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Polygon subdivision for pocket machining process planning ☆

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ABSTRACT

This paper presents a new approach to improve tool selection for arbitrary shaped pockets based on an approximate polygon subdivision technique. The pocket is subdivided into smaller sub-polygons and tools are selected separately for each sub-polygon. A set of tools for the entire pocket is obtained based on both machining time and the number of tools used. In addition, the sub-polygons are sequenced to eliminate the requirement of multiple plunging operations. In process planning for pocket machining, selection of tool sizes and minimizing the number of plunging operations can be very important factors. The approach presented in this paper is an improvement over previous work in its use of a polygon subdivision strategy to improve the machining time as well as reducing the number of plunges. The implementation of this technique suggests that using a subdivision approach can reduce machining time when compared to solving for the entire polygonal region.

1. Introduction

Pocket machining strategies for complex pockets have primarily been focused on using a single tool approach; the main concern being manual tool change time. The advent of rapid tool changers has reduced this tool change time to a minimum, offering new approaches to process planning. There has been significant research on pocket milling, too broad of a topic to discuss sufficiently without a review paper (Chuang & Lin, 1997; Hansen & Arbab, 1992; Held, 1991; Held, Lukacs, & Andor, 1994; Jeong & Kim, 1999a, 1999b; Persson, 1978). Various techniques have been developed, ranging from simple polygon offset generation to more sophisticated approaches using Voronoi diagrams. However, most researchers have focused on design strategies using a single tool. In the case of simple pockets, a single tool approach can be efficient but it is less effective as the complexity of the pocket increases. Once again, advances in CNC machining have slowly lead to more advanced designs in products, for both function and aesthetics. However, more complex pocket designs have lead to the need for more complex process planning strategies. In many of these cases, a multiple tool approach can overcome the tool change time by machining larger areas using large tools and smaller tools only as needed.

While designing a multiple tool strategy, it is desirable to select an optimal set of tools in order to reduce the initial plunge cutting of these tools. Plunging typically requires significantly slower feed rates, and equally important, requires center-cutting tools. This paper focuses on presenting a multiple tool strategy for the pocket machining of freeform pockets that may contain islands. It also presents a tool selection and sequencing strategy to minimize machining time, and to reduce or eliminate plunge cutting.

2. Related work

There has been considerable research in the field of tool path design for pocket machining. There are numerous methods designed for creating tool paths within a pocket. These methods vary from simple offset generation or contour parallel methods to complex methods like those based on Voronoi mountains. In the contour parallel method (Bohm, 1981; Hansen & Arbab, 1992; Manuel, Liang, & Kolahan, 1996; Persson, 1978) for machining of arbitrary shaped pockets, row offsets undergo decomposition, removal of interfering chains and then merging to form a clean offset. Successive offsets of this clean curve form tool paths for the pocket. In another approach based on contour parallel machining (Chuang & Lin, 1997), boundary B-spline curves are converted into Bezier curves by knot insertion until the required tolerance is obtained. Tool paths are designed by intersecting offset removal and decomposition of the profiles. The Bezier convex hull is used to avoid any overcut in machining.

In pocket machining using distance maps (Jeong & Kim, 1999a), researchers have constructed the discrete distance map by determining the closest curve segment and minimum distance for each point between the inside boundary and offset of the boundary and then using a z-buffer method (Jeong & Kim, 1999b). In the z-buffer method, a right cone is constructed and moved along the boundary

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with different color assignments for each curve. A tool path is generated by extraction of the characteristic points from the distance map and connections of all the offset profiles. In an approach based on the monotonic pouches designed from Voronoi diagrams, Held et al. (1994) first draws a Voronoi diagram of the pocket. Next, an imaginary surface over the Voronoi diagrams is created by varying the *z*-coordinate and keeping *x*- and *y*-coordinates constant. The mountains obtained in this process are used to determine the location of bottlenecks in the pocket. Paths for individual pouches are designed and joined together to construct the tool path. In this approach, a proximity map of the features is created and used to determine the set of tools that can be used to machine the pocket. According to the authors, the largest tool that can be used for the rough cut is equal to the smallest bottleneck or smallest fillet radius.

In the feature recognition-based method based on delta volume (Mascle, Lu, & Maranzana, 2007; Sheen & You, 2006), tool paths were generated using residual delta volume calculation. However, the primary focus is to machine the entire pocket using a single tool (except minimal boundary finishing). In the zig–zag machining method (Held, 1991) a pocket is machined by parallel motion of the tool. This method is useful when the machining tool has some preferred direction. In most of the above methods plunging has been recommended for each of the tool path centers before machining. Since plunging feed rates are much slower than linear cutting motion feed rates, it requires significantly more time. Efforts were also directed at finding the optimal tool based on economic constraints, but the authors restricted themselves to simple shapes and zig–zag machining. Others have made improvements upon current methods, for example, spiral tool paths for pockets without islands (Held & Spielberger, 2009) and other Voronoi Diagram based methods (Salman, Mansor, Hinduja, & Owodunni, 2006). There are also other methods to make the single tool approach more efficient, such as (Oysu & Bingul, 2009; Pyo Moon, 2008).

Practically all the above methods for generation of a tool path prefer to use a single tool to machine the entire pocket. Unfortunately, there can be a small neck present that would force the use of a small tool to machine the entire pocket. Some of the researchers realized the advantages of using multiple tools for pocket machining. Although there were a few algorithms designed for determining tool sizes, sequencing of the tools remained a problem. In addition, the use of multiple tools can increase the number of plunge cuts required. Even though it can have a significant effect on the overall machining process, there has been little attention given to reducing the number of plunge cuts in order to save machining time. In one of the multiple tool selection methods based on Voronoi diagrams (Veeramani & Gau, 2000), a Voronoi mountain of the pocket was created to obtain the un-machined area. The tool sizes were based on these un-machined area calculations. Another method based on geometric and volumetric calculations (Lim, Corney, & Clark, 2000; Lim, Corney, Ritchie, & Clark, 2000) used feature-based analysis for selection of the tools, with various types of decision graphs generated to support the system. In the tool selection optimization method of Bouaziz and Zghal (2008) and sidewall machining method of Chang, Man Kim, and Park (2009) researchers have extended different techniques for multiple tool selection, but their approaches require the search of an entire set of tools which could be quite large in the case of complex pockets. The time loss due to increased plunge cuts has been ignored while calculating the total machining time in the above methods. In contrast to the previous work, the proposed method in this paper uses multiple tools to minimize both the machining time as well as the number of plunge cuts. The following section describes the overall problem framework and solution approach for this paper.

3. Problem definition and solution overview

Pockets can be defined as sculpted regions on the face of a workpiece formed by the impression of some shape to a given depth. The main parts of interest in a pocket for this research are pocket *boundary*, *islands*, and *necks* (Fig. 1). The pocket *boundary* is the wall defining the region of a pocket and its shape generally dictates the ease or difficulty in machining. An irregular boundary will require a smaller tool and more time while a smooth boundary will require a comparatively larger tool and correspondingly shorter amount of time. A boundary *neck* can be defined as a region where the sides of the boundary wall come very close to form a narrow region. If there are several necks in a pocket of varying width, a single tool strategy would have to use the smallest width as the single tool diameter. The last feature, *islands*, forms another type of the necks called *island necks*. An island can be defined as an un-machined region (by design) inside the pocket area. They are considered a major source of problems because their presence increases the complexity of the pocket and often require significant modification of the methodology used to design the tool path. Necks not only complicate the tool path design procedure by tool size restriction but can also lead to discontinuous tool paths in the pocket. The advantage of a single tool approach of continuous tool path is negated by the fact that it often leaves multiple centers of tool paths which may require multiple plunge cuts (Fig. 2).

The method of this paper uses a pocket subdivision process to solve the problems of single tool approaches. The subdivision process can be defined as the process of dividing a pocket into smaller regions. Each of these regions is analyzed separately, and then they are recombined in the tool selection process so that the continuity of the pocket tool path is maintained. The initial tools are selected separately for each sub-polygon depending on its features. A small region in one sub-polygon does not affect the tool selection for other sub-polygons; hence, this subdivision facilitates the use of multiple tools. The final tool selection process attempts to optimize the selection procedure based on machining time and the number of tools. The weight placed on either machining time or number of tools can be adjusted accordingly for a particular need. In this work, a branch and bound approach is used to solve this optimization problem. The new approach can be summarized into three important steps: (1) polygon subdivision – the pocket is subdivided at boundary and island necks, (2) tool selection – based on an initial set of tools, selection refinement is conducted to obtain final tools, and (3) polygon sequencing – sequencing of the sub-polygons to avoid multiple plunge cut operations.

3.1. Polygon subdivision method

The goal of polygon subdivision is to separate the polygon into smaller region that are divided by *necks* formed by combinations of

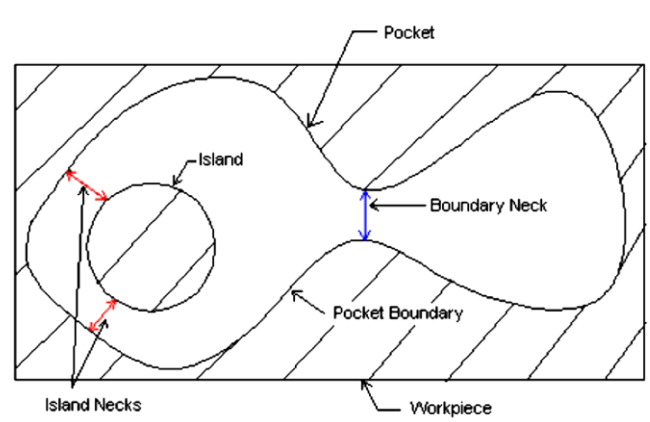

Fig. 1. Pocket boundary features.