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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（情報科学）　氏名　張　同

学 位 論 文 題 名

Using Four-Dimensional Geometric Models for Representing Dynamic Machining Process
（動的な機械加工プロセスの表現への 4 次元幾何モデルの適用）

In the trend of Industry 4.0, the relationship between cyber field and physical field is gradually being established and deepened. In the field of processing and manufacturing, cyber field can be used to simulate the processing. This simulation can guide the real processing from multiple aspects and be applied to various processes.

In the machining simulation process, the interaction between the cutting tool and the workpiece, known as cutter-workpiece engagement (CWE), is essential for assessing the cutting process's quality. To achieve a more precise evaluation, three-dimensional (3D) geometry milling simulation systems have been extensively developed and utilized. These systems are designed to estimate the quality and efficiency of the cutting process beforehand, with a particular emphasis on the CWE.

In this study, the authors tried to propose a series of CWE analysis system based on four-dimensional(4D) geometric model in spatio-temporal space. This system consists of applications of different 4D models, corresponding processing algorithm and a flow of analyzing process of CWE.

Comparing to 3D representation of machining 4D representation is an integration. Common 3D representation of a CWE process can be consisted by a series snapshots of moving 3D shapes or 3D model with it moving trajectory. Regardless of the method, expressing the geometric changes of CWE requires some discrete data, and it is also discrete in time. At the same time, the state of the intermediate time needs to be extrapolated or interpolated from the known time state, and this part of the calculation is unavoidable.

The 4D CWE system contains 5 fundamental part:

As the part A, a kind of 4D models called tool-occupied region (TOR) is constructed. It generates by a part of the tool model which extract from 3D cutting tool shape library with the rotation and translation in a very short period of time. It is essentially a differentiation of the tool's 4D movement trajectory. Additionally, 4D tool models can be stored in a moving tool shape library. Part B serves as an editor for users who wish to design the TOR by configuring the tool' s location, orientation, speed, and other parameters.

Apart from inputting tool data, Part C involves inputting a 3D workpiece model for computation alongside the TOR. Additionally, a nominal product model is inputted for reference.

Part D constitutes the pivotal segment of the entire research. The process involves determining cutter-workpiece engagement in Spatio-Temporal context, aiming to identify the intersection between the edited TOR and a 3.5D workpiece model generated by sweeping a static 3D workpiece along the T-axis. The resulting data is extracted and fed into a 4D cutting process library, applicable across various scenarios.

Part E list a part of possible potential applications, such as case search, condition verification, cutter path planning, optimization, monitoring reference, case search, deep learning, knowledge base, process visualization.

Part D is the core part of the research and dissertation, the author have developed three different strategies to analyze CWE in 4D space:

The T-map method emphasizes continuity in the time axis direction and abandons continuity in 3D space. It is a method that extends the traditional Z-map. T-map is based on XYZ-hyperplane grids (voxel) and extend T-map segments along T-axis. T-map method records the length of T-map segments. This length represents the time period that the 3D voxel exists on the workpiece model and the author called it "first touch time". For T-map method, parallel processing strategies have been introduced to accelerate the computing process and reduce time cost.

The 4D imprint method are developed to emphasizes the continuity of the 3D surface and simple structure for computing. But it gives up the continuity of the T- axis. The basic idea of 4D imprint is split 4D mesh by T-axis, process in 3D space, then connect them to 4D mesh again. The algorithm extracts vertices data and relationships from a 3D mesh model of the workpiece. Specifically, the vertices are calculated with cutter trajectory's 3D temporal slices. Algorithm record points moving and re-mesh the result of CWE.

Set operation based method is a general method. Its basic principle is very simple, solving CWE situations through set operations between geometric models. This method ensures continuity in all directions and also withstands the data explosion caused by the introduction of 4D models, so it requires an extremely long computing time.The set operation results of the two 4D models were combined with the original tetrahedrons and subdivided tetrahedrons.

Finally, this research introduces 4D model to conduct CWE analysis in spatio-temporal space. An entire system frame of CWE analysis based on 4D geometric models was established. Additionally, three different methods that utilize 4D geometric models for CWE analysis explain detailly in this article.

The author expects this research can become the bridge of 4D geometric model in spatio-temporal space and its machining application. In addition, the research also enable to serve as a starting point for future research which based on 4D geometric model, 4D space and corresponding algorithms.