Tool-path Generation for Groove Machining Feature

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Abstract. In this study, algorithm in generating machining sequences and tool-path for groove machining features are developed. The algorithm is based on ruled-based method and enhancing automatic feature recognition (AFR) via volume decompositions method. From the position of the vertex in z-axis and x-axis directions, machining sequences can be determined, and machining features can be sorted out. From the sub delta volume (SDV) generated from the recognized features of 3D part model, vertex positions of each SDV is determined thus positioning of the tool-path can be obtained. To validate the generated machining sequence and tool-path, one workpiece has been assigned to the algorithm. This workpiece is also tested with commercial software CAM function. The result shows that the developed algorithm is capable in generating the tool-path and can be visualized.

1. Introduction
Computer-aided Process Planning (CAPP) is an essential way to link computer-aided design (CAD) and computer-aided manufacturing (CAM). It works by determining manufacturing processes by identifying parameters that can lead to the justifications of machining purposes [1], [2]. Automation is the main keyword to address researches done by researchers to cultivate CAPP system since 1960’s [3]. By automating the way toward supporting the machining parameters which done in CAM, numerous methodologies had been worked. The thoughts on connecting CAD and CAM need to begin by passing on the upheld configuration of record from CAD to CAM. Many commercial software either work with various sort of documents handling from CAD to CAM or these software’s applications just have single CAD or CAM capacities. User need to import the files to process it. Therefore, information exchange for the software end up being progressively complicated. Moreover, groove recognition in processing the manufacturing information in CAM is always difficult as most software cannot perform it automatically.

Decomposed features from CAD model that were characterized as Sub-delta Volume (SDV) can be mapped towards machining features. Explicitly for cylindrical part models, Sub-delta Volume for Finishing (SDVF) were ordered dependent on its geometrical face definitions [4]. For instance, cylindrical SDVF which decomposed from cylindrical surfaces are correlated to straight turn and grooving process. Moreover, machining features for example taper and internal features can likewise be mapped. To make decomposed features beneficial, sequencing processes can be done in order to advance establish the SDVFs towards manufacturing purposes. Past studies shows by machining features’ sequencing, energy consumption in machining system can be diminish [5], [6]. Furthermore, a study concentrating on interacting prismatic features by adopting knowledge-based and geometric reasoning [7] and graph-based tolerances [8] had been done. These investigations utilized features’ information to produce more data towards machining highlights in various ways.
This paper will utilize the SDVs to locate the particular vertices positions for the tool-path development task. By having SDVs, volume of materials that should be removed from the stock model can be determined [9]–[11], in this manner machining cost can be determined.

2. Related works
Machining with CNC can diminish production time in contrast to manual NC machine. Consequently, tool-path codes generation is required. The benefits of utilizing machining codes or bound to be called G-codes contrast with manual machining or manual parameter insert to the machine control unit (MCU) is perplexing geometry part model can be machine specifically and geometry related issue as a result of machine CAD lack of ability can be dismissed. This is because of the absence of sketching or drawing capacity at the MCU amid the data exchange from typically 2D attracting to the machine before machining is begun.

Related research lately demonstrates researchers were concentrating on obvious issues with obvious methodologies. Toolpath optimization for sharp corner pockets had been developed by Zhao et al [12], tool–path planning had been developed by Xiuzhi and Brent for circular hole based on STL file format [13] for milling machining. An important viewpoint in generating the tool-path is the vertex positions of the machining features. These positions will decide the situation of hardware to do the machining forms. Previous research shows tool-path can be produced by utilizing cloud data point [14]. These cloud data points are resolved from STL CAD file format to support reverse engineering.

Furthermore, groove machining feature was recognized in one of many machining features. One example is by using graph decomposition strategy that issues in multiple extreme faces [15]. Moreover in machining sequences, groove operation is considered after facing and straight turn operations [16] or secondary feature [17]. The recognition of groove operation is important as it will reflects the tooling selection and machining tool-path.

In this paper, the decomposed SDV are used to obtain the vertex point positions. Geometry-base data from the perceived features were inserted with manufacturing feature-based information to create the tool-path. The viability of the created algorithm is proved through tool-path simulation run through commercial CAD software SolidWorks 2018 CAM function.

3. Methodology
To produce tool-path for grooving, maximum diameter of each SDVF should be resolved. SDVF that have a similar most extreme point in x-axis will be the first segment to be removed from the stock model. This feature will be the first toolpath’s profile distance. This toolpath will eliminate material from the edge of stock model in x-axis direction until the maximum point of the SDVF in x-axis direction with addition with the finishing thickness. Finishing thickness of the workpiece will be evacuated after roughing process is complete. The second SDV will be the feature with subsequent largest diameter. Minimum z-axis point of second feature is larger or the same with the first feature maximum point of z-axis direction. To create the grooving tool-path it is essential to measure each SDVF by determining its maximum and minimum vertex in x-axis and z-axis. This rule-based algorithm opt the IF THEN rule to acquire the information. The method of applying rules to get the desired information has the advantages of fast data acquaintance compare to other method such as heuristic approach which used more complex formulations.

![Figure 1. Process flow of the algorithm](image)

3.1 Automatic feature recognitions
One important aspect before the recognition starts is the orientation of the 3D file. It has to be in correct positions before recognitions work can be done [18]. Cylindrical part model can be recognized by its features. This include internal features [19], chamfer and fillet [20]. Moreover, part model complexity can be measure by determining the topological data of the part model[21].
3.2 Auto-sequencing
For turning machining, sequence of machining operations will begin from facing and completed with parting. In the middle of these two activities, profiling, grooving, tapering, drilling and forming are done. These operations need to be established by automatic sequencing. By finding the data explicitly SDV’s boundary positions, auto-sequencing should be possible. Before positioning determinations, SDVs which are decomposed in single body should be separated to ensure each single SDV’s boundary positions can be resolved. Next to facing operations, SDV with the largest diameter is chosen and straight turn operation is allocated to it. Subsequently, it will rely on the second largest SDV positions.

If the next SDV is a cylindrical SDVF, profiling operation will be allocated. Algorithm will continue assigning profiling until the algorithm detect possible groove feature in the form of rule-based. Profiling will begin by roughing operation in bigger depth of cut and completed with finishing operation to all the SDV that been recognized.

3.3 Groove feature determination.
Whenever a depression detected on the surface of a workpiece, there is a possibility of grooving feature to be map for lathe machining part model [22]. However, these depression characteristics can be machined as a straight turn if it is located at front of the workpiece. This can save machining time as grooving required different tool from straight turn process. To save time, grooving tools can be selected as same as parting tool and grooving process can be planned to be the second last process before parting.

Therefore, this study is focusing on grooving tool-path generations. Volume removal of groove from the stock model can be expressed in Eqn. 1.

\[ G_1 = SDVR_1 + SDVF_{C1} + SDVF_{P1} \]  

Where SDVR₁ is the Sub-delta Volume for Roughing (SDVR) at the groove feature, SDVF_{C1} is the cylindrical SDVF at the groove feature and SDVF_{P1} is the planar SDVF at the groove feature. These SDVs are illustrated as Figure 3.

3.4 Sequencing of groove features
For the case of a workpiece that has more than one groove, the algorithm will detect groove feature which is less z-axis point value that the last groove feature to be selected. For example, in Figure 3, G2 will be evacuate prior to G1. This is to manage the tool change so that the last (G1) will be in sequences with parting process. This can be done by having rule that is designated as shown in the flow chart in Figure 2.

3.5 Tool-path generations of groove
Tool to do the groove process will start from home position. This home position is normally set at some point away from the (0,0). The tool will move in G00 mode towards the first z-axis point and an offset location of x-axis point that is detected from planar SDVF at the groove feature location. The tool will then be set towards the first cutting position that is normally depend on the tool width in lead angle that is set. In this study case the lead angle will be 45°. Next the tool will move downward to the x-axis point that is set from the cylindrical SDVF at the groove feature. This movement will continue until the last point of the z-axis position of the cylindrical SDVF. The tool will return to home position and proceed to another groove feature.
4. Case Study
A 64-bit operating system with the performance of 8GB RAM Intel (R) Core i7-3770 CPU 3.40GHz is used to build the algorithm. It was built in Microsoft Visual Studio 2010 Professional Edition version 10.0.40219.1 SP1Rel with Microsoft.NET Framework version 4.6.01055 SP1Rel platform and ACIS solid modeller version R25 SP1 platform.

A workpiece consists of different regular faces type and position being verified by the developed algorithm. It is shown in Figure 4. This workpiece consists of five cylindrical features and a conical

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**Figure 2.** Groove determination process.

**Figure 3.** Example of part model with groove features.
feature. These features are selected to verify the auto-sequences and tool-path generations that were developed. If depressions appear in the surfaces of the workpiece, there are possibilities of groove feature to be recognized.

Feature recognition process was successfully done, and Figure 5 shows the result of the generated SDV. The workpiece itself is in silver color, blue color indicates SDVR, green color indicates SDVF and yellow color indicate SDVF-FR.

![Figure 5](image)

**Figure 4.** (a) Case Study workpiece and (b) the possibility of groove feature.

To compare the generated tool-path, the same workpiece was simulated via SolidWorks 2018 CAM function. Figure 4 shows the tool-path and sequences of the machining features determined by the developed algorithm. The toolpaths are expressed in different line colors, where red is for the facing, black for the first profiling, white line is the second profiling, purple line are for grooving and tapering and cyan color line is for parting. For visual purpose, Figure 6 is expressed in wireframe, blue color indicates the stock model or SDVR and green line indicates the SDVF. The algorithm successfully generates the groove tool-path and notice that the front groove is not generated. This happen as the algorithm considered it to be machined by straight turn and tapering that will use the same tool as the first profiling and facing. Figure 7 shows the toolpath simulations in SolidWorks 2018.
Figure 5. AFR of the workpiece. (a) Thee assembly of workpiece with half section of SDV and (b) the exploded view of all the SDV.
Figure 6. Tool-path for groove generated for the workpiece.

Figure 7. Tool-path simulations in SolidWorks 2018.

From the comparisons between the developed algorithm and SolidWorks 2018 CAM feature, it is founded that, the developed algorithm will generate the sequences by the SDV generated during the AFR process, while SolidWorks has its own machining feature recognitions. Groove features in SolidWorks 2018 were defined in the same sequence as generated by the developed algorithm rules. The sequences in SolidWorks can be seen from the NC manager product tree. Therefore the generated sequences is validated. The simulation in SolidWorks offer more options such as selections of display for the tools, stock model, chuck and more. This however can contribute to more options that can be equipped in the algorithm in future. Moreover, the develop algorithm suggest the toolpath in line based on different colours that depend on the machining features.

5. Conclusions
The developed algorithm is capable in recognizing groove feature, its operation sequences and generating the tool-path for the workpiece. The comparisons of generated tool-path are done with commercial software SolidWorks 2018 CAM function. The results shows that sequencing generated comply with the commercial technique used by SolidWorks. Further investigations can be done by implementing the G-codes generated to real machining.
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References
[1] S. Subrahmanyam and M. Wozny, “An overview of automatic feature recognition techniques for computer-aided process planning,” Comput. Ind., vol. 26, no. 1, pp. 1–21, 1995.
[2] M. Al-Wswasi, A. Ivanov, and H. Makatsoris, “A survey on smart automated computer-aided process planning (ACAPP) techniques,” Int. J. Adv. Manuf. Technol., 2018.
[3] X. Xu, L. H. Wang, and S. T. Newman, “Computer-aided process planning: a critical review of recent developments and future trends,” Int. J. Comput. Integr. Manuf., vol. 24, no. 1, pp. 1–31, 2011.
[4] A. F. Zubair and M. S. Abu Mansor, “Automatic feature recognition of regular features for symmetrical and non-symmetrical cylinder part using volume decomposition method,” Eng. Comput., vol. 34, no. 4, pp. 843–863, 2018.
[5] L. Hu, Y. Liu, C. Peng, W. Tang, R. Tang, and A. Tiwari, “Minimising the energy consumption of tool change and tool path of machining by sequencing the features,” Energy, vol. 147, pp. 390–402, 2018.
[6] Z. Zhang, R. Tang, T. Peng, L. Tao, and S. Jia, “A method for minimizing the energy consumption of machining system: integration of process planning and scheduling,” J. Clean. Prod., vol. 137, pp. 1647–1662, 2016.
[7] Z. Liu and L. Wang, “Sequencing of interacting prismatic machining features for process planning,” Comput. Ind., vol. 58, no. 4, pp. 295–303, 2007.
[8] H. Samuel, “Automated setup planning for lathe machining,” 1998.
[9] A. Y. Bok and M. S. Abu Mansor, “Generative regular-freeform surface recognition for generating material removal volume from stock model,” Comput. Ind. Eng., vol. 64, no. 1, pp. 162–178, 2012.
[10] P. S. Kataraki and M. S. Abu Mansor, “A novel classification of freeform volumetric features and generative CAPP approach for milling machine selection,” Int. J. Adv. Manuf. Technol., pp. 1–25, 2018.
[11] P. S. Kataraki and M. S. Abu Mansor, “Auto-recognition and generation of material removal volume for regular form surface and its volumetric features using volume decomposition method,” Int. J. Adv. Manuf. Technol., 2016.
[12] Z. Y. Zhao, C. Y. Wang, H. M. Zhou, and Z. Qin, “Pocketing toolpath optimization for sharp corners,” J. Mater. Process. Technol., vol. 192–193, pp. 175–180, 2007.
[13] X. Qu and B. Stucker, “Circular hole recognition for STL-based toolpath generation,” Rapid Prototyp. J., vol. 11, no. 3, pp. 132–139, 2005.
[14] A. Masood, R. Siddiqui, M. Pinto, H. Rehman, and M. A. Khan, “Tool path generation, for complex surface machining, using point cloud data,” Procedia CIRP, vol. 26, pp. 397–402, 2015.
[15] L. Liu, Z. Huang, W. Liu, and W. Wu, “Extracting the turning volume and features for a mill / turn part with multiple extreme faces,” Int J Adv Manuf Technol, 2017.
[16] M. C. Kayacan, I. H. Filiz, A. I. Sijnmez, A. Baykasoglu, and T. Dereli, “OPPS-ROT : An optimised process planning system for rotational parts,” vol. 32, pp. 181–195, 1996.
[17] A. Oral and M. C. Cakir, “Automated cutting tool selection and cutting tool sequence optimisation for rotational parts,” Robot. Comput. Integr. Manuf., vol. 20, no. 2, pp. 127–141, 2004.
[18] A. F. Zubair and M. S. Abu Mansor, “Cylindrical axis detection and part model orientation for generating sub delta volume using feature based method,” ARPN J. Eng. Appl. Sci., vol. 11, no. 22, pp. 13415–13419, 2016.
[19] A. F. Zubair and M. S. Abu Mansor, “Hole Feature on Conical Face Recognition for Turning Part Model,” IOP Conf. Ser. Mater. Sci. Eng., vol. 328, p. 012026, 2018.
[20] A. F. Zubair and M. S. Abu Mansor, “Automatic Feature Recognition of Chamfer and Fillet for Turning Part Model by Volume Decomposition Method,” *J. Mech. Eng.*, vol. 5, no. 2, pp. 204–216, 2018.

[21] A. F. Zubair and M. S. Abu Mansor, “Auto-recognition and part model complexity quantification of regular-freeform revolved surfaces through delta volume generations,” *Eng. Comput.*, vol. 0, no. 0, p. 0, 2019.

[22] P. Gavankar and M. R. Henderson, “Graph-based extraction of protrusions and depressions from boundary representations,” pp. 442–450, 1990.