論文の内容の要旨
Abstract of Dissertation

論文題目 Model-based Planning System for CNC-driven Multi-axis 3D Surface Scanning Machine (CNC 駆動 3D サーフェススキャニングマシンに適したモデルベースプランニングシステムに関する研究)

氏　名：　　伍　鵬

Abstract（本文）

3D (three-dimensional) surface scanning is widely used in the industry recently. It is applied in the reverse engineering field and dimensional inspection field mainly. The advantage using 3D surface scanning is its high measurement speed and wide surface of the measurement range. At the same time with the development of surface scanning techniques the scanning accuracy has been greatly improved.

However it is actually a time-consuming process to scan an object though the scanning speed itself is high. The reason is that it usually requires taking several tens or hundreds of scans (shots) to measure an object surface and thus need to plan scanning positions of the scanning device. It is very difficult to define the best scanning positions that achieve sufficient scanning accuracy. It is also taken into account to avoid occlusions in the sensing area, collisions between the scanners and the objects, and leak of scanned surface. Generally expert engineers spend tremendous amount of time on planning carefully with these conditions depending on the shapes of the object surfaces, scanning sensor specification.

This research aims at developing a planning system for automatically generating such scanning positions and a scanning path to continuously scan an object at these scanning positions. This is based on two technological backgrounds. One is a CNC-driven 3D surface scanning machine by which the positions (locations and orientations) of a scanning device can be numerically controlled from a computer system. Thus once the scanning positions are defined by the planning system, they can be fed to control the CNC-driven 3D surface scanning machine. The other is 3D CAD (Computer Aided Design) model of objects to be scanned. In industry, products are now designed by using 3D CAD systems. So it can be assumed that the 3D CAD models of the parts are available

for the scanning process. Our planning system fully utilizes this 3D CAD model information of the object to be scanned to generate scanning positions and paths. Specifically, we use triangular mesh representations of 3D CAD models.

The system architecture consists of three parts. The first one is a scanning simulation. A multi-axis scanning machine simulator is constructed. A 3D mesh model of a scanned object surface is inputted into this simulator. The simulator executes not only a visualization process, but also three other functions. A visualization process is that motion commands can be executed by executing the simulator with visualization functions. The other three functions of the simulator include data acquisition, collision detection and occlusion detection. Data acquisition can be used to capture the scanned triangle IDs and coordinates of the object surfaces. This function is based on a graphics hardware acceleration algorithm. The occlusion detection is also based on the graphics hardware acceleration algorithm. The collision detection can be used to detect collisions between the scanning machine and the object surface. In this way, the computation time can be balanced between GPU (graphic processing unit) and CPU (central processing unit) in order to improve computing speed significantly.

The second part is sensor position planning to generate scanning positions (we call them sensor configuration positions hereafter.) based on 3D mesh model of the scanned object. First the model is divided into a set of cubic cells each of which contains a set of triangles representing a part of the object surface. Then a sensor configuration position is determined to each cell by taking into account the above mentioned factors such as scanning accuracy, occlusions, collisions and leaks by using the simulator. This cell decomposition is made in two levels for rough position planning and fine planning. At the rough position planning the object is uniformly decomposed into an array of cells whose size is determined by the maximum sensor scanning scope. The fine position planning is needed to achieve good coverage and accuracy for complex shape surface. These cells are further subdivided if a valid sensor configuration position cannot be defined and thus form a multi-root octree structure. The multi-root octree cells are made up of those un-completed scanned cells from rough position planning. Again, a sensor configuration position is defined to each of the cells in this multi-root octree structure.

The third part of the research is measurement path generation. With the sensor position planning mentioned above, a set of sensor configuration positions is calculated. This is the measurement path generation that links these sensor configuration positions to generate a scanning path. The difficult problem here is to find an optimal path in terms of various aspects of scanning procedures.

Particularly, we consider scanning time and accuracy and introduce cost functions to evaluate these factors. Then an optimization method to find the best path to minimize these cost functions is proposed based on a "divide and conquer" approach. For "divide", the entire sensor configuration positions are divided into several clusters. It is called a clustering procedure in this research. Then the local optimal scanning path is calculated for each cluster. Path generation of each cluster can be considered as the same problem as TSP (traveling salesman problem). For "conquer", the optimization goal is decided first. To realize the optimization goal, two different kinds of evaluation cost functions are established. A GA (genetic algorithm)-based method is adopted for calculating the optimal measurement path generation. The speed of implementation is improved with a multi-thread method in order to reducing calculating time. The sensor configuration positions of the global cluster consist of the head and tail sensor configuration positions of each local optimized path. The global path is generated with the same method of the local path generation and the same evaluation cost functions are used, and besides, the cost between the two head and tail sensor configuration positions from the same local cluster is considered as zero.

This research is aiming at the application to the scanning in automotive industry, such as measuring stamping die models and car body parts. Some examples are implemented with our developed planning system. The automation and high calculating speed show the efficiency of this system. The experiments on real CNC-driven surface scanning machine have also proofed the effectiveness of our proposed methods with the cooperation of maker experiments.