The study of total-removal-volume (TRV) feature in handling the flexible machining shapes generation

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Abstract. Previous researches have shown the great use of a total removal volume (TRV) in supporting a straightforward machining process plan generation for milling operation. TRV constitutes as any volumes that need to be removed from the blank material in order to achieve the product shape. The TRV is considered as an alternative of the feature-based unit in complementing the well-known 'machining feature'. This paper shows the elaboration and the application of the TRV-based machining process plan generation to support the re-work of a workpiece. To support this study, TRV is proposed to be enriched into two kind of forms, primitive removal volume (PRV) and actual removal volume (ARV). One PRV might have several ARV forms. In a feature-based system, the PRV might be analog as the primitives while ARV represents the exact machining shape. This routine is an effort to manage the future generation of machining shapes in terms of exchangeable feature information.

Keywords: total removal volume, machining feature, machining process plan, computer-aided process planning (CAPP), computer-aided manufacturing (CAM).

1. INTRODUCTION

The handling of shapes during machining stage is still become the challenging task when it comes to the problem in automating the machining process plan (MPP) generation. Two products can be highlighted to be the example of the shape`s variety, mold and dies. The recent practice shows that these products are extremely varied in the term of design and may involve many variety of required machining features (MF). Two kind of computer-aided process planning (CAPP) system might be involved to aid the extraction of MF from shapes, the variant and the generative. In case of the product will be highly repetitively manufactured, the variant CAPP system will be more efficient for helping the production routines. In case of the product is having low order quantities, the generative CAPP system might be considered further. Hence, to cope with these MFs variability, Isnaini and Shirase (2014) suggested that the CAPP is required to be more flexible and robust to be more useful in practical works.

The determination of MF is still highly depended on the existence of the pre-defined features which is populated inside a MF database and always renew once a new MF is found. The former Computer-Aided Process Planning (CAPP) systems are believed to spend huge efforts to extract and match MF with the pre-defined features (Nasr and Kamrani, 2007). The large number of database will add another difficulty during the extraction of the similar MF. Matching process in large database of MF definitions will obviously become an exhaustive and time-consuming process (Shah, 1991). In case of a generative CAPP system, a sophisticated MF extraction module might also be added-on to prepare prior to the extraction to shorten the searching time. Thus, the associated machining information can be used to thrive the product's machining. By considering the efforts in evaluating MF, Nakamoto *et al.* (2004) has introduced a total removal volume (TRV) as another main feature-based unit which can be used for defining the MPP instead of using MF. TRV is defined as any volumes that need to be removed in shaping the workpiece as simply described in Figure 1. Naturally, the MF is decomposed from TRV of blank material. However, the term of blank material can be acquired from any shapes of material if it can fit the lateral size of the product.

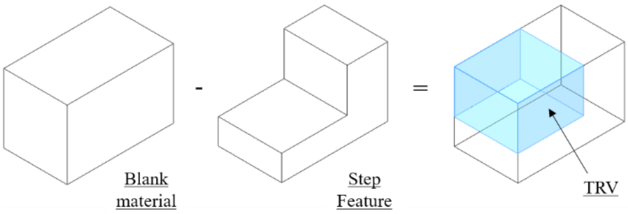

Figure 1. Simple illustration of TRV which is shown as a blue shaded area.

In practical cases in metal manufacturing industries, the sequence of machining process can be interrupted by failures that can cause the machining sequence to stop at any states (for example, if the tool is broken, electricity stops, and so on). These failures can produce intermediate shapes which needs to be re-worked or it might further reject the product as the other consequences. These intermediate shapes might become difficult to solve if the prediction of shapes` feature is still based on its final shapes. The main idea of TRV can be useful to recognize an irregular shape or any shapes which may significantly have different form from the traditional MF, e.g. slot, step, and pocket. Other research by Park (2006) tried to consider a near net shape or intermediate shape as its feature-based unit. This form also can be considered as the form of TRV, which might act similar like the target machining volume. Henceforth, it can be inferred that the raw material shape does not have to be the blank square material for prismatic part or blank cylinder for rotational part. On the contrary, the traditional MF will depend heavily on singular or composition of primitive features which are the subtracted volume from either the blank square material or blank cylinder.

This paper focus in re-defining the TRV definition as the new method to explain features of product. The second section explains the elaboration of TRV and its subset to show the ability in forming the shapes. The third section explains the merits of the new form of TRV. Finally, the last section draws the conclusion of this study.

2. TRV-BASED MPP

The first system of TRV-based MPP which was introduced by Nakamoto *et al.* (2004) exploited the cell decomposition process to generate the removal volume naturally from the TRV. Later, the MPP is constructed by ordering the removal volume based on its plane that were paralleled to Y-Z or Z-X planes. A couple years later, Morinaga *et al.* (2011) enhanced the MPP selection by optimizing the selection based on its configuration of plane's cutting tool access direction (TAD). The number of cells which were included in the selection was limited by using only the concave reference of the TRV shapes. From other perspective, the treatment of cells decomposition method might suffer on computational issues once the number of cells are becoming larger, as in (Han *et al.*, 2000). Another study was taken by Isnaini *et al.* (2013) to investigate further in using directly the cell's constructor, i.e. reference plane. By this method, the cell of TRV will not be generated. Each corresponding decomposition of each reference plane is considered as the small portion of TRV.

2.1 TRV Definition

In order to analysis the TRV, the entire of the reference plane, *P*, is collected as the representation of TRV's surface as depicted in Figure 2. In the process of decomposition, several VIP might be involved. The TRV can be expressed as the collection of volume in-process (VIP) and its reference planes as expressed in Equation (1) and illustrated in Figure 2. VIP is considered as the subset of TRV during the process of decomposition or analog as the process of shaping into the final shape of a product.

$$\boldsymbol{TRV} \equiv \{\cup_{\boldsymbol{i=1}}^{\boldsymbol{m}} \boldsymbol{VIP_i}, \cup_{\boldsymbol{i=1}}^{\boldsymbol{n}} \boldsymbol{P_i}\} \quad (1)$$

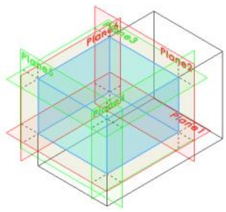

Figure 2. Generated reference planes, *P*, which are bounding the TRV.

Each VIP can be defined simply as a feature which consist of solid body, *b*, the main reference plane, *mp*, a collection of the new reference plane, *p*, and a number of open faces, *OF*. Their relation can be expressed as in Equation (2). Open face is defined as the exposed surface of VIP. The main reference plane is defined as the reference of any machining process on the corresponding VIP. Figure 3 shows two different kinds of VIP to handle the similar body of TRV. The candidates of removal process can be chosen either by *plane1* or *plane2* respect to a particular *b*, *mp*, remaining *p*, and it's *OF*.

$$\boldsymbol{VIP} \equiv \{\boldsymbol{b}, \boldsymbol{mp}, \cup_{i=1}^{j} \boldsymbol{p}_i, \cup_{i=1}^{k} \boldsymbol{OF}_i\} \qquad (2)$$

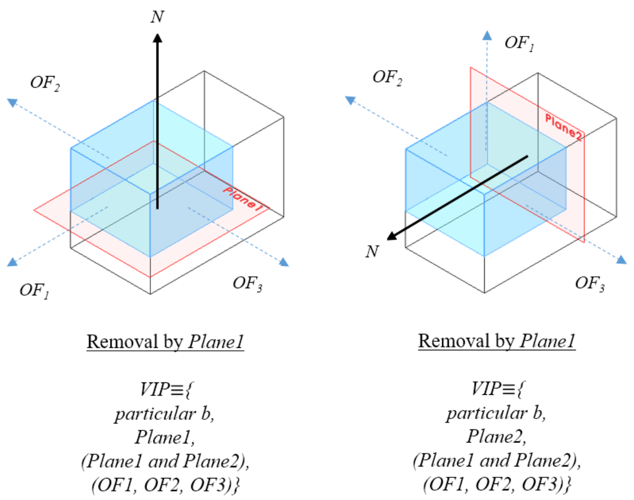

Figure 3. VIP feature-based unit.

2.2 Types of removal volumes

The VIP can be enriched further by introducing two kinds of forms, an actual removal volume (ARV) and a primitive removal volume (PRV) as illustrated in Figure 4 as in (Shinoki *et al.*, 2014). The ARV is used for holding the real shape information while the PRV is used for holding the estimated geometry information. Both forms are going to be used for providing and complementing VIP description to find the corresponding machining operation and can be expressed as in Equation (3) and (4).

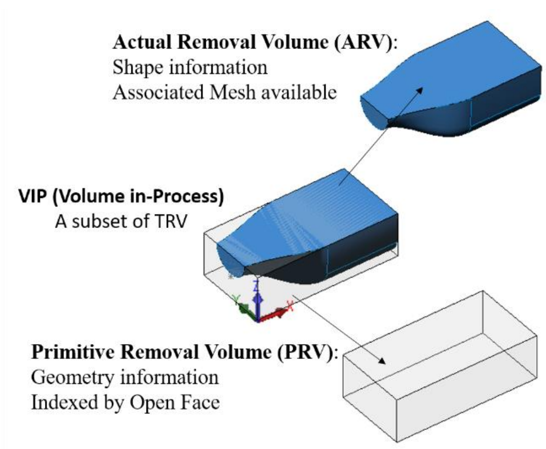

Figure 4. TRV enrichment.

$$\boldsymbol{ARV} \equiv \{\boldsymbol{b}, \boldsymbol{mp}\} \qquad (3)$$

$$\boldsymbol{PRV} \equiv \{\cup_{i=1}^{j} \boldsymbol{p}_i, \cup_{i=1}^{k} \boldsymbol{OF}_i\} \qquad (4)$$

The ARV can simply support the feature description that might have a difficulty in term of definition based on geometry reasoning only. The ARV definition relies on the definition of its actual solid body, *b* and the corresponding machining reference, *mp*. The PRV can simply support the definition of removal shapes by defining its collection of the plane, *p*, and topology of its open faces, *OF*. The relation between VIP, PRV and ARV can be expressed as in Equation (5).

$$\boldsymbol{VIP} \equiv \{\boldsymbol{PRV}, \boldsymbol{ARV}\} \qquad (5)$$

3. TRV MERITS

This section elaborates the merits of TRV utilizations based on the ability of three aspects, handling the dynamic of process, flexible definition of shapes and long-term data preservation.

By recalling again several details from the previous section, the TRV might also be dissolved into a sequence by considering the order of the reference plane, *P*. In this case, the VIP (the dissolved volumes of TRV) will have its natural and the least unit for representing the steps of process. Accordingly, it may show the changes of shape dynamically. At this point, the pre-defined features might be lack of information to recognize the feature in the form of VIP. The enrichment of the VIP may treat the dynamic of features to accommodate the distinct features to evolve more generatively based on the situation during the machining processes.

The common way of constructing the MPP is to be mainly based on the design of a product, i.e. the target shape as explained in (Nasr and Kamrani, 2007). This practice is primarily comprehended because of the process plan is decided more on the upstream of the production line. Since the realization of the product finally will be determined by the downstream situation, i.e. the shop floor, the MPP will need to be prepared with strategy in actualizing the rapid changes which may occur during the machining operation to achieve the target shape. Previous work by Wang *et al.* (2006) showed the example of consideration based on the enriched machining features (EMF) to accommodate the occurrence of the intermediate machining volumes (IMV) during the machining stages. These IMVs will analog to the VIP and play a significant role in the EMF-based reasoning. However, a sufficient basic machining information was only associated for determining any shapes which had been included in the pre-defined MF. Thus, the routine was lack of treatment for any other remaining possible shapes which were not included in the pre-defined MF. Moreover, the IMV cannot possible to accommodate the free-form surface feature. The ARV might become the complement to explain the detail of VIP shapes as depicted previously in Figure (4).

By referring to Equation (5), each VIP will consist of PRV and ARV. One PRV might have several ARV forms. For example, a configuration of reference plane and it`s open faces can be analyzed as a particular PRV, e.g., step or slot feature. In the term of design, the latter information might be enough, however, in the term of machining, the specific details of step or slot feature might be needed to configure the machining operation. This is where the ARV will take the great function to explain further the details of PRV. This practice shows another possible enhancement of TRV to support the linkage between CAD and CAM to support MPP generation in the form of VIP. Two form of removal volumes, ARV and PRV, can be considered as a new way to maintain an efficient pre-defined feature evaluation. The ARV is used for holding the real shape information and useful within CAM operations while PRV is used for holding the estimated geometry information and useful within CAD operations. Both forms are going to be used for complementing TRV description to find the corresponding machining operation details, i.e. machining information.

By using previous simplifications, we can observe more ARV shapes in the latter stages (CAM) to elaborate the machining condition properly while keep the necessary information as PRV for data manipulation in earlier stage (CAD). Several difficult definition for features can be determined easily without neglecting the necessity control of the corresponding shapes, for example, free-form surface. Although it might infer that two kinds of the database which consist of PRV and ARV is needed respectively as depicted in Figure 5, this might enable the flexibility of data and manage the evolution of shapes while keep maintains the unique aspect of its topology.

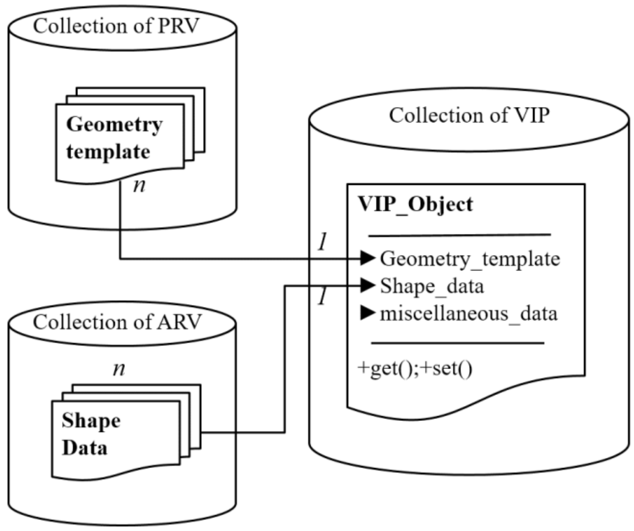

Figure 5. The data abstraction of PRV, ARV and VIP.

4. CONCLUSION

By using the findings that has been explained in the previous sections, the current on-going research has been able to give insights and confirm several points as follows:

1. The formation of VIP features can be used as an alternative way to complement or substitute the term of machining features in order to configure the MPP, generatively, to deal with the irregular shapes during re-work process.
2. Both forms, PRV and ARV, can be seen as a new way to integrate the machining information between planner and operator. Planner which have more concern in geometry information can utilize the PRV and operator which have more concern actual parameter can utilize the ARV.
3. In the long term, both forms can be easily maintain individually while also keep the data relation between PRV and ARV in forming the VIP (the representation of the dynamic shapes) in order to increase the reliability in constructing a flexible CAPP system.

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REFERENCES

Champati, S., Lu, W. F., Lin, A. C. (1996) Automated operation sequencing in intelligent process planning: A case based reasoning approach, *International Journal of Advanced Manufacturing and Technology*, Vol. 12, No. 1, pp. 21-36.

Han, J.H, Pratt, M., Regli, W.C. (2000) Manufacturing feature recognition from solid model: a status report, *IEEE Transactions on Robotics and Automation*, Vol. 16, No. 6, pp. 782-796.

Igari, S., Tanaka, F., Onosato, M. (2012) Computer-aided operation planning for an actual machine tool based on updatable machining database and database-oriented planning algorithm, *International Journal of Automation Technology*, Vol. 6, No. 6, pp. 717-723.

Isnaini, M.M., Sato, R., Shirase, K. (2013) A concept of total removal volume feature in selecting machining sequence for generative automated process planning, *Proceedings of the 7th International Conference on Leading Edge Manufacturing in 21st Century (LEM21)*, No. 13-203, pp. 135-140.

Isnaini, M. M., Shirase, K. (2014) Review of computer aided process planning systems for machining operation – Future development of a computer-aided process planning system, *International Journal of Automation Technology*, Vol. 8, No. 3, pp. 317-332.

Morinaga, E., Yamada, M., Wakamatsu, H., Arai, E. (2011) Flexible process planning method for milling, *International Journal of Automation Technology*, Vol. 5, No.5, pp.700-707.

Nasr, E.A., Kamrani, A.K. (2007) *Computer-Based Design and Manufacturing: an Information Based Approach*, Springer Science.

Nakamoto, K., Shirase, K., Wakamatsu, H., Tsumaya, A., Arai, E. (2004) Automatic production planning system to achieve flexible direct machining, *JSME International Journal*, Vol. 47, No. 1 (C series), pp. 136-143.

Park, S. (2006) Generating intermediate models for process planning, *International Journal of Production Research*, Vol. 44, No. 11, pp. 2169-2182.

Shah, J.J. (1991) Assessment of features technology, *Computer-Aided Design*, Vol. 23, No. 5, pp. 331-343.

Shinoki, Y., Isnaini, M. M., Sato, R., Shirase, K. (2014) Automation of machining operation planning by reconfiguring past case data on machining operations, *Proceedings of 2014 International Symposium on Flexible Automation (ISFA2014)*; 2014-63S.

Wang, L., Cai, N., Feng, H.-Y., Liu, Z. (2006) Enriched machining feature based-based reasoning for generic machining process sequencing, *International Journal of Production Research*, Vol. 44, No. 8, pp. 1479-1501.