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Workpiece setup simulation based on machinable space of five-axis machining centers

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Abstract

An actual machining center specification, e.g. the axes travel, the workpiece size allowance, etc., needs to be considered for constructing a machining process plan. In this paper, a machinable space of a five-axis machining center is proposed for simulating the workpiece setup. The machinable space is constructed by a table region and a tool cone. The tool cone is an allowance of the spindle diameter and the cutting tool length. By fitting in the visibility area from a total removal volume (TRV) of the machining process plan, a TRV network can be established. The workpiece setup is estimated by positioning the TRV network within the table region. The positioning process can be used for estimating the number of setup changes on the corresponding machinable space.

Keywords: machinable space; workpiece setup; five-axis machining; process planning

1. Introduction

Manufacturability analysis is considered to be essential in reducing the planning time of a machining process plan. One important factor of manufacturability is the workpiece setup planning. Current machine tools have the capability of performing a five-axis machining process [1, 2]. The time required to define the workpiece setup increases because more axes have to be considered than in the three-axis machine tool. The conventional way to define this setup mostly depends on the skills of experts. As a complementary procedure, several fixtures have been invented for reducing the complexity of the workpiece setup in the five-axis machining center. However, fixture planning also requires a large amount of time and labor. The dependencies on the skills of experts and the fixturing process need to be reduced to simplify the workpiece setup.

Previous studies have investigated several methods for efficiently orienting the workpiece. The workpiece orientation is considerably useful for defining any related successive processes, e.g. the setup planning, the fixture planning and the tool path planning. In this study, a new method is proposed for defining the workpiece setup that can align with and support the machining process plan. This paper consists of six sections. In the second section, the previous studies related to setup planning are described. The third section describes the issue of setup planning. The fourth section explains the details of the proposed methodology. The fifth section discusses an example and results. The sixth section states the conclusion and future work.

2. Theoretical background

2.1. Visibility map and the workpiece orientation

The use of a visibility map has been introduced by Woo et al [4] for estimating the cutting tool access requirement of particular workpiece shapes. The visibility map is represented as a visibility cone in Fig. 1. Afterward, Kang and Suh [5] introduced a binary spherical map (BSM) approach as a further enhancement of the visibility map. The BSM is constructed by projecting the visibility cone onto a virtual

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sphere. The smallest travel distance of the cutting tool can be achieved by finding the intersection of any feasible tool motion with the BSM. Lee et al [6] proposed an evaluation methodology, called the Preliminary Manufacturability Evaluation System (PMES), which incorporates the visibility cone into a workspace analysis. PMES can find the optimal workpiece orientation and configuration on the machine tool. Moreover, Anotaipaiboon et al [7] introduced a similar method to the visibility cone by considering a set of the cutting tool contact points and the cutting tool orientation. To define the workpiece orientation, a least-squares optimization procedure is executed for finding the minimum kinematics error during axes rotation.

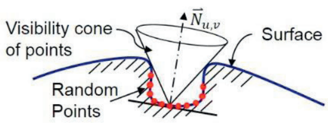

Fig. 1. Visibility cone.

2.2. Machinable space

Apart from the previously mentioned studies, Nishiyama et al [8] introduced a machinable space for positioning the workpiece. The machinable space is used for exposing the actual machining space that can be used for machining. The machinable space, with a maximum 420 mm X travel, 210 mm Y travel and 400 mm Z travel, is shown in Fig. 2. Figure 2 shows a condition in which the mounting table is tilted to its maximum B-axis rotation (until colliding with the spindle). To create the machinable space, several points, as depicted in Fig. 3-a, are calculated using a transformation function in Eq. (1). In Eq. (1), t_{Bx} and t_{Bz} are the offset points of the center of the B-axis centroid in the X- and Z-axes, respectively, which are calculated from the center of the mounting table. The entire machinable space can be constructed by considering several angle rotations, as depicted in Fig. 3-b.

$$\begin{bmatrix} x_W \\ y_W \\ z_W \\ 1 \end{bmatrix} = \begin{bmatrix} cos\theta & 0 & -sin\theta & t_{Bz}sin\theta - t_{Bx}cos\theta + t_{Bx} \\ 0 & 1 & 0 & 0 \\ sin\theta & 0 & cos\theta & -t_{Bz}cos\theta - t_{Bx}sin\theta + t_{Bz} \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_T \\ y_T \\ z_T \\ 1 \end{bmatrix} \quad (1)$$

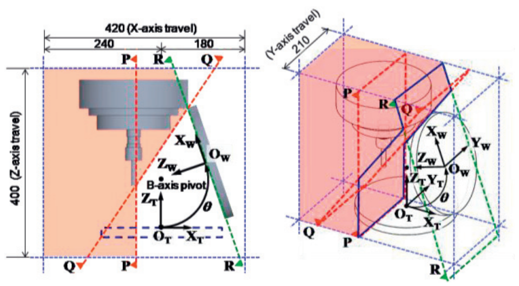

Fig. 2. Example of the machinable space of a maximum table rotation by the B-axis. [8]

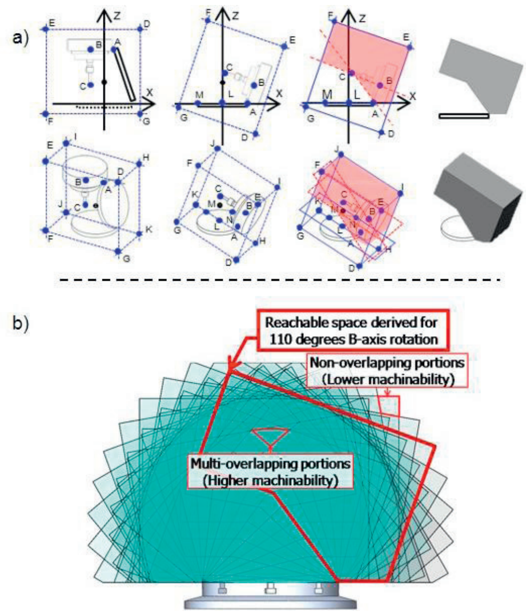

Fig. 3. (a) Determination of machinable space vertices; (b) Total machinable space. [8]

2.3. Total removal volume (TRV) feature-based unit

Generally, the machining process is set to correspond to a particular machining feature. The machining features are calculated from the workpiece shape. For each workpiece model, the machining features are estimated by assuming the initial shape of the material stock is a block or a cylinder. To realize the actual machining condition, this practice has a weakness if any non-standard stock shape is considered in the machining processes. The initial shape and its removal volume can vary, as shown in Fig. 4. To improve the machining feature definition, Isnaini et al [9] proposed a new approach for defining the machining processes based on the shape of the workpiece removal volume. The removal volume estimation is more suitable than using the machining feature definition if the material stock is irregularly shaped. In Fig. 4, the TRV is decomposed into several removal volumes, which in [9] are called TRV features. The TRV features are generated by using reference planes that coincide with each TRV face. The TRV feature corresponds to a particular reference plane. Further, the corresponding reference plane will represent the machining plane.

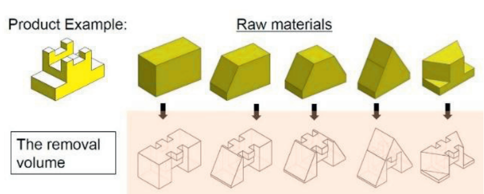

Fig. 4. Workpiece instances, raw materials and the corresponding removal volume.