Automated microplanning for 2.5-D pocket machining

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Abstract

Microplanning, as defined in this research, consists of the decomposition of machining features generated by the macroplanner into sub-features, selection of appropriate tools to machine these sub features, and the selection of appropriate cutting parameters. This paper describes the implementation of a microplanner that is capable of optimally accomplishing the abovementioned tasks, either minimizing time or cost.

Keywords: Pocket Machining, Feature Decomposition, Process Planning, Optimal Tool Sequence Selection

Introduction

Process planning (Sarma 1997) is the act of generating a plan for manufacturing a part from a given design. This research concentrates on manufacturing using the three-axis milling process. In previous research (Sarma 1997, Stori 1998, Sundararajan and Wright 1998), process planning has been subdivided into three distinct tasks, namely, macroplanning, microplanning, and tool path planning. Macroplanning is concerned with generating machining features (Sundararajan and Wright 1998) from a given CAD model and sequencing the order in which these features are manufactured. Microplanning is concerned with the decomposition of features generated by the macroplanner into subfeatures depending on feature geometry and on the tools available, the selection of appropriate tools, and the selection of appropriate cutting parameters. Tool path planning is concerned with the generation of actual NC codes for the three-axis milling machine.

Features generated by the macroplanner can either be pockets or holes. Holes of a given diameter can be machined with drills of the same diameter. On the other hand, different milling tools can be used to machine a pocket. To reduce the time needed to machine a given pocket, it is necessary that large tools be used to remove large amounts of material quickly. Subsequently, smaller tools have to be used to clean up areas where large tools cannot enter. It is therefore necessary to subdivide a given pocket into subpockets to be removed by different tools. Overall, there is the issue of selecting a combination of tools that will result in the minimum total machining time or cost. Significant time savings in the manufacturing cycle can be achieved by automating the process of pocket subdivision, tool selection, and selection of cutting parameters.

Previous work in this area concerns the subdivision of pockets and the selection of an optimal tool sequence. Lee and Chang (1995) described the selection of cutters based on the minimum channel width in a 2.5-D pocket. A 2.5-D pocket is defined as the volume generated by sweeping a 2-D profile along the normal of the plane containing the 2-D profile for a specified distance called depth (Figure 1). Minimum channel width is the width of the smallest constriction in the 2-D profile of the pocket. This is a serious limitation as larger tools are not considered even if they are capable of clearing large parts of the pocket. Moreover, this method is restricted to the use of a single tool.

Bala and Chang (1991) developed a method by which two cutting tools may be selected. The smaller of the two tools had a radius equal to the desired corner radius of the pocket, while the larger tool is selected to clear the maximum amount of material possible. When the larger tool is done with machining, corner cleanup is done by moving the smaller tool along the boundary of the pocket. Bala and Chang did not consider total machining time when selecting the tools.

Chen, Lee, and Fang (1998) extended Lee and Chang's work to 3-D freeform pockets. They considered such 3-D pockets as a series of slabs of uniform thickness and flat bottoms. Tools were selected for each of the slabs based on Lee and Chang's method. Chen, Lee, and Fang also developed integer programming and dynamic programming methods to select the optimal tool sequence based on minimal tool changes. However, machining time was not considered in selecting the tool sequence.

Veeramani and Gau (1997) developed an approach based on the Voronoi mountain to decompose pockets into subpockets to be machined by different tools. In the second part of their work, they used dynamic programming to select the optimal sequence of tools. However, their method does not address the issue of inter subpocket boundaries, and the pocket geometries were restricted to prismatic polygonal pockets with rounded corners.

Lim et. al. (2000) developed a contour offset approach to subdivide 2-D contours into regions for different tools. In the second part of their work, they used a recursive tool-ranking scheme to select an optimal sequence of tools. The search for a good tool sequence is a greedy algorithm that does not guarantee optimality. Lim et al. also did not address the issue of inter subpocket boundaries.

Commercial CAM systems (SDRC-IDEAS 2000, Pro/ENGINEER 2000) have automated tool path generation routines. Typically, they generate spiral or zigzag tool paths; however, selection of appropriate tools and cutting parameters is left to the human process planner. Typically, two tools are selected-a large tool for roughing and a smaller tool for cleaning up the leftover material. The selection of the tools is typically done manually based on the educated guess of an experienced machinist. It takes an experienced process planner several iterations to generate good plans. Moreover, optimality cannot be guaranteed.

This paper describes the implementation of a microplanner for the machining of 2.5-D pocket features on a three-axis machine. The manufacturing resources are represented in terms of a tool database that not only comprises a list of all available tools but also encompasses the tool holder geometry and the cutting parameters (feeds, speeds, depth of cut, width of cut). A 2-D contour offset approach is used for finding accessible areas for various tools. Accessible area is defined as the region within the 2-D contour that the tool can reach without gouging the boundary (Figure 2). The decomposition of the pocket into subpockets is carried out based on the accessible areas of various tools. It must be ensured that at least one tool traverses over inter subpocket boundaries. If not, slivers of material may be left over on the inter subpocket boundaries. A scheme to cover inter subpocket boundaries has been developed.

The main contribution of this research work is posing the problem of optimal tool sequence selection as finding the shortest path in a single-source, single-sink, directed acyclic graph. This algorithm guarantees that the tool sequence selected will be optimal within the assumptions stated in the next section. Other contributions include pocket subdivision and inter subpocket boundary covering. The system developed in this research is flexible enough to accommodate different tool sets and different cost functions.

Problem Statement and Formulation

The problem addressed in this research is that of selecting a sequence of end milling cutters to machine a 2.5-D pocket with the goal of incurring the minimum combined cost of tool wear and machining time, while taking into account the specified cutting parameters of the tools, the size of the tools, and the pocket geometry.

In the first step, the available set of tools is pruned by eliminating all tools that have a cutting length less than the pocket depth. In the second step, all tools that cannot enter the pocket without gouging are eliminated. The remaining set of tools is called the usable set of tools. Within the usable set of tools, larger tools have smaller accessible areas within the 2-D contour of the pocket as compared to smaller tools. Moreover, the accessible area of a tool is always a subset of the accessible area of a tool that has a smaller diameter. These facts are valid under the assumption that the tool and tool holder assembly do not collide with the final part within the accessible area of the tool in question. This means that if a sequence of tools is used to machine a given pocket, starting with larger tools first and subsequently using smaller tools, the area that has to be covered by any particular tool is dependent only on the immediately preceding tool in the sequence.

All possible sequences can be represented as a directed graph (Figure 3a). In the graph, the nodes represent the state of the stock after the tool named in the node is done machining. Upstream nodes in the graph have tools of larger diameter compared to downstream nodes. Edges are weighted with the cost of machining to go from one state of the stock to another. The first node represents the given stock. The smallest tool appears at the leaf node. It always is the largest tool in the usable set of tools that has the requisite length and can cover the entire area of the 2-D contour or approximate the given contour to within an acceptable corner radius. Because of the observation made in the previous paragraph, the nodes of the graph that have the same tool named in them can be collapsed into a single node. This greatly reduces the complexity of the graph. Moreover, each tool pair can be analyzed independent of the tool sequence it occurs in. Figure 3b shows the reduced graph. This is a single-source, single-sink directed acyclic graph. The optimal sequence is the one that has the least cost. Standard shortest-path algorithms can be used to find the optimal sequence. This formulation includes three main tasks:

(a) Finding the accessible areas for different tools.

(b) Given a tool pair, subdividing the pocket between the tools in the tool pair. An associated subtask is that of covering inter subpocket boundaries.

(c) Finding the cost of going from one node in the graph to another.

Subsequent sections will deal with the three tasks in detail.

Finding Accessible Areas

Any tool that has a non NULL accessible area and requisite tool length is considered to be a usable tool. Determining the accessible area requires knowledge about tool and pocket geometry. A concise tool description schema has been developed for this purpose. Figure 4 shows this schema. It lists various dimensions of the tool like diameter, total length, cutting length, and cutting parameters depending on the type of cut (roughing, finishing) and type of work material. The values are obtained from standard data handbooks (Oberg et al. 1988).

The following steps are followed to obtain the accessible areas for a given tool within a given pocket contour (Figure 5).

Step 1: Get the outer contour of the pocket. Get island contours that lie within the pocket contour.

Step 2: Shrink outer contour by a distance equal to radius of the tool.

Step 3: Grow island contours by a distance equal to radius of tool.

Step 4: Subtract result of step 3 from result of step

2.

Step 5: Grow result of step 4 by a distance equal to radius of tool.

If the tool has the requisite cutting length and has non NULL accessible area, one must also ensure that the tool and tool holder assembly does not collide with the final part. The following procedure is followed to check for collision and eliminate the tools that do collide (Figure 6).

Step 1: Get the outer contour of the accessible area.

Step 2: Offset inward the result of step 1 by the tool radius.

Step 3: Sweep the cross section of the tool and tool holder assembly along the offset contour that is the result of the step 2.

Step 4: Intersect the result of step 3 with the geometry of the final part.

Step 5: If the result of step 5 is not NULL, eliminate the tool from the set of usable tools.

Tool Pair Analysis and Pocket Subdivision

Summary

This paper addresses automated tool selection for 2.5-D pocket milling. A concise tool database schema was developed to represent all available tools and their tool holder geometry and also the associated cutting parameters. Usable tools are selected based on accessible areas and analysis of the possible interferences. Accessible areas for each tool are calculated using 2-D planar offsets. Pockets are subdivided into subpockets that have to be machined by different tools. The problem of inter subpocket boundaries was addressed through an algorithm that extends subpockets to effectively cover inter subpocket boundaries. The problem of identifying the optimal tool sequence was reduced to that of finding the shortest path in a single-source, single-sink directed acyclic graph of all ordered sequences of usable tools. Cost functions to account for machining cost as well as tool wear and tool replacement were developed.

The approach developed here can readily be incorporated into commercial systems. Once macroplanning has been accomplished either manually or by automatic means, the identified pockets can be sent to the system described above, specified by their 2-D contours and depths. The system will then return optimal tool paths either with respect to machining time or machining cost.

This approach to selecting a tool sequence is a significant improvement over current practice, which relies on an experienced process engineer to select appropriate tool sequences and to subdivide the pockets. Significant time savings can be achieved by the automated process of selecting near-- optimal tool sequences.

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