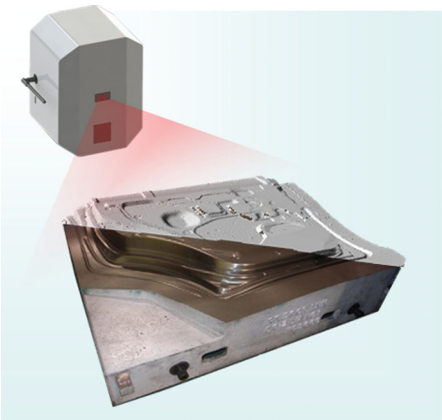
Simulation for Collision Prediction Based on "Visionplus" Non-contact Measurement System



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Mitsubishi Heavy Industries, Ltd. (MHI) developed an on-machine shape measurement system with non-contact sensors and modeling technology. These technologies can accomplish various objectives, and the entire system is named "Visionplus." The Standard Triangulated Language data (STL data)(Note 1) constructed with this system produce on-machine, real-time simulation for collision prediction. Furthermore, this simulation has been developed to a practical level. This paper introduces a method of three-dimensional modeling and examples of simulation for collision prediction based on "Visionplus."

Note 1. Standard Triangulated Language is the industry-standard file format for 3D CAD systems developed by 3D Systems, Inc.

1. Introduction

In machining, various factors often cause unexpected issues for machine tools that cannot be predicted from the machining condition. Consequently, to maintain efficient and stable machining precision, machine conditions must be determined precisely at all times. To minimize the negative effects of poor workpieces, mistakes in machining, variations of machine characteristics and other problems, a shape recognition system that can model the shapes of workpieces and tools, and then quantitatively evaluate and control them is necessary. Therefore an on-machine measurement system with non-contact sensors has been developed.

This paper introduces the principles and characteristics of a three dimensional shape measurement system that can be used to accomplish various objects, the method to construct a three-dimensional model and on-machine and real-time simulation for collision prediction based on this system as practical examples.

2. Outline of Visionplus System

2.1 Principles of Visionplus

"Visionplus" is a collective on-machine measurement system with non-contact sensors that recognizes the state of the workpiece, jig, tool and other components and models their shapes on a machine. Visionplus includes a hole position measurement system with non-contact sensors used specifically for the construction of machine parts (automatic compensation of hole position, determination of workpiece fixing, quality of workpiece, etc.) and a vision-based tool shape measurement system. **Figure 1** shows examples thereof.

This paper introduces the technology of a three-dimensional shape measurement system with a laser scanner. This measurement system with a laser scanner enables the measurement of workpieces and jigs at any stage of the machining process, and makes three-dimensional models thereof.

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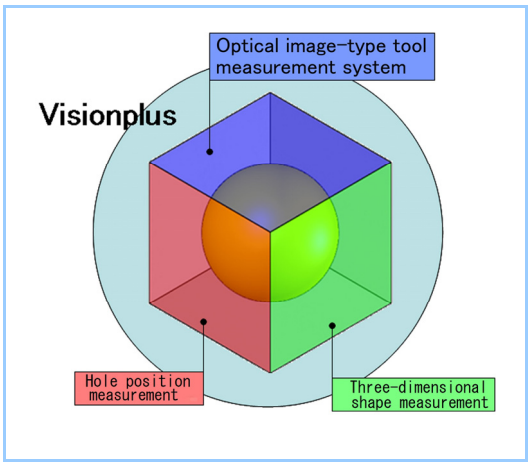

Figure 1 Concept of Visionplus

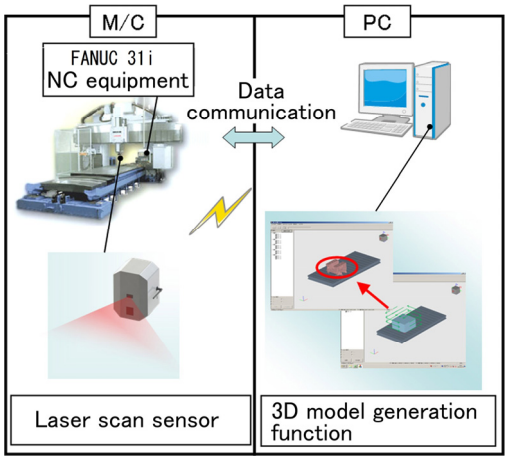

Figure 2 Equipment configuration

2.2 Mechanism of measurement system

Figure 2 shows the configuration of the system. The system only requires a sensor unit, a dedicated personal computer, and a wireless communication device. Consequently, it is a very simple configuration. To make the measurement system automatically connect to and disconnect from the machine tool, the sensor controller, wireless communication device and battery are integral to the housing, so that the measurement device is made wireless. Specialized software must be installed on the personal computer for this system. **Figure 3** shows the configuration of the software.

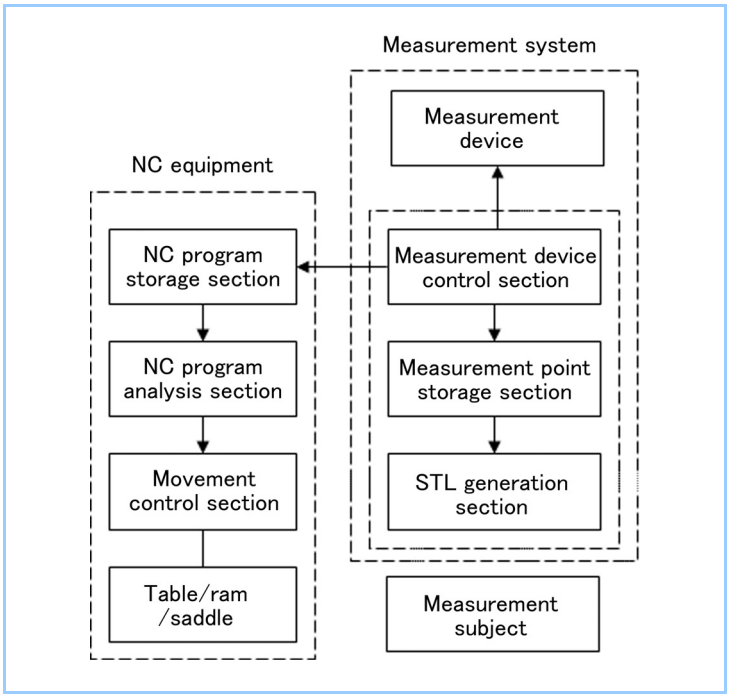

Figure 3 System configuration

The measurement procedure is as follows:

(1) Set workpiece on machine

(2) Input specification of workpiece

(3) Initiate machine operation according to automatically calculated measurement path

(4) Scan the workpiece from four sides and the top surface and measure displacement

(5) Calculate position dates (group of point dates) with displacement data

(6) Construct three-dimensional model

Figure 4 shows an example of the constructed model.

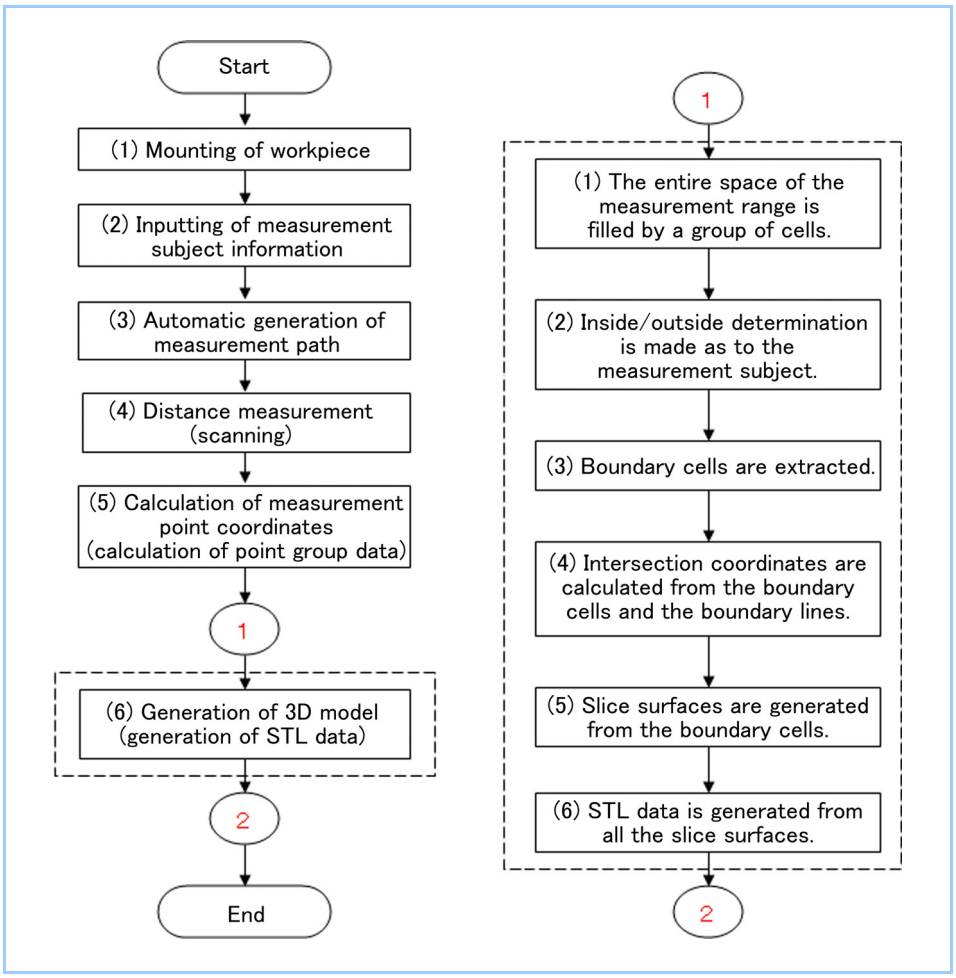

Figure 4 Operation flow

2.3 Setting for measurement

The developed software, which enables shape measurement by simple operation using a GUI(Note 2), can automatically construct the measurement path by simply inputting the estimated size and position of the workpiece. The measurement path is constructed while considering the sensor characteristics (measurement range and direction). Unnecessary measurement processes can be eliminated by the operator choosing the appropriate surface and measurement path in the GUI based on the measurement conditions. **Figure 5** shows the GUI.

Note 2. "GUI" refers to "graphical user interface," a type of interface that represents the display and motion graphically on a screen in order to improve usability for the operator.

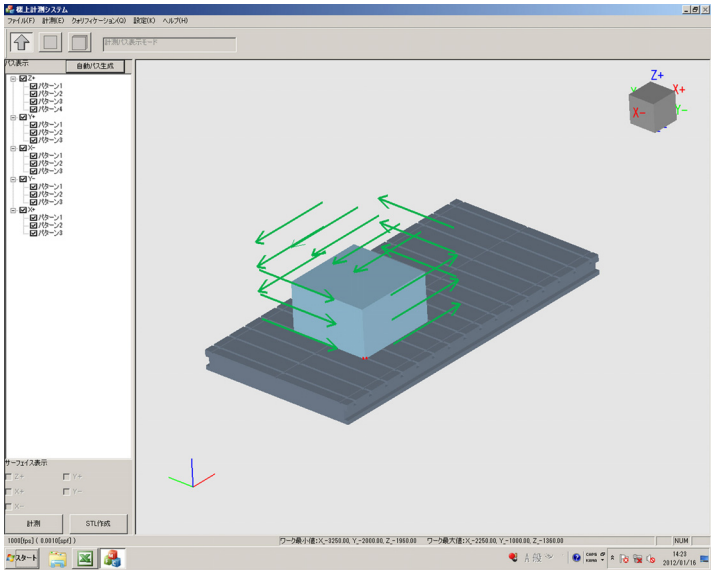

Figure 5 GUI screen for measurement

3. Characteristics of 3D Model Generation System

3.1 Measurement sensor unit

In general, measurement with a laser scan sensor is effected by the material characteristics and the surface properties of the subject. Laser light tends to be diffusely reflected on glossy surfaces such as metal, and be absorbed on black painted surfaces. Thus, it is difficult to ensure stable precision in the measurement of workpieces with various surface properties

The system prevents the effect of the surface properties of a subject through the adoption of an automatic light modulating function to optimally adjust the laser light in real time during measurement. The system has an automatic laser light adjustment system. The system can prevent the effect of the surface properties. Even if the subject is large or significantly irregular (unevenness) in shape, it is possible to measure large workpieces on a large machine tool. The system has a wide dynamic measurement range, so that it can measure large or significantly irregular workpieces (unevenness) on a large machine tool. Furthermore, no special rotation mechanism is required to measure the subject from four sides and the top surface because the scanning direction can be freely changed by mounting the sensor unit on a standard attachment.

3.2 Model generation

To apply the measurement data to various objectives, surface and solid data in STL format are often constructed. In general, if solid data is to be generated from point group data, it is difficult to generate data satisfying the input restrictions of the application software that performs the simulation of machine operation and geometric operation. In general, solid data generated with the data of points is inconvenient. The solid data doesn't satisfy the input restrictions for the simulation of machine operation and geometric operation must be corrected.

The operator must correct the data. This system can generate model data that satisfies the input restrictions for application software, thereby eliminate the manual correction.

4. STL Data of 3D Solid Model Generation Technique

4.1 Problem and task of solid modeling

(1) Purpose of development

Depending on the use of measurement data, conventional surface data(Note 3) is sometimes enough. However, in order to be used for the application software for performing various types of geometric operations, it is no enough. Therefore the developed system is required. In the restrictions of geometric operation, the most important one is that the input data must be a closed polyhedron. And it provides easy implementation in the application software and to improved robustness. The precise characteristics of input shape data are "a closed polyhedron(Note 4)," "a manifold polyhedron(Note 5)" and "no self-intersections(Note 6)."

Note 3. "Surface data" refers to a group of shape data represented only by planar elements.

Note 4. A "closed polyhedron" refers to the state in which vertices, sides and planes constituting the polyhedron are precisely combined and closed.

Note 5. "Manifold" refers to the state in which regarding the connection between the sides and planes of a polyhedron, one side is not shared by more than two planes.

Note 6. A "self-intersection" refers to the state in which triangles constituting a polyhedron overlap each other.

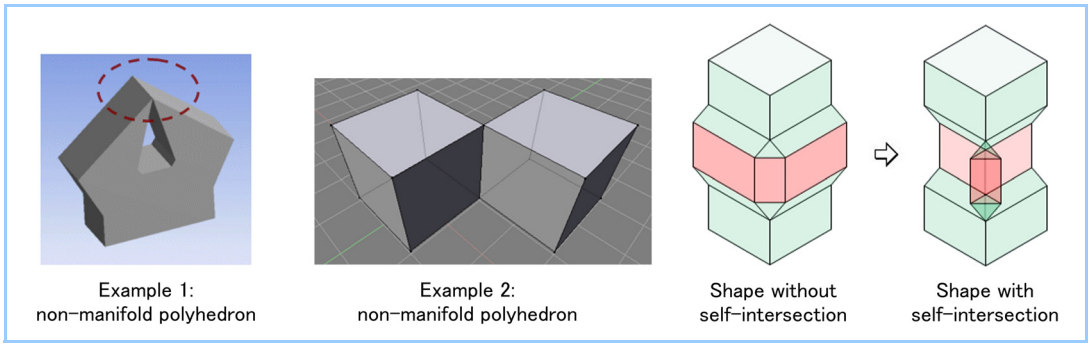

Figure 6 Restrictions on input shapes

(2) Problems

In general solid model generating process, cannot provide a completely closed shape model if there are any missing parts in combining point group data. In addition, there is a method that divides three-dimensional space into discrete voxel modeling (**Figure 7**) for attaining closed polyhedrons. However, with this technique, the result of data modeling is represented as discrete shape data. If high definition data is required, the amount of memory usage and the number of processes increases in proportion to the cube of the original values.

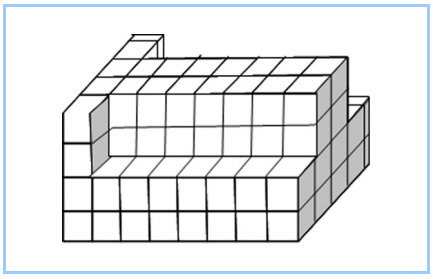

Figure 7 Voxel modeling

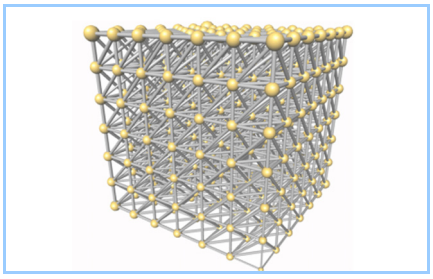

Figure 8 3D Delaunay division

4.2 Explanation of solution

The shape measurement technique of the system is divided into following three processes:

(1) The measurement subject is scanned from multiple measurement directions with the measurement sensor, thereby obtaining point group data for each direction.

(2) Implicit functions are generated from the point group data, which represent the shape of the subject.

(3) Based on the implicit function, polyhedron data is generated with a 3D Delaunay diagram.

"3D Delaunay diagram" refers to an aggregation of tetrahedrons elements (cells). Each of the cells satisfies the restriction that the circumscription-balls do not include vertexes of other cells (**Figure 8**).

The polyhedron generation processing, listed above as item (3), is the most important process. The details are discussed below. **Figure 9** shows the flow of polyhedron generation processing.

i. The entire space of the measurement range is filled by a group of cells.
ii. Inside/outside determination is made as to each of the vertices of the cells.
iii. Boundary cells are extracted.
iv. Intersection positions are calculated from the boundary cells and surfaces.
v. Slice surfaces are generated from the boundary cells.
vi. STL data is generated from all the slice surfaces.

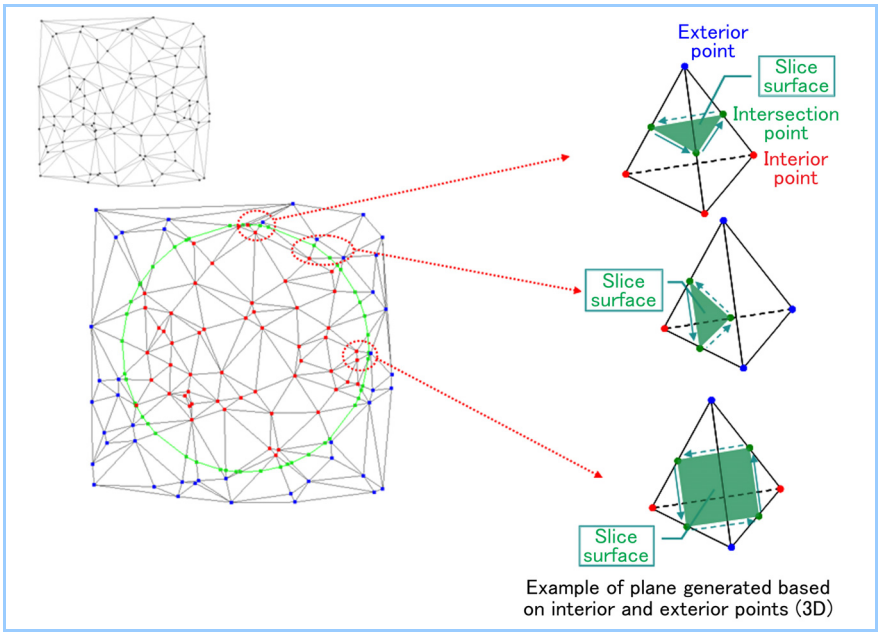

Figure 9 Flow of polyhedron generation processing

4.3 Effects of technique

This technique based on a 3D Delaunay diagram divides the entire space of the measurement range into tetrahedron cells without gaps or overlaps.

Closed and manifold polyhedrons can be generated by combining surfaces (cutting planes), even in boundaries. Furthermore, it can be assured that each of the cells is free from self-intersections, according to the definition of a 3D Delaunay diagram (Effect 1).

Since MHI has succeeded in providing a technique that can easily and reliably generate data on manifold and closed polyhedrons without self-intersections, it is no longer necessary to manually correct the shapes, which is otherwise required when using other application software (Effect 2). Compared with voxel modeling and other discrete modeling methods, this technique has a higher modeling precision to reduce the deterioration of shape accuracy because it allows the use of coordinates of consecutive intersections on boundaries (Effect 3).

4.4 Results of measurement

The results of workpiece measurement using the system are illustrated in Figures 10 and 11. Figure 10 (workpiece dimensions: L 950 × W 900 × H 650 mm) shows that the system is even capable of accurately modeling fixtures. Figure 11 (workpiece dimensions: L 1,300 × W 950 × H 350 mm) indicates that even the details of the letters engraved on glossy and casting surfaces of the metal can be measured. Note that the time required to measure a subject of approximately 1 m3 was about 15 minutes, including the time for arithmetic operation. The measurement can be performed at an accuracy of ±1 mm.

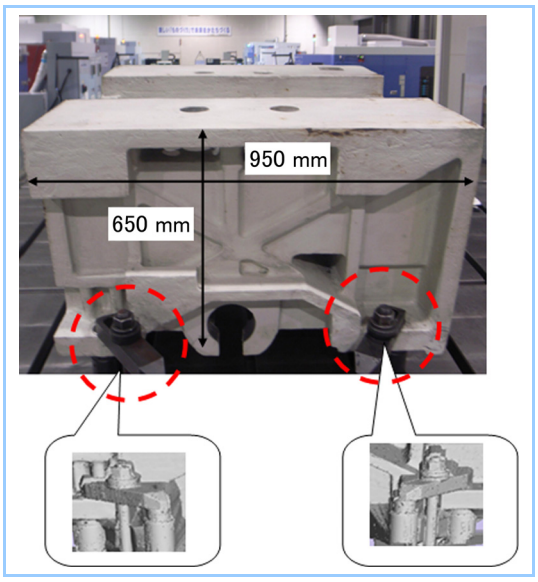

Figure 10 Measurement result (fixtures)

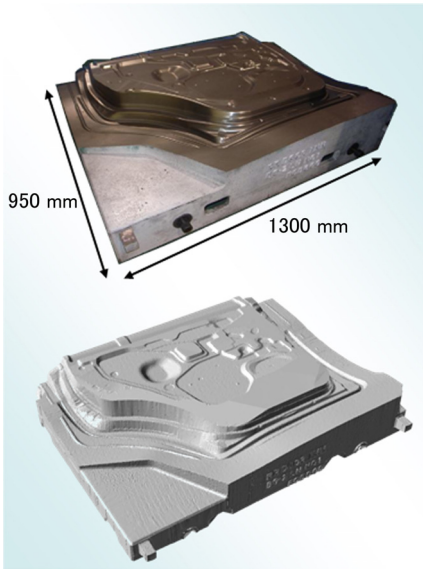

Figure 11 Measurement result (mold)

5. Example Application of Collision Prediction Simulation

5.1 Outline and characteristics of collision prediction simulation

(1) Background

When machining a single workpiece on a large machine tool, debugging is often carried out simultaneously with the processing, frequently causing collisions between the tool and the workpiece.

There have been a number of interference simulators, but in reality they are not suitable for practical use because they require CAD data of workpiece materials and fixtures.

Therefore, MHI has contrived to integrate interference simulation and the Visionplus system so as to provide a practical simulation technology to predict collisions by performing on-machine workpiece measurement and modeling, and by utilizing STL data obtained accordingly.

(2) Features

The simulation can predict collisions irrespective of the auto/manual operation mode and can accurately determine collisions on portions other than the cutting part of a tool. In addition,

the function can even recognize the constantly-changing cutting state, and it allows continuous monitoring until the final machining process. The generated model data is compatible with the simulation and thus correction is unnecessary. The function calls for a simple operation before measurement. During the period from measurement to debugging, it allows the automation of processing without operations.

5.2 Effects and advantages

Unnecessary machining sometimes occurs due to the inferior shapes of materials, because CAD models of materials are normally not available. Thus, measuring the material shapes in advance is helpful in deriving the optimum machining conditions. In addition, since the function accurately simulates the shapes and mounting positions of fixtures after setup, it is capable of predicting collisions with workpieces as well as fixtures. As a consequence, the use of the system is expected to reduce machine repair expenses that are likely to be incurred as a result of collisions, as well as the possible risk of operation shutdowns and the discarding of inferior workpieces. By incorporating the 3D solid models generated by the Visionplus system into a commercially available machine operation simulation, the efficiency of debugging work for machining programs can be improved.

6. Conclusions

We have discussed the measurement performance of the Visionplus system, which can establish an essential technology of a 3D model generation system for performing measurement on a machine tool, and which can be applied to various fields. We have also discussed the feasibility of the collision prediction simulation function of the system. We will provide a comprehensive measurement system by promoting the further development of application software.