COORDINATE MEASUREMENTS OF FREE-FORM SURFACES IN REVERSE ENGINEERING PROCESS

Andrzej WERNER*

*Faculty of Mechanical Engineering, Białystok University of Technology, ul. Wiejska 45 C, 15-351 Białystok

anwer@pb.edu.pl

Abstract: This paper presents the issues of coordinate measurements of three-dimensional objects whose shape is defined with the use of parametric surface description methods applied in CAD systems. The paper also describes a mathematical as well as a geometrical presentation of surfaces used CAD systems, and discusses coordinate measurement techniques applied in measuring objects of this class. Further in the article, a practical implementation of the methodology of reconstructing objects described with the use of free-form surface patches has been presented. The methodology includes subsequent object measurements and reconstructing the object's geometric model, and concentrates on the possibly most accurate reconstruction of the shapes and dimensions of the researched object.

1. INTRODUCTION

Nowadays, more and more emphasis is put on the quality, ergonomics and aesthetics of products. Applying coordinate measurements and CAD/CAM systems to industry opens great possibilities of integrating the two techniques, which not only greatly influences simplifying the processes of designing and manufacturing but also makes them shorter (Alan et al., 1998; Soni et al., 2009).

Today, coordinate measuring machines are widely used and they often form an integral part of the machine facilities in companies. Moreover, using the machines is not restricted to the quality control; they are also applied in reconstructing objects of complex and unknown shapes (Ainsworth et al., 2000). It happens very often at the first stage of designing that a designer creates an object, which might result in obtaining a hand-made model made of a soft material and with a shape made up of multiple surfaces of complex shapes. In order for such an object to be produced and then to undergo different analyses, it is necessary to create its virtual model. Applying coordinate measurements is the only way to obtain such a model (Yadong and Peihua, 2004; Xie et al., 2005).

2. PARAMETRIC METHODS OF SURFACE DESCRIPTION

Parametric methods of surface description are currently used in creating geometric models in CAD (computer aided design) systems. A B-spline surface (Fig. 1) is described with the use of two parameters, *u* and *v* (Piegl and Tiller, 1987, 1997; Sun et al., 2006).

A mathematical presentation of a B-spline surface is illustrated below:

$$P(u,v) = \sum_{i=0}^{m} \sum_{j=0}^{n} D_{i,j} N_{i,k}(u) N_{j,r}(v) \qquad (1)$$

where: $D_{i,j}$ – apexes of the control grid on which the surface is stretched, $N_{i,k}(u)$, $N_{j,r}(v)$ – basis B-spline functions, *k, r* – degrees of the basis B-spline functions.

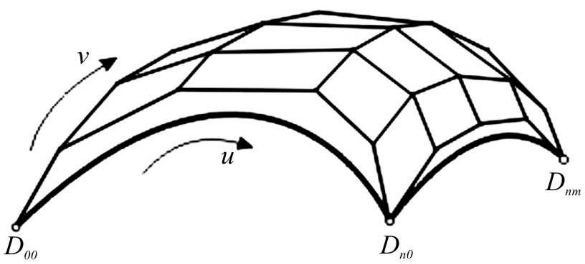

Fig. 1. B-spline surface patch

It is important to know it, since this technique is used in creating surface models on the basis of point clouds which might be created as a result of coordinate measurements. The state-of-the-art software controlling coordinate measuring machines includes, among its numerous object scanning methods, procedures of scanning surfaces of the *uv* type, i.e. according to the surface patch parameterisation directions.

3. APPLYING THE REVERSE ENGINEERING PROCESS TO AN OBJECT DESCRIBED WITH A FREE SURFACE PATCH

Coordinate measurements of complex-shape surfaces were carried out on the example of the object shown in Fig. 2. The shape of the object was described with the help of a B-spline surface patch.

Fig. 2. Reconstructed object

Performing the reverse engineering process aimed at obtaining the greatest possible accuracy of reconstructing the shape surface (Schemenauer et al., 2002). To that end, the following were performed consecutively:

- preliminary coordinate measurements with manual defining of the scanned surface,
- constructing the initial surface model of the object,
- automatic mode coordinate measurements (with the use of a previously prepared geometric model of the object),
- constructing the actual surface model,
- repeating the coordinate measurements and determining the accuracy of reconstructing the surface model.

The tests were made on a test stand comprising (Fig. 3):

- a CNC control milling centre,
- a PC-class computer integrated with a coordinate measuring machine, with the CAD/CAM (Mastercam) as well as (PC-DMIS) software installed.
- a DEA (Brown & Sharpe) Mistral 070705 coordinate measuring machine.

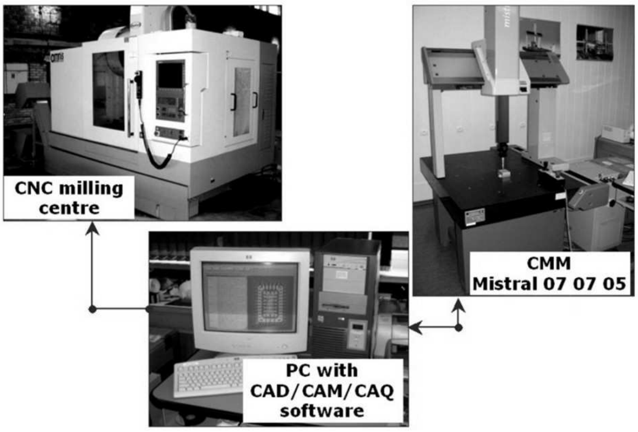

Fig. 3. Test stand

Firstly, the object described with a surface patch of complex shapes was created on this stand, and then the preliminary coordinate measurements were performed with the use of open linear scanning procedures. The object under question was scanned in successive parallel sections. The beginning, direction, and end of scanning were indicated manually. The distance between consecutive measuring points during scanning was 2 mm, while the distance between the successive scanned sections amounted to 2 mm. In that way, a point cloud of measuring points was obtained, on which a series of spline curves was stretched (Fig. 4a). These curves were afterwards used to construct the initial surface model of the object (Fig. 4b) (Park et al., 2004).

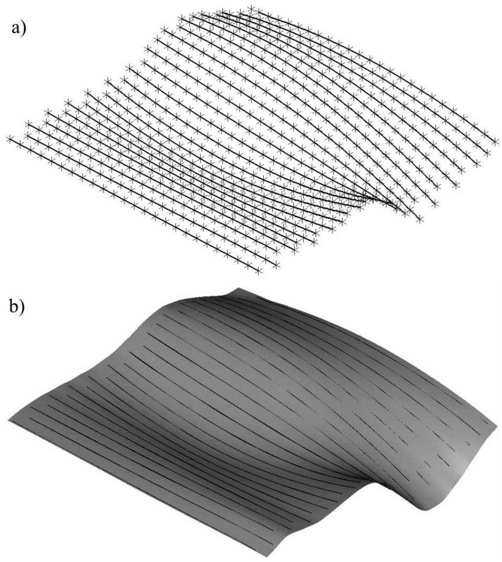

Fig. 4. Graphical presentation of measurement results
a) measurement points and spline curves,
b) surface patch

It has to be emphasised here that indicating the borders of scanning manually is a lengthy and troublesome process. The open linear scanning method is characterised by restrictions stemming from the very method of scanning. In this method, the initial vectors of the probe tip approach were defined by the system the moment the probe tip touched the object in the manual process. The PC-DMIS system defines the directions at which the probe tip approaches the measured surface at the consecutive measuring points on the basis of both the scanning increase pre-determined at the beginning and the last two measuring points (Fig. 5).

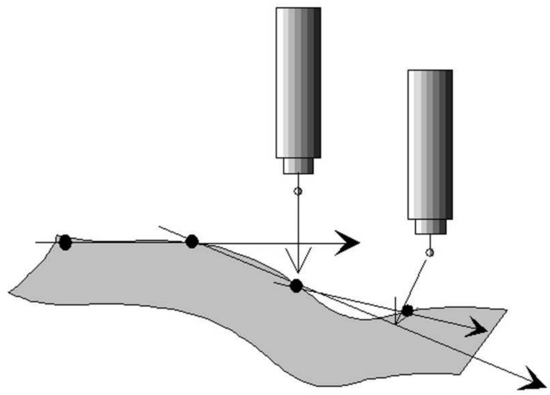

Fig. 5. Determining the direction of the measuring probe tip approach in open linear scanning

In the method presented in this paper, the measuring probe tip approach to the measured object is not located on the normal direction to the measured surface patch. This might result in inaccurate determining the compensation vector for the measuring ball tip end, which in consequence causes declining the measurement accuracy. In the light of these facts, the measurement described above was performed mainly in order to obtain data for building the initial geometric model of the measured surface. This model in turn constitutes a basis for carrying out the actual measurement of the reconstructed object. The advantages of using a geometric model of the measured surface are as follows:

– the model includes the information concerning the borders of the scanned object,
– the measurement tip approach vectors are generated in the normal direction to the measured surface,
– it becomes possible to make use of automatic procedures of measuring the reconstructed surface.

In the following coordinate measurements, the *uv* scanning procedure was applied. This method involves scanning along the spline surface patch parameterisation directions (Fig. 1). The PC-DMIS programme window for the procedure is illustrated in Fig. 6.

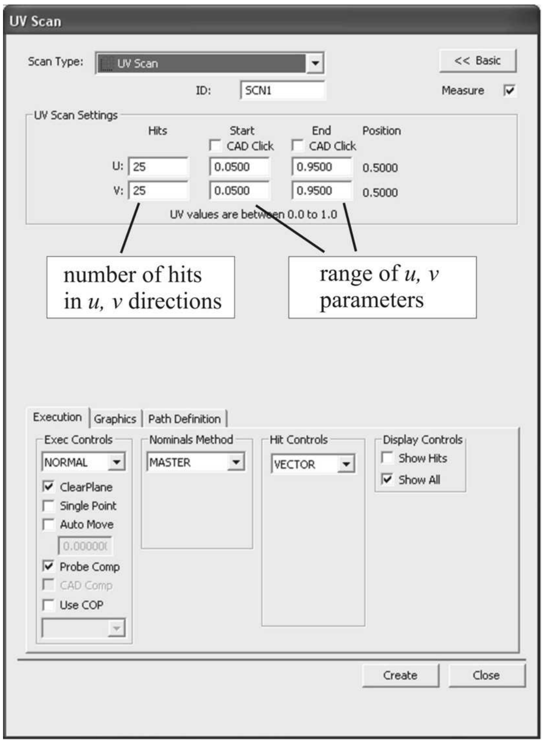

Fig. 6. UV method scanning window

The window requires the user to enter such data as:

– the scanning range through entering the *uv* parameters border values,
– the number of the measuring tip contacts in the *u* and *v* directions.

On the basis of the data listed above, the PC-DMIS system generates measuring samples on the surface patch, and the vectors of the measuring tip approach in the normal direction to the measured surface are also generated. An exemplary distribution of measuring points and the *uv* scanning directions are presented in Fig. 7. The measurement procedure in this case is performed automatically, which significantly simplifies measurements and reduces the amount of time needed to complete them.

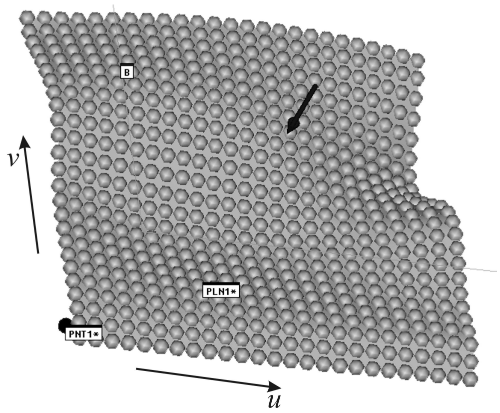

Fig. 7. Measuring points distribution and scanning directions

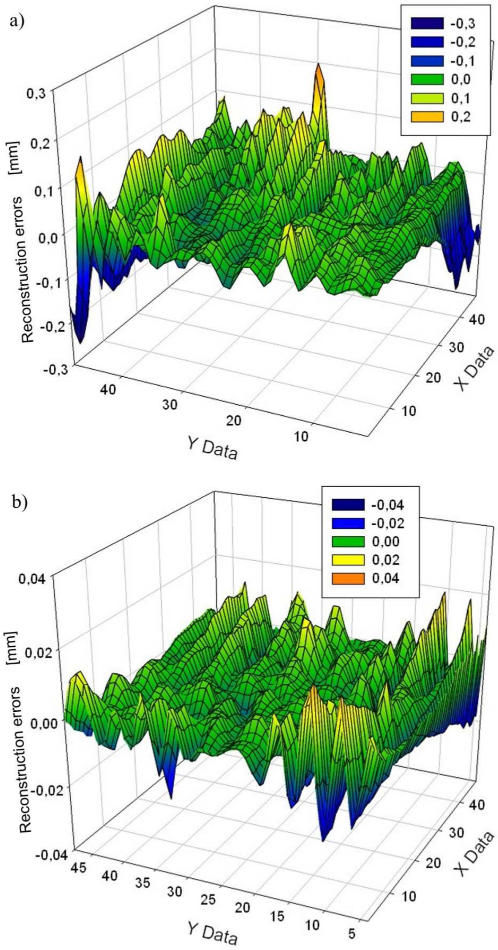

Fig. 8. Reconstruction accuracy a) after preliminary measurement, b) after subsequent measurement

Taking advantage of the *uv* scanning procedure, the measurements of the reconstructed free surface were repeated, which resulted in obtaining a cloud of 625 measuring points. On the basis of these points (in a way similar to the one in which the initial geometric model was created), the actual geometric model of the reconstructed surface was made. The model was then used to verify the suggested method of reconstructing objects described with the use of free surface patches; using this model, the control measurements of the reconstructed object were reprogrammed. Owing to making use of automatic measurement cycles, these measurements were completed in a short period of time. They constituted the basis on which the reconstruction errors of the researched shape surface were determined. The surface reconstruction errors plot are presented in Fig. 8.

The plot shows a comparison of inaccuracy in surface reconstruction on the basis of the results of the preliminary (Fig. 8a) and actual measurement results (Fig 8b). In the end, the obtained accuracy of the surface object reconstruction amounted to 0.035 mm.

4. CONCLUSIONS

Applying surface objects obtained in the two measurement stages in the reverse engineering process, greatly contributes to increasing the accuracy of the produced object's geometric model as well as to simplifying the whole procedure. Preliminary measurements are intended to define the scanned area borders and to construct a surface patch on the basis of which the second stage of measurement is performed. At this stage, having prepared a surface model of the reconstructed object, it is possible to have a greater choice of selecting the distribution and number of measurement points. In this case, the directions of the probe tip approach are generated more rationally, which contributes to increasing the measurement accuracy. It is very significant that it is possible to make use of the procedures of automatic scanning of the reconstructed surfaces, which makes the whole process last considerably shorter.

REFERENCES

1. **Ainsworth M., Ristic M., Brujic D.** (2000), Cad-Based Measurement Path Planning for Free-Form Shapes Using Contact Probes, *Advanced Manufacturing Technology*, n^{o} 16, 23-31.
2. **Alan C. Ling, Shou-Yee Lin, Tse-Hao Fang** (1998), Automated sequence arrangement of 3D point data for surface fitting in reverse engineering. *Computers in Industry*, 38, 149-173.
3. **Park H., Jung H. B., Kim K.** (2004), A new approach for lofted B-spline surface interpolation to serial contours, *International Journal of Advanced Manufacturing Technology*, 23, 889–895.
4. **Piegl L., Tiller W.** (1987), Curve and surface constructions using rational B-splines, *CAD*, vol. 19, no. 9, 485-498.
5. **Piegl L., Tiller W.** (1997), *The NURBS Book*, 2nd ed. Springer-Verlag, New York, USA.
6. **Schemenauer L., Li N., Peng X., Zeng Y., Gu P.** (2002), A reverse engineering system for rapid manufacturing of complex objects, *Robotics and Computer Integrated Manufacturing*, vol. 18, 53–67.
7. **Soni K., Chen D., Lerch T.** (2009), Parameterization of prismatic shapes and reconstruction of free-form shapes in reverse engineering, *International Journal of Advanced Manufacturing Technology*, 41, 948–959.
8. **Sun Yuwen, Guo Dongming, Jia Zhenyuan, Liu Weijun** (2006), B-spline surface reconstruction and direct slicing from point clouds, *International Journal of Advanced Manufacturing Technology*, 27, 918–924.
9. **Xie Zexiao, Wang Jianguo, Zhang Qiumei** (2005), Complete 3D measurement in reverse engineering using a multi-probe system, *International Journal of Machine Tools & Manufacture*, 45, 1474–1486.
10. **Yadong Li, Peihua Gu** (2004), Free-form surface inspection techniques state of the art review, *Computer-Aided Design*, 36, 1395–1417