Digitizing of Unknown Sculptured Surfaces Using a Collaborative Sensor System

Jae Hyun Kim[1], Jung Whan Park[2], Tae Jo Ko[3] and Sun Ho Kim[4]

[1]Youngnam University of KOREA, hyun7240@yumail.ac.kr
[2]Youngnam University of KOREA, jwpark@yu.ac.kr
[3]Youngnam University of KOREA, tjko@yu.ac.kr
[4]KOREA Institute of Machinery & Materials, ksh675@kimm.re.kr

ABSTRACT

In product design, a CAD model often needs to be constructed from physical part. This process is called reverse engineering and is performed through dimensional digitization and CAD modeling. There are several methods for digitizing, but commonly it can be divided into contact and non-contact type. In terms of speed, accuracy, each system has its own strong and weak points. By combining those two methods, unknown features can be digitized efficiently. This paper proposes a digitizing methodology using an approximated surface model obtained from laser-scanned data, followed by the use of a scanning probe. Each surface boundary curve and the confining area are investigated to select the most suitable digitizing path topology, which is similar to generating NC tool-paths. Experiment was executed with a simple physical model whose shape is comprised of base surface, draft walls and cavity volumes.

Keywords: Reverse Engineering, Digitization, Laser-scanned Data, Probe Path, Scanning Probe

1. INTRODUCTION

Reverse engineering (RE) is a kind of process that extracts CAD model from a physical object without CAD data. Typical applications are the construction of car, aircraft bodies, ship hulls, turbine blades, shoe lasts, telephone sets, and other household appliances[3]. The first step of the reverse engineering is digitization. For the sake of modeling, geometrical discrete points data taken by some sampling technique is needed. There are many kinds of digitization methods and devices, but commonly it can be divided in two main parts: contact and non-contact 3D scanning devices.

The most commonly used contact probe is the along probe which can move along the object surface to obtain the point data. While the data is highly accurate, scanning process is very slow and sometimes it is difficult to scan large objects[1],[10] . Computer controlled coordinate measuring machines, as an alternative, equipped with a touch trigger probe, represent the standard measuring instrument for dimensional measurement. In spite of a wide range of non-contact measuring systems becoming widely available, the CMM continues to be the first choice solution for its high accuracy and the widely available operator's skill. The sculptured surfaces of a model may require thousands of points for adequate definition, and the CMM probe diameter introduces surface offsets, which may be difficult to remove. In addition, the surfaces may be delicate or flexible.

To these regards, various non-contact digitizing methods have been developed, of which laser scanners are the most common. Compared to CMM touch probes, laser based surface measurement has the advantages of speed, non-contact sensing. The primary limitations of laser scanning systems are cost and accuracy. The scanned data is irregular, unformatted, has measurement errors, and requires extensive processing in order that smooth and accurate reconstruction of the constituent surface patches of an object may be obtained[6],[11].

An ideal reverse engineering system will automatically digitize the object from multiple viewpoints, segment the cloud data points into constituent surface patches and generate an accurate solid model. However, in case of unknown object on a measurement table, the CMM cannot be driven without operator's intervention. Therefore, it is recommended that the global coordinate is identified using a vision system and precise measurement is executed by contact sensory system. Such kind of collaborative measurement is generally used for rapid digitization and accuracy assurance[2],[5].

This paper deals with collaborating two sensory systems for obtaining cloud-of-points data efficiently for reverse engineering. One is a rapid digitization using non-contact vision system in order to know the global coordinate that was calibrated with CMM probe. The other one is accurate digitization using contact touch probe to acquire precision model. In other words, after generating a rough CAD model from non-contact digitizing data, surface boundary curve is extracted and feature characteristics are defined to the segmented each surface. Finally, efficient probe path is generated according to the feature shape similar to NC codes in CAD/CAM system. Fig. 1 shows overall procedure of reverse engineering and the scope of the research.

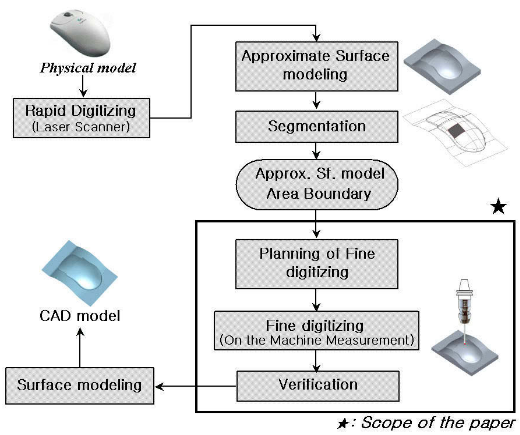


Fig. 1. Schematic flow chart of the reverse engineering system.

2. SYSTEM CONFIGURATIONS

The system is mainly comprised of three modules: probe compensation, measurement, and inspection module. Programs of Visual C++ language in Windows NT OS environment drive the overall system, and programs were developed based on commercial CAM system (Z-Master, Cubic Tech.). In this research, for the sake of easy operation, OMM system with CNC machining center was used for test bench. A sensor for OMM was scanning probe (SP2-1, Renishaw Co.).

Probe compensation module compensates center shift, tilting angle that comes from when a probe is mounted in the spindle of machine. It is misalignment between probe internal coordinate and machine coordinate. Pulse generation rate should also be calibrated with respect to feed rate of axis motion. Detailed procedure for compensation is well describe in [9]. Measuring module decides path topology and makes probe path. Probe path was generated using CL data generation function in Z-Master. Abnormal signal is also detected in this module to prevent from abrupt damage of machine tool system. Inspection module compares digitized data with surface model data. Table 1 shows specifications of probe and NC machining center.

Probe	Model	SP2-1 touch scanning probe (Renishaw, UK)
	Type	3-axis measurement Liner & parallel motion
	Measuring	± 4.5mm
	Resolution	1□m
	Spring rate	350 g/mm ± 20%
NC M/C	DAWOO CNC AV45 (FANUC 0M)	

Tab. 1. Hardware specifications.

3. MEASUREMENT AND INSPECTION

3.1 Segmentation for probe path generation

If there are some noise, data missing, or needs more precise data in the vision data, contact type measurement can be done by segmenting some measurement areas. Segmentation is the procedure for tracing the boundary curves of a part and dividing the scanned data into segments. After this process, probe path can be generated according to the feature type of each separated surface. In this research, the base model is firstly generated from the non-contact vision data to grasp global geometrical information. Then boundary-searching algorithm is applied to segment surface patches. Consequently the probe path to drive a touch probe can be generated. The base model is approximately fitted CAD data.

Fig. 2(a), (b) shows a laser scanner (Survey 1200) and physical model used in the experiment, respectively. The size of model is 50 50mm, and the digitized cloud of points data is shown in Fig. 2(c).

Z-map model is generated an approximate CAD model from laser scanned data. As well known, Z-map has a few strengths: representation structure is simple, shape modification such as offsetting or blending is efficient and robust, which makes it relatively easy to extract the boundary curve of each featured area (segmentation)[7],[8]. Therefore, it is useful to extract area boundary curve simply.

Fig. 2(a). Surveyor 1200

Fig. 2(b). Physical model

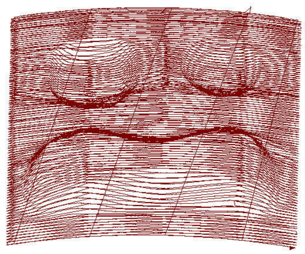
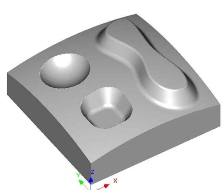


Fig. 2(c). Digitized points

Fig. 2. Experimental environment and digitized example.

Fig. 3 shows an approximate Z-map model from laser-scanned data and a computed area boundary curve as prerequisite information. The boundary curves to separate surface patches, those are features of convex sink, concave with incline plane and concave hemisphere, are well searched as represented in Fig. 4. The approximate CAD model and the boundary curves are input data to the fine digitization stage for probe path planning and generation, physical scanning and verification.



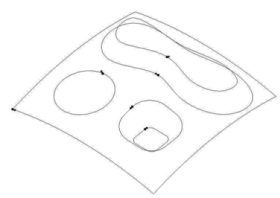


Fig. 3(a). Z-map model Fig. 3(b). Area boundary curve

Fig. 3. Prerequisite information.

3.2 Selection of probe path topology

Probe path topology is similar to tool path topology in NC cutting, for example one way or zigzag pattern, and it decides the type of probe path to drive a sensor. From the reverse engineering's point of view, probe path topology is appropriate when it describes a selected surface well as in cutting path. In this research, probe path topologies are categorized as in Table 2 from based on previous study in taxonomy[4].

The features are classified into floor, wall, volume, and strip type. Each surface type has some kind of features. According to these grouped surface type, each measuring path topology is classified into serial-pattern, radial-pattern, contour-pattern and strip-pattern. Example of each surface type is depicted in the physical model as shown in Fig. 4.

3.3 Measuring path generation and measurement

After selecting a suitable probe path pattern for a surface to be measured, probe path is generated and measurement is executed. In this research, the diameter of probe tip is 6mm, and the position of probe center is obtained without probe radius compensation. Therefore, real coordinate of a surface point is ideally offset surface with ball radius.

Type	***Feature***	***Topology***
Floor type	Slant floor, Horizontal floor Compound floor	Serial-pattern
Wall type	Vertical wall, Draft wall, Cavity wall, Core wall	Radial-pattern
Volume type	Cavity-volume, Shoulder-volume	Contour-pattern
Strip type	Fillet, Round, groove	Strip-pattern

Tab. 2. Overall mapping relationships between scanning feature and probe path topology[11].

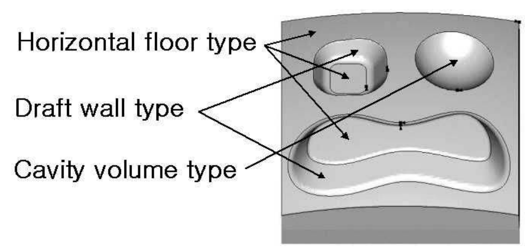


Fig. 4. Typical scanning features.

Probe path to define the position of probe center can be generated from the cutter locate data, which is calculated with a ball end mill of diameter of 5mm to an approximate z-map model. The difference between ball and surface is 0.5mm, and this is for pressing the ball onto surface. That is, constant pulse is always generated during measurement. For example, when probe is touched on xy plane, pre-travel pulse number to be occurred along to z-direction is 500 (difference of radius=0.5mm, 1000 pulse/mm).

Fig. 5 shows an example of continuous probe path to the smooth base feature. A method to calculate the coordinate of ball center along the probe path is referred in [9].

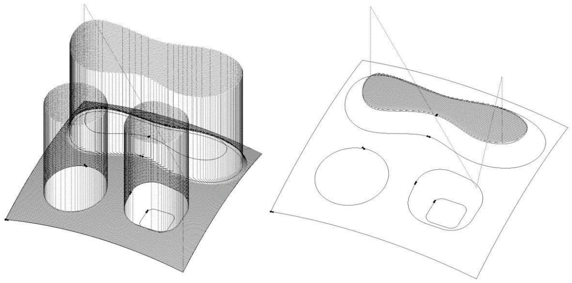


Fig. 5. Probe path for floor features.

4. EXPERIMENTAL RESULTS

Fig. 6 shows a developed user interface window with Z-Master CAM System. In order to evaluate the system, first, a CAD model is designed and machined with NC machine, which gives exact geometry data.
Therefore, comparison between original CAD model and generated model can be possible.

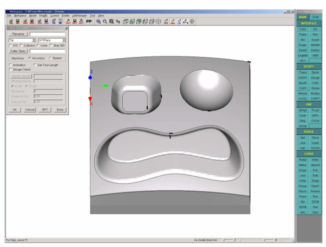


Fig. 6. Z-Master CAM system.

4.1 Experimental model

In this paper, an example model includes base surface, convex surface with 30° draft angle, cavity shape with 30°draft angle, and concave hemisphere shape. NC tool path for machining is generated from commercial CAD/CAM system. Dimension of entire shape is 50×50×25mm, and material is mild steel. Fig. 7 shows a CAD model, machining with machining center, and measuring process. Machined workpiece was digitized with laser scanner as shown in Fig. 2, and segmentation is carried out. Then measurement starts after selection of probe path topology.

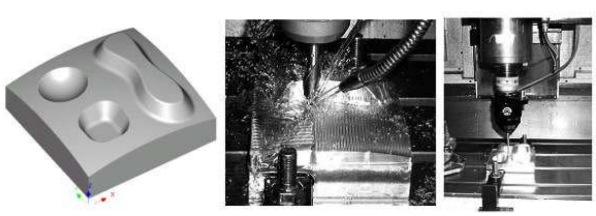


Fig. 7. Example model construction & digitizing.

Area	***Feature Type***	***Point Number***	***Point interval***
F1	Horizontal Floor	6865	More than 0.2mm
F2	Horizontal Floor	2823	More than 0.1mm
F3	Horizontal Floor	146	More than 1.0mm
V1	Cavity Volume	7645	More than 0.05
W1	Draft Wall	17010	More than 0.05
W2	Draft Wall	5408	More than 0.1mm

Tab. 3. Measuring path data information.

4.2 Data acquisition and error evaluation

In this research, the model has three feature types including horizontal, floor, draft wall, and cavity

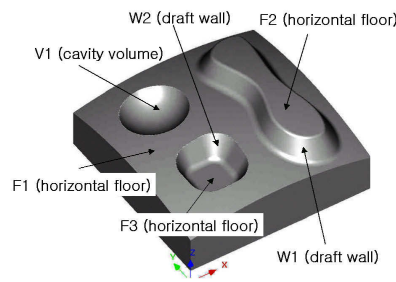


Fig. 8. Scanning areas.

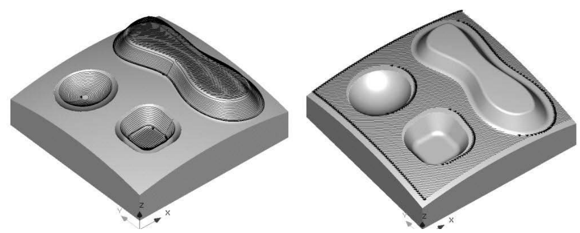


Fig. 9. Digitized points data.

volume, and those are segmented six areas as shown in Fig. 8. After that, a probe scans each surface and calculates the real coordinate data from scanned data. Each path topology selected in this example is represented in Table 3. Digitized points data is shown in Fig. 9, and the data here is just the center position of probe tip. Every measurement is separated with six areas. Example of probe path is shown in Fig. 5 with respect to area F1, and F2, respectively. Number of point and interval is summarized in Table 3. Scanning was done according to point interval with respect to each feature, and massive data points were obtained. The error in measurement is shown in Fig. 10.

The error in Table 4 means the difference between measured data and offset surface of CAD model. In other words, the error, dN, is the difference between the center of probe, $P_{measure}$, and offset surface with probe radius, P_{offset}. It can be calculated using a measuring box (MBox) that is a rectangular enclosing probe radius as shown in Fig. 10. Then, he error is defined as minimum distance between grid points of offset surface model and probe center point. Offset surface of CAD model is generated by z-map structure.

According to Table 4, measurement is quiet precise except horizontal surface F1, and F3. The error might come from volumetric error of NC machine tool, thermal deformation, elastic deformation in clamping workpiece, and probe calibration and measurement errors. It gives opportunity to further research.

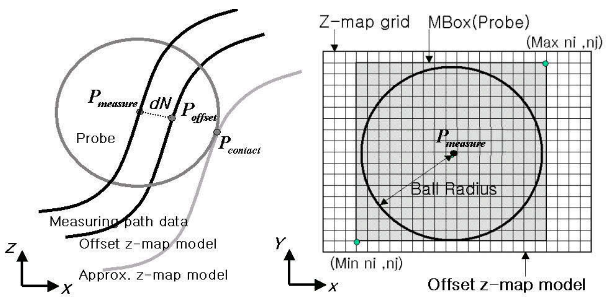


Fig. 10. Error verification method.

Area	Feature Type	Path Topology	Error	
			Average	Range
F1	Horizontal Floor	Serial	0.04989	0.031~ 0.122
F2	Horizontal Floor	Serial	0.01319	0.009~ 0.027
F3	Horizontal Floor	Serial	0.10694	0.103~ 0.112
V1	Cavity Volume	Contour	0.01705	0.015~ 0.057
W1	Draft Wall	Contour	0.00548	0.002~ 0.094
W2	Draft Wall	Contour	0.00709	0.004~ 0.157

Tab. 4. Experimental results.

5. CONCLUSIONS

In this research, a sensor collaborative digitization system was suggested to fully automate a digitizing process. Laser scanner, as a non-contact type sensor, was fast enough to grasp overall information about unknown object. Z-map model approximated the huge number of digitized data well. From the model, the boundary curves segmented each feature, and probe path topology were selected from the point view of modeling. Consequently, point data were digitized with contact type sensor to improve the accuracy or sometimes to supplement the vague point data.

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6. REFERENCES

[1] Ainsworth, I., Ristic, M. and Brujic, D., CAD-based measurement path planning for free-form shapes using contact probes, Int. J. Adv. Manuf. Technol., Vol. 16, 2000, pp. 23-31.

[2] Bradley, C. and Chan, V., A complementary sensor approach to reverse engineering, Journal of Manufacturing Science and Engineering, Vol. 123, 2001, pp. 74-82.

[3] Chen, L. C. and Lin, G. C., An integrated reverse engineering approach to reconstructing free-form surfaces, CIMS, Vol. 10, 1997, pp. 49-60.

[4] Choi, B. K. and Jerard, R. B., Sculptured surface machining: theory and applications, Kluwer Acacemic Publishers, 1998, pp. 58-64.

[5] Chan, V. H., Bradley, C. and Vickers, G. W., A multi-sensor approach for rapid digitization and data segmentation in reverse engineering, Journal of Manufacturing Science and Engineering, Vol. 122, 2000, pp. 725-733.

[6] Milroy, M. J., Weir, D. J., Bradley, C. and Vickers, G. W., Reverse engineering employing a 3D laser scanner: A case study, Int. J. Adv. Manuf. Technol., Vol. 12, 1996, pp. 111-121.

[7] Park, J. W., Chung, Y. C. and Choi, B. K., Precision Shape Modeling by Z-Map Model, J. of KSPE, Vol. 15, No. 11, 1998, pp. 180-188.

[8] Park, J. W., Ko, T. J., Kim, H. S. and Yoo, W. S., Segmentation method for surface fitting in reverse engineering, Seventh International Pacific Conference on Manufacturing & Management, Bangkok, Thailand, Nov. 27, 2002.

[9] Park, J. W. and Ko, T. J., OMM system based on CAD model, J. of KSPE, Vol. 18, No. 6, 2001, pp. 37-42.

[10] Song, C. K. and Kim, S. W., Reverse engineering: Autonomous digitization of free-formed surfaces on a CNC coordinate measuring machine, Int. J. Mach. Manufact., Vol. 37, No. 7, 1997, pp. 1041-1051,.

[11] Zhang, G. and Ma, L., Modeling and calibration of grid structured light based 3-D vision inspection, Journal of Manufacturing Science and Engineering, Vol. 122, 2000, pp. 734-738.