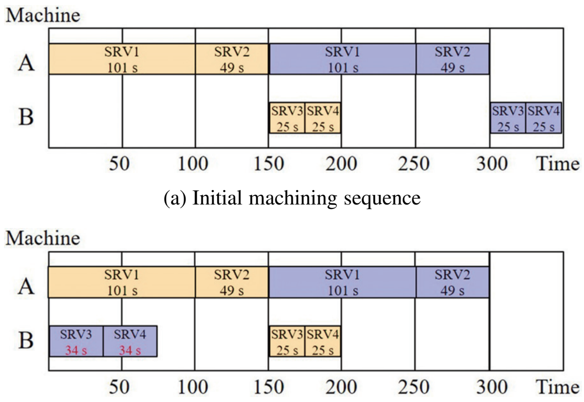


Fig. 13. Tool path used for machining and machined workpiece.

time, while machining for SRV3 and SRV4 was assigned to machine B; the setup time was not considered. The results of the automatically generated tool path and the finished workpiece after machining are shown in **Fig. 13**. The results of the case study show that machining can be conducted with the generated NC program without any problems.

Subsequently, the study discussed the machining of two pieces instead of just one product. For the machining sequence SRV1→SRV2→SRV3→SRV4, the machining time of one product was the shortest, and two products



(a) Initial machining sequence

(b) Modified machining sequence

Fig. 14. Gantt chart when some machines are used for machining.

were machined; the Gantt chart is shown in **Fig. 14(a)**. According to the Gantt chart, machine A performed the first process of the second product after completing the second process of the first product. The third process of the first product was machined by machine B, which was idle until that time. Then, the study considered whether the makespan would be shortened by allowing machining of the same overlapping region (allowing inefficient machining) as described in Section 2.

Figure 14(b) shows the Gantt chart, in which the machining sequence of the second product was SRV3→SRV4→SRV1→SRV2. **Fig. 14(b)** shows that the machining time for SRV3 and SRV4 of the second product was longer (25 s to 34 s) than that of the initial machining sequence because the machining region was larger. However, the makespan for the two products was shortened by 50 s. Thus, it is not always the best to machine all the products in the optimized machining sequence when machining one product. This study did not consider the setup time for installation and removal or the moving time between machines. This is the fundamental discussion that shows the possibility of improving manufacturing efficiency. Furthermore, calculation of the optimized machining sequence and scheduling when machining a plurality of products are beyond the scope of this study, and will be dealt with in a subsequent paper.

6. Conclusion

This study proposed a method to automatically generate NC programs by referring to the machining case data for each machine tool. Only the 3D-CAD models of the product and workpiece were used as the input data in order to select the machine tool for machining the target removal region among several machine tools with different characteristics. The present study constructed the system to realize the proposed method.

1. The SRV was obtained from the TRV, which was extracted from the workpiece and product using a Boolean operation, by dividing it on the *XY* plane. The extracted SRV was changed according to the determined machining sequence.

2. The machining conditions for the SRV was automatically determined according to the machining case data, which was stored by linking the geometric properties of the SRV with the machining conditions determined by experienced operators. Furthermore, an NC program was automatically generated by the extracted SRV and machining conditions.

3. The machine tool for machining the target SRV was selected according to the predicted machining time for each machine tool connected to a network.

A case study was conducted to validate the effectiveness of the proposed system. The results confirmed that machining can be conducted using only 3D-CAD models as input data. It was suggested that the makespan would be shortened by changing the machining sequence from the optimized machining sequence when machining a plurality of products. Calculation of the optimized machining sequence and scheduling when machining a plurality of products will be examined in a subsequent paper.

Acknowledgements

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References:

[1] N. Sugimura, "Research trends in process planning," J. of the Japan Society for Precision Engineering, Vol.72, No.2, pp. 165-170, 2006 (in Japanese).

[2] D. Hamada, K. Nakamoto, T. Ishida, and Y. Takeuchi, "Development of CAPP system for multi-tasking machine tool," Trans. of the Japan Society of Mechanical Engineers, Series C, Vol.78, No.791, pp. 2698-2709, 2012 (in Japanese).

[3] L. Wang, M. Holm, and G. Adamson, "Embedding a process plan in function blocks for adaptive machining," CIRP Annals-Manufacturing Technology, Vol.59, Issue 1, pp. 433-436, 2010.

[4] Y. Woo, E. Wang, Y. S. Kim, and H. M. Rho, "A hybrid feature recognizer for machining process planning systems," CIRP Annals-Manufacturing Technology, Vol.54, Issue 1, pp. 397-400, 2005.

[5] M. El-Mehalawi and R.A. Miller, "A database system of mechanical components based on geometric and topological similarity. Part I: representation," Computer-Aided Design, Vol.35, No.1, pp. 83-94, 2003.

[6] M. El-Mehalawi and R. A. Miller, "A database system of mechanical components based on geometric and topological similarity. Part II: indexing, retrieval, matching and similarity assessment," Computer-Aided Design, Vol.35, No.1, pp. 95-105, 2003.

[7] K. Nakamoto, K. Shirase, H. Wakamatsu, A. Tsumaya, and E. Arai, "Automatic production planning system to achieve flexible direct machining," JSME Int. J. Series C, Vol.47, No.1, pp. 136-143, 2004.

[8] A. Ueno and K. Nakamoto, "Proposal of machining features for CAPP system for multi-tasking machine tools," Trans. of the JSME, Vol.81, No.825, p. 15-00108, doi: 10.1299/transjsme.15-00108, 2015 (in Japanese).

[9] E. Morinaga, M. Yamada, H. Wakamatsu, and E. Arai, "Flexible process planning method for milling," Int. J. Automation Technol., Vol.5, No.5, pp. 700-707, 2011.

[10] E. Morinaga, T. Hara, H. Joko, H. Wakamatsu, and E. Arai, "Improvement of computational efficiency in flexible computer-aided process planning," Int. J. Automation Technol., Vol.8, No.3, pp. 396-405, 2014.

[11] K. Dwijayanti and H. Aoyama, "Basic study on process planning for turning-milling center based on machining feature recognition," J. of Advanced Mechanical Design, Systems and Manufacturing, Vol.8, No.4, JAMDSM0058, 2014.

[12] H. Sakurai and P. Dave, "Volume decomposition and feature recognition, part I – polyhedral objects," Computer-Aided Design, Vol.27, Issue 11, pp. 793-869, 1995.

[13] H. Sakurai, and P. Dave, "Volume decomposition and feature recognition, part II – curved objects," Computer-Aided Design, Vol.28, Issues 6-7, pp. 519-537, 1996.

[14] T. Inoue and K. Nakamoto, "Proposal of a recognition method of machining features in computer aided process planning system for complex parts machining," Trans. of the JSME, Vol.83, No.850, p. 16-00574, doi: 10.1299/transjsme.16-00574, 2017 (in Japanese).

[15] M. M. Isnaini, Y. Shinoki, R. Sato, and K. Shirase, "Development of a CAD-CAM interaction system to generate a flexible machining process plan," Int. J. Automation Technol., Vol.9, No.2, pp. 104-114, 2015.

[16] I. Nishida, R. Sato, and K. Shirase, "Proposal of process planning system for end-milling operation considering product design constraints," Trans. of the Institute of Systems, Control and Information Engineers, Vol.30, pp. 81-86, 2017 (in Japanese).

[17] I. Nishida, T. Hirai, R. Sato, and K. Shirase, "Automatic process planning system for end-milling operation considering CAM operator's intention," Trans. of the JSME, Vol.84, No.860, pp. 81-86, doi: 10.1299/transjsme.17-00563, 2018 (in Japanese).

[18] I. Nishida and K. Shirase, "Automated process planning system for end-milling operation considering constraints of operation (1st report Process planning to minimize the number of times of tool change)," Trans. of the JSME, Vol.84, No.866, doi: 10.1299/transjsme.18-00242, 2018 (in Japanese).

[19] T. Inoue, T. Kishinami, and F. Tanaka, "Study of process planning based on feature dependency of manufacturing features (1st Report: The representation of feature dependency and basic concept of process planning system)," J. of the Japan Society for Precision Engineering, Vol.73, No.4, pp. 487-491, 2007 (in Japanese).

[20] I. Nishida and K. Shirase, "Automatic determination of cutting conditions for NC program generation by reusing machining case data based on geometric properties of removal volume," J. of Advanced Mechanical Design, Systems, and Manufacturing, Vol.12, No.4, JAMDSM0093, doi: 10.1299/jamdsm.2018jamdsm0093055, 2018.

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• "Voxel Based End-Milling Simulation Considering Elastic Deflection of Tool System," J. of the Japan Society for Precision Engineering, Vol.84, No.6, pp. 572-577, 2018.
• "Automatic process planning system for end-milling operation considering CAM operator's intention," Vol.84, No.860, 17-00563, doi: 10.1299/transjsme.17-00563, 2018.

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• M. M. Isnaini, Y. Shinoki, R. Sato, and K. Shirase, "Development of CAD-CAM Interaction System to Generate Flexible Machining Process Plan," Int. J. Automation Technol., Vol.9, No.2, pp. 104-114, 2015.
• K. Shirase, "CAM-CNC integration for innovative intelligent machine tool," Proc. of the 8th Int. Conf. on Leading Edge Manufacturing in 21st Century (LEM21), A01, 2015.
• I. Nishida, R. Okumura, R. Sato, and K. Shirase, "Cutting Force Simulation in Minute Time Resolution for Ball End Milling Under Various Tool Posture," ASME J. of Manufacturing Science and Engineering, Vol.140, No.2, 021009, doi: 10.1115/1.4037427, 2018.

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