Accuracy of The Element Geometry Mapping Using Non-Invasive Computer Tomography Method

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Abstract:

Non-invasive method of the measurement and identification of shape and geometrical characteristics of measured detail based on the computer tomograph is widely applied in medicine with high efficiency. The paper is aimed at presenting the metrological analysis of the accuracy of shape reproduction. The examined shape was described due to the tomography and compared to the results of coordinate measurement. The comparative accuracy analysis of the tomography was performed for the typical details, as well as for the masters made with high accuracy. Using the results of the analysis, the respective models of measured details were created and used as a nominal in the further investigations. The results of the measurement with tomography were compared with the results achieved from the measurement by means of typical coordinate measuring machines and by means of 3D measurement optical scanner. Analysis of the gained values of the form deviations and important geometrical characteristics enabled to perform complex analysis of the shape reproduction of the examined detail with the method of computer tomography.

The main purpose of the performed researches was the determination of the reproduction accuracy of surface measured with non-invasive computer tomography method. The investigations and analysis have been performed with the following equipment: computer tomograph, 3D printer and coordinate optical scanner supported with specialized software for advanced CAD data analysis.

Keywords: *computer tomography, optical coordinate measuring technique, reverse engineering, accuracy of workpiece mapping*

1. Introduction

The computer tomography became one of the basic diagnostic and measuring tool in modern medicine. Continuous development of this technique, which is oriented to both minimize radiation and obtain maximum data, determine innovation in solving technical problems. In the past, computer tomography systems was applied only to the diagnosis. Nowadays, there are more and more new applications of this non-invasive measuring technique not only for medicine but also for archeology, mechanical engineering, metrology, criminology or even art.

The goal for researchers was to evaluate accuracy of geometric feature mapping using non-invasive computer tomography. Research and analysis were conducted using computer tomograph, special software dedicated to analysis and the transformation of measurement data, optical 3D measuring scanner, advanced software for CAD data analysis.

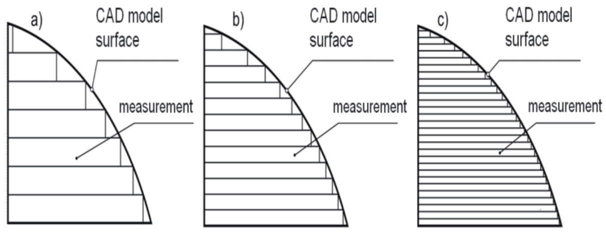

Fig. 1. Influence of the sampling step (tomograph photos) on the model accuracy: a) thickness 1.0 mm, b) thickness 0.5 mm, c) thickness 0.2 mm

Processing of the measurement data and its transformation into 3D model depends on the type of the examined model surface. In the presented researches, the authors have concentrated on the 3D freeform surfaces describing any type of detail. For the elements with curved surfaces and lines (2D and 3D) and with vertical and horizontal surfaces related to the coordinate system of tomography, the tolerance could be defined as a distance between the point of the CAD model and the point of the real model in the line orthodox to the CAD model surface. Figure 1 and 2 show the correlations between the layer thickness and other geometrical parameters of the model in the intersection along y-axis.

The correlations between the parameters presented in the Figure 3 could be written as follows:

– for the outer flat declined surface

$$\delta = h \cdot \sin\gamma \tag{1}$$

– for the outer curved surface

$$\delta = -\rho + \sqrt{\rho^2 + h^2 + 2 \cdot h \cdot \sin\gamma} \tag{2}$$

Where: P(x,y,z) – point in the measured surface, δ – distance between the point in the curve and the measuring point, ρ – curve radius, h – distance between subsequently captured pictures, N – normal vector in the point P of the surface, $n\{n_x, n_y, n_z\}$ – elementary vector.

Geometrical analysis in the direction is dependent on measuring parameters of the tomograph. There is an opportunity of its regulation in order to meet expected accuracy with respect for technical limits of the measuring device. According to that, both the accuracy of used measuring system and algorithms of data transformation into digital 3D form are factors which determine the accuracy of element mapping with computer tomography.

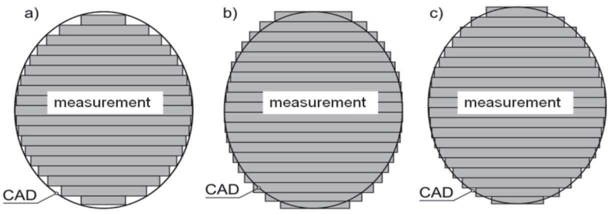

Fig. 2. Layer modeling methods: a) negative tolerance, b) positive tolerance, c) mixed tolerance

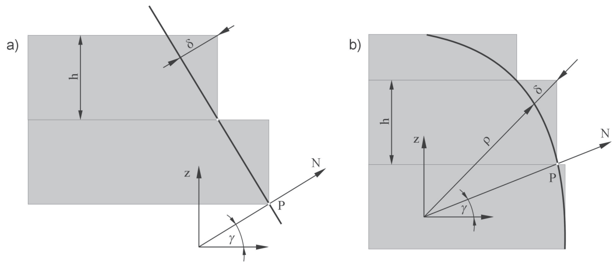

Fig. 3. Geometrical relations in the model's layers: a) intersection of the model with flat side, b) intersection of the model with curved side

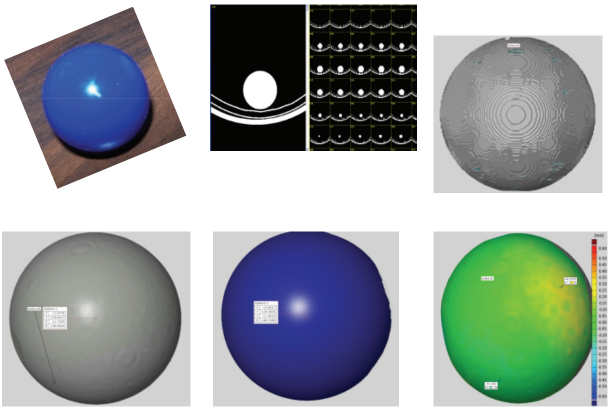

Fig. 4. Spherical element. Deviation of the surface identification ± 0.3 mm. Diameter deviation 0.0135 mm (least square fitting element)

2. Research results

The first part of research was conducted on the computer tomography Hitachi ECLOS 16 which was shared by KIE Sp. z o. o. in Poznan. The distance between the x-ray source and each separate picture was 0.5 mm for every single element that was put to the tests.

The second part of research, which dealt with the evaluation of the surface mapping accuracy using computer tomography and the optical 3D measuring scanner, was conducted in accordance with the process of reverse engineering (RE). Elements selected to research are characterized by geometrical features and surfaces that are the most popular in both engineering industry and medicine.

On each step of the geometry mapping process in use were available methods and algorithms with simultaneous verifying the precision of each transformation in order to guarantee the accuracy of element mapping on the highest possible level. Particular attention was paid to the individual characteristic element and geometric features formed by the free surfaces. In the pictures of particular elements (Figures 4 and 5), there are presented following parameters: a) picture of element, b) results gained from tomography, c) initial 3D model, d) modified 3D model, e) 3D element gained from coordinate scanner, f) comparison (inspection) – deviation of the model.

3. Conclusions

Metrological analysis of the whole reproduction process of the geometrical characteristics of an object measured with computer tomography, specialized CAD software and 3D coordinate scanner leads to the following conclusions:

– deviation of the described process for the elements consisting of 3D freeform flat and convex surfaces (respectively concave ones), compared to the whole dimensions of the object does not exceed ±0.2 mm,

– accuracy of the spherical surface reproduction with substantial curvature related to the whole dimensions does not exceed ±0.3 mm (Fig. 4),

– analysis of the surface built up with freeform surfaces of various and variating curvature based on the proposed methodology does not exceed ±0.5 mm (Fig. 5),

– analysis of geometric deviations of mapping the circle described by free surfaces with varying and variable curvature (Fig. 6), based on the methodology developed does not exceed ±0.7 mm (Fig. 7).

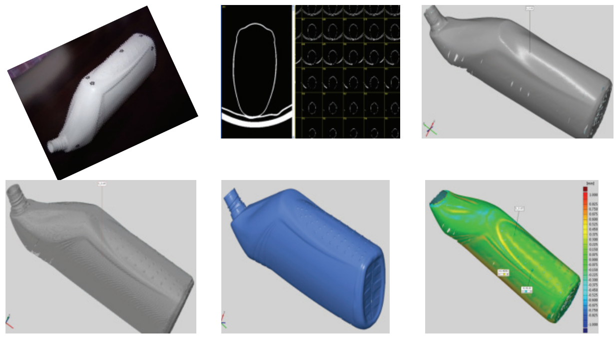

Fig. 5. 3D surface with various curvatures and small details. Deviation of the surface identification ±0.5 mm

Fig. 6. View of a pig spinal verterbra and image of a pig spine measurement on tomography

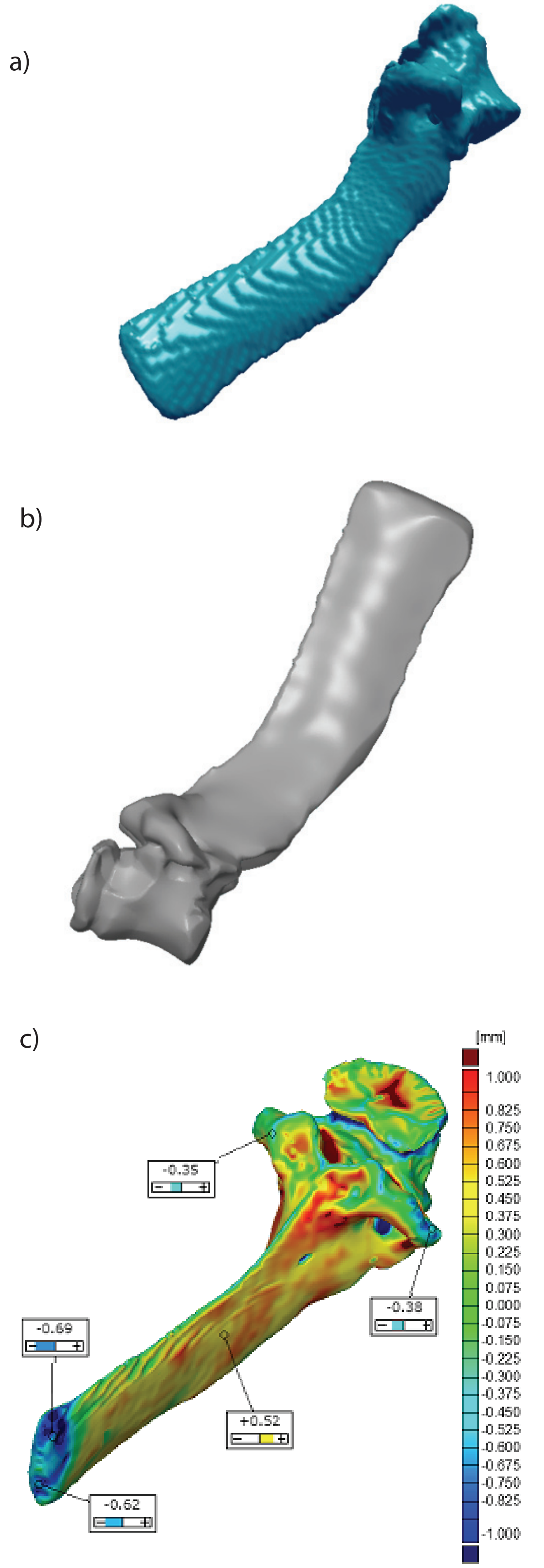

Fig. 7. The results: a) image of a model directly from the tomography, b) model with smoothing in the software for data analysis, c) comparison of the CT measurement results with model obtained from direct measurements on the optical scanner

The reproduction process of the freeform surface is very complicated from technical point of view and requires advanced equipment and software. Computer tomograph supported with Rapid Prototyping system and coordinate measuring technique enables to perform the metrological analysis of the geometrical element with certain accuracy. The measurement method is non-invasive and in some applications is irreplaceable.

The performed investigations and metrological analysis lead to the ability to describe and determine the reproduction accuracy of any kind of object.

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