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Simulation and verification of belt grinding with industrial robots

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Abstract

A new simulation and verification system of belt grinding with industrial robots is presented in this paper. The workpiece surface is represented by a discrete height field, an array of extended height segments, and a fast collision detection algorithm using ***k***-DOP bounding volumes is adopted to accelerate the localization of the contact area. A local grinding model is incorporated to decide the real material removal. Unlike the usual global linear model, it determines the removed material in the contact area based on the acting force distribution and some other grinding parameters. With this new system, robot programmers can improve the path planning by visualizing the manufacturing process, predicting potential problems and measuring dimensional errors.

Keywords: Simulation; Verification; Belt grinding; Industrial robots

1. Introduction

The simulation and verification technologies of numerical controlled (NC) manufacturing processes have been developed since the end of 1970 s and a lot of significant accomplishments have been achieved. This kind of technology has an important impact on the product development and quality control. The production process can be simulated on the computer to avoid expensive and time-consuming experiments. If any potential problem, such as collision, improper parameters or gouge, is found during the simulation, the manufacturing process can be adjusted to meet the quality demands. Due to these features, simulation and verification hold the tremendous promise for cost reduction, quality improvement and time-to-market shortening.

Many methods have been developed to simulate turning, milling and wire-EMD during the last decades. But little work has been done in the area of belt grinding with industrial robot. With the introduction of industrial robot as manipulator, it is especially suitable to process free-form surfaces with complicate geometry like turbine blades and water taps.

1.1. Simulation and verification technologies

Direct solid modeling was the first approach used in NC simulation. But the high computational cost limits its usage. So a lot of approximate methods have been brought up. Van Hook [1] developed a real-time shaded display of a model, which is suitable for manufacturing simulation. The workpiece and tool geometries are represented by dexels and the geometry update is achieved by boolean set operations on the one-dimensional dexels. Takafumi [2] also used an extension of the z-buffer method (called G-buffer) to simulate NC machining. Jerard [3] proposed a completely different approach. The designed surface is approximated by a set of points. The workpiece is represented by the associated vectors on these points. These vectors are shortened to the amount of over- or under-cutting error when tool moves over them. This method is very efficient for error evaluation but inconvenient to calculate the material removal rate. Some other methods based on these basic data structures are also developed [4–6]. Nowadays, most of the commercial CAM software, such as Vericut, PowerMill, masterCAM, etc. can simulate both 3-axis and 5-axis milling manufacturing quite well. But concerning belt grinding processes, things become

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much more complicated because the real removal is simultaneously affected by many factors. So there are comparatively much less achievements in this area.

1.2. Local grinding model

It is more difficult to simulate grinding than other processes like turning and milling, which render the material removal process mainly using boolean set operations between the swept volume of tool envelop and the workpiece stock. In these processes, it is helpful to take into account environmental and cutting parameters but usually not necessary. While in belt grinding the actual removed material is a result of the combination of many factors such as grinding belt type, material type, elasticity of grinding wheel, environment temperature and so on. Hammann [7] introduced the following global linear grinding model in 1998:

$$r = C_A \bullet K_A \bullet k_t \frac{V_b}{V_w l_w} F_A \tag{1}$$

where r, material removal rate; C_A, constant decided by experiments; K_A, combination constant of resistance factor of the workpiece and grinding factor of the belt; k_t, grinding belt wear factor; V_b, grinding velocity; V_w, workpiece infeed speed; l_w, width of the grinding area; F_A, acting force between the contact wheel and the part.

Many factors in this model have a certain value during the process and their values can be got from a series of designed experiments. The constant C_A and K_A in (1) represent the combination of these factors. The relationship between the removal and other parameters k_t, V_b, V_w and l_w also can be described as function curves through experiments. For simple shape workpieces, the global removal is roughly linear to the global force given that other factors are unvaried. But for free-formed surface grinding, this linear global relation of this model is no longer sufficient. In such a case, the force is not uniform anymore and the local distribution should be considered. Then the removal distribution can be approximated based on the local force distribution and other parameters' influence.

Calculating the force distribution problem is actually a contact problem. Blum [8,9] and Suttmeier [10] worked out a Finite Element model that considers this contact problem as a Signorini contact problem [8,11]. To overcome the time consuming computation of FEM, Zhang [12] developed a very fast model based on support vector machine to approximate a certain contact situation out of the precalculated FEM database with a desired precision.

1.3. Motivation

Although some powerful off-line programming systems exist, robot programming is still a labored task when handling complex surfaces. So it is of great importance to develop a simulation system to help predicting any potential problems, assessing grinding error and correcting improper grinding paths. To achieve such a goal, a suitable simulation technology should be developed, which works like those mentioned technologies but uses the local grinding model to calculate the removal. The idea of a discrete height field based on surface points set and associated height segments is adopted to represent the workpiece. The fast contact detection algorithm using ***k***-DOP bounding volumes is also introduced and extended in order to improve the efficiency

2. Discrete height field representation of free-form surfaces

The spatial partitioning simulation technologies such as dexel and G-buffer are very efficient in representing complicate solid geometry while the discrete vector intersection approach performances better in free form surface simulation. Considering that the workpiece machined in this system usually has surfaces with complicated geometry, a method called discrete height field is developed. It is derived from the technologies proposed by Jerard [3] and Ayasse [13]. Unlike the spatial partitioning technologies, this method takes designed surface as the basis and discretizes it into a points set. Then the associated normal vectors are used to intersect the stock using ray tracing. This approach has the same working procedure: discretizatin, localization and intersection as the original method used by Jerard. But the major distinctions are that an array of short segments distributed on both sides of the designed surface is used and a faster localization method based on ***k***-DOP collision detection algorithm is introduced. In addition, the intersection does not happen between vector and tool or tool envelop any more. Instead, it happens between height segments and the real removal, which is calculated by local grinding model.

2.1. Discrete height field generation

As mentioned above, the first step to generate a discrete height field is to select a point set to approximate the designed surface. The workpiece surface is regarded as a two dimensional domain and the vertices of a regular grid in this domain is taken as the point set. The point number is proportional to the user-defined precision. Then, the associated normal rays on these points are used to intersect the stock surface. The segments between the designed surface and stock surface form a shell. In some cases, the stock is defect and results in some segments under the designed surface. This kind of situation is hard to handle since the corresponding ray does not intersect stock at all. But fortunately, it seldom happens and can be precluded in advance. Since the manufacturing tolerance is in both direction of the designed surface, we extend the segments under the surface to a certain length. The choice of distance