Force Profile study of Virtual Cutting

Five Keywords:
Virtual cutting, Cutting force, polygonal model, Voxel model, Tactile display, Force sensor

Abstract:
Research of virtual surgical operations has advanced in recent years based on virtual reality technology. One basic operation is virtual cutting simulation. In order to realize the virtual cutting, there are two types of research, i.e. using a voxel model and a polygonal model. The voxel model expresses volume and is made by a small cube size. The polygonal model expresses the surface and is constructed by a triangular polyhedron. Tanaka's research using the voxel model allows the object to be cut through a simple algorithm that eliminates the interfering voxel between cutter and object. Then, the cutting operation process, accompanied by the advance of the knife, can be easily visualized. However, it is difficult to express the smooth surface caused by the resolution of the voxel model. To avoid this problem, the size of the cube can be reduced to improve the surface quality. However, the amount of data increases greatly and the processing of surgical simulation takes a long time. On the other hand, research using the polygonal model can construct a smooth surface. However, it is difficult to gather information about the inside of the object. In this research, surface shape is represented by a polygonal model, and a voxel model is used for expressing the inside of the model locally. We developed the virtual cutting simulation system by combining the advantages of both the polygonal and voxel models. Moreover, the virtual cutting system is evaluated by an improved analysis model compared with real cutting.

Voβ’s research was not consider force profile. The composition of a development system is shown in Figure 1. Triangular polygon data is used for the 3D surface shape and robot mechanism, operated with the right hand, are used for tactile display. A force sensor is constructed from two thin parallel detectors, inserted into the sensor body, and force is detected by 4 strain gauge. Cutting forces of actual and virtual are measured by attaching the force sensor to a knife and the tactile display handle. In the cutting process, surface points of voxel and vertex position of the polygon will be renewed. Recreation of surface points of voxel is constructed in two parts; one is depth direction and other is cut direction. For each direction, the force value of the cut simulation is investigated and the surface point is advanced if the force value exceeds the critical force for each direction. Critical value of force and exceed value are adjusted for cut material. Tactile display can formulate the force and contact points from polygon data, after which we must renew the position of polygon vertex according to the transfer of voxel surface points. The cutting stick is making progress in the object from the above-mentioned mechanism. Here, elastic, friction, and damping coefficients are given as physical properties of a cut object. And, critical force value of depth and cut direction are given as a
cutting parameter. In this case, as the size of the cutting stick and the triangular polygon are similar, then division of the polygon is not considered. Moreover, it is desirable to register the information of internal physical property to each voxel, thus we set uniform property of every voxel in this experiment.

Moreover, cutting is executed by buring the knife edge in the material, instead of the point. It is line cutting. Then, local stiffness is added which increase by depth of cutting edge. Hereafter this local stiffness is called depth cutting stiffness (DCS). Coefficient of DCS is $0.066E/mm$ from the experiment in which we measured the increment rate of different cutting depths. $E$ is material stiffness.

Here, we consider two cutting methods. In the first method, cutting depth is proportional to cutting length (Proportional depth cut). In the second method, the first cut is to depth direction until setting depth, and the next cut progresses at the same depth (Constant depth cut). Figure 2 shows the cutting force profile of sponge and virtual cutting for proportional depth cut. In the figure, b) is force profile which considers depth cutting stiffness; this profile is similar to actual cut a). Figure 3 shows the cutting force profile of sponge and virtual cutting for constant depth cut. In the figure, b) is force profile which considers depth cutting stiffness; this profile is similar to actual cut a)

Changing the force profile is confirmed with setting the variety of the cut parameter. Moreover, the force profile of cutting must be more precise, considering depth cutting stiffness, to make a similar virtual simulation as a real cut.