Method of Noncontact Calibration of the Robotic Ultrasonic Tomograph

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Abstract. The method of calibration of robotic ultrasonic tomograph with the construction of the trajectory of movement of the robot-manipulator on the object of control by using 3D-scanner is described. This method can significantly accelerate the process of calibration of tomograph and prevent possible displacement of the object during calibration. The algorithm of transition from use of a contact method of calibration of the tomograph to noncontact calibration is offered. Experimental data of application of this algorithm show a positive result: the time of research of object considerably decreases. Results of researches prove the practical relevance of the presented work and high efficiency of application of robotic ultrasonic tomography for nondestructive testing of objects of different forms.

1. Introduction

It is difficult to imagine the modern testing without ultrasonic control methods. Ultrasonic inspection does not destroy and does not damage the studied sample; this is the main advantage of this method [1 – 3]. It is also necessary to mention the ability of control of the products from variety of materials, both metal and nonmetals. Besides, it is possible to note the high speed of research at the low cost and the low danger to the person (in comparison with X-ray defectoscopy) and the high mobility of the ultrasonic defectoscope.

A few years ago the ultrasonic detectors were primarily hand-held devices; the difficulties of obtaining of bulk pictures of defects are encountered during using them, the interpretation of the data was virtually impossible. Such devices were succeeded by the ultrasonic tomographs which can reconstruct a three-dimensional picture of defects. Disadvantages of such devices are considerable constraints due to the shape of the surface of the studied object.

The rapid development of additive technology places the new demands to ultrasonic defectoscopes, since the shapes of objects, obtained with the help of three-dimensional printing technology is usually very complex and nonlinear. One solution of this problem is development of device which capable of monitoring the surface of parts of complex shape. This system is designed on a base of Tomsk Open Laboratory for Material Inspection (NDT Institute, Tomsk Polytechnic University).

2. Experimental

Robotic ultrasonic tomograph (figure 1) consists of a six-axle manipulator, immersion tank and block of electronics.

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The precise definition of the relative position of the controlled object and the manipulator is one of the main problems of such devices. Today this problem is solved by a contact method.

The operator of installation should touch to the angles or distinctions of the controlled object by the special gauge needle. This method is labor-consuming; it has the low accuracy of definition of provision of object and it also is interfaced to direct contact of needle with controlled sample; it isn't always admissible.

The following algorithm is used for construction of trajectory of the movement of robot - manipulator on object of control. A special tool with sharp tip is mounted on a robot-manipulator. This tool is brought to pre-selected points of the object to determine the coordinates of these points (including the length of the tool). These coordinates are entered to the software and compared with the chosen object points (as a rule, angles). This process is quite laborious occupation; the slightest mistake leads to the need to start measuring again.

It is proposed to solve the problem through the use of 3*D* - scanner; it determines the coordinates of all points of the object at the scanning process. Development in the field of 3*D* - laser tomography is described in detail in [4]. The method of using the system of tomographic analysis with 3*D* - representation of the data is presented in [5 – 6].

Special attention should be paid to the fact that the scanner has the system of coordinates (*SC*) for determination of coordinates of points, which differs from the coordinate system of the robot.

Let *Oabc* – the coordinate system of the robot; *Ox'y'z'* – the coordinate system of the scanner; *Oxyz* – the abutment coordinate system, it is located at the same point as the coordinate system *Ox'y'z'*, but it is oriented as the coordinate system of the robot (figure 1).

Figure 1. Complex of ultrasonic inspection.

Also we assume that *a*, *b*, *c* – the coordinates of point in the coordinate system of the robot, *x'*, *y'*, *z'* – the coordinates of point in the coordinate system of the scanner, *x*, *y*, *z* – the coordinates of point in the abutment coordinate system.

Then it is possible to write down:

$$a = x + n \\ b = y + k \\ c = z + l \quad (1),$$

where *n*, *k*, *l* – shifts of *SC* of the scanner relatively *SC* of robot.

Thus for systems of coordinates of *Ox'y'z'* and *Oxyz* the equation will be fair:

$$\begin{vmatrix} x \\ y \\ z \end{vmatrix} = C \begin{vmatrix} x^{/} \\ y^{/} \\ z^{/} \end{vmatrix},$$

where C – the matrix of transformation of coordinates; it has the following form:

$$C = \begin{vmatrix} c_{11} & c_{12} & c_{13} \\ c_{21} & c_{22} & c_{23} \\ c_{31} & c_{32} & c_{33} \end{vmatrix}.$$

Then

$$x = c_{11}x^{/} + c_{12}y^{/} + c_{13}z^{/};$$
$$y = c_{21}x^{/} + c_{22}y^{/} + c_{23}z^{/};$$
$$z = c_{31}x^{/} + c_{32}y^{/} + c_{33}z^{/}.$$

In accordance with this the system (1) is converted to

$$a = c_{11}x^{/} + c_{12}y^{/} + c_{13}z^{/} + n;$$
$$b = c_{21}x^{/} + c_{22}y^{/} + c_{23}z^{/} + k;$$
$$c = c_{31}x^{/} + c_{32}y^{/} + c_{33}z^{/} + l.$$

It is necessary to scan the calibration tool tip for determination of coordinates of one point in *SC* of the robot and *SC* of the scanner (thus, to receive its coordinates in *SC* of the scanner); the coordinates in *SC* of the robot can be seen on the control panel.

It should be noted that the 12 unknowns (9 – guides of *cos* and 3 – displacement on respective coordinate) are present in the existing system of three equations. 12 equations required to solve for obtaining of all 12 unknowns. The grouping of these equations is made as follows after establishing of the equation for 4 points:

$$a_1 = c_{11}x_1^{/} + c_{12}y_1^{/} + c_{13}z_1^{/} + n$$
$$a_2 = c_{11}x_2^{/} + c_{12}y_2^{/} + c_{13}z_2^{/} + n$$
$$a_3 = c_{11}x_3^{/} + c_{12}y_3^{/} + c_{13}z_3^{/} + n$$
$$a_4 = c_{11}x_4^{/} + c_{12}y_4^{/} + c_{13}z_4^{/} + n$$

$$b_1 = c_{21}x_1^{/} + c_{22}y_1^{/} + c_{23}z_1^{/} + k$$
$$b_2 = c_{21}x_2^{/} + c_{22}y_2^{/} + c_{23}z_2^{/} + k$$
$$b_3 = c_{21}x_3^{/} + c_{22}y_3^{/} + c_{23}z_3^{/} + k$$
$$b_4 = c_{21}x_4^{/} + c_{22}y_4^{/} + c_{23}z_4^{/} + k$$

$$c_1 = c_{31}x_1^{/} + c_{32}y_1^{/} + c_{33}z_1^{/} + l$$
$$c_2 = c_{31}x_2^{/} + c_{32}y_2^{/} + c_{33}z_2^{/} + l$$
$$c_3 = c_{31}x_3^{/} + c_{32}y_3^{/} + c_{33}z_3^{/} + l$$
$$c_4 = c_{31}x_4^{/} + c_{32}y_4^{/} + c_{33}z_4^{/} + l$$

A solution of the obtained equations allows obtaining complete information about the mutual position of the scanner relative to the robot - manipulator.

The easiest way to solve this system of equations is Cramer's method, whereby the solution takes the form:

$$C_{11} = \frac{D_1}{D};\ C_{12} = \frac{D_2}{D};\ C_{13} = \frac{D_3}{D};\ n = \frac{D_n}{D},$$

where

$$D = \begin{vmatrix} x_1' & y_1' & z_1' & 1 \\ x_2' & y_2' & z_2' & 1 \\ x_3' & y_3' & z_3' & 1 \\ x_4' & y_4' & z_4' & 1 \end{vmatrix};\ D_1 = \begin{vmatrix} a_1 & y_1' & z_1' & 1 \\ a_2 & y_2' & z_2' & 1 \\ a_3 & y_3' & z_3' & 1 \\ a_4 & y_4' & z_4' & 1 \end{vmatrix};\ D_2 = \begin{vmatrix} x_1' & a_1 & z_1' & 1 \\ x_2' & a_2 & z_2' & 1 \\ x_3' & a_3 & z_3' & 1 \\ x_4' & a_4 & z_4' & 1 \end{vmatrix};$$

$$D_3 = \begin{vmatrix} x_1' & y_1' & a_1 & 1 \\ x_2' & y_2' & a_2 & 1 \\ x_3' & y_3' & a_3 & 1 \\ x_4' & y_4' & a_4 & 1 \end{vmatrix};\ D_4 = \begin{vmatrix} x_1' & y_1' & z_1' & a_1 \\ x_2' & y_2' & z_2' & a_2 \\ x_3' & y_3' & z_3' & a_3 \\ x_4' & y_4' & z_4' & a_4 \end{vmatrix}.$$

Thus, the cloud of points of studied object in the coordinate system of ultrasound tomograph can be obtained by noncontact method, using the resulting matrix of the guides.

The proposed method allows making the transition from using the contact method of calibration of the tomogragh to noncontact method, which greatly reduces the time of research.

3. Results and considerations

Figure 2 shows the position of the studied object.

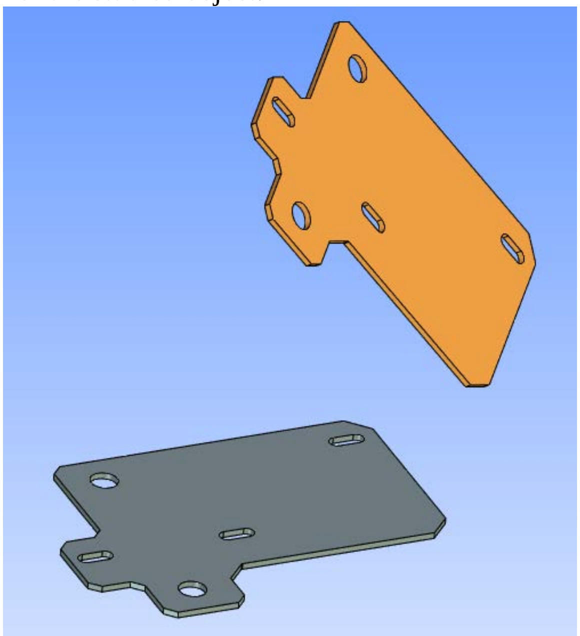

Figure 2. The simulation of working of algorithm.

The software MathCAD was chosen to validate the selected method. The proposed algorithm was fully implemented by the program MathCAD.

The software T-Flex CAD is additionally used. With the help of this software the object of study was modeled and the initial characteristics of this object were defined: translation and rotation relative to the basic coordinate system. Further on the object the four control points were selected, parameters of mutual translation and rotation are calculated by using these points. Map of reference points is shown in figure 3.

The result of running of the algorithm became the reliable matrix, which are the guides for this system of coordinates.

The same experiment was done on real sample by using three-dimensional scanner. The sample is placed in the tub, three-dimensional model of sample is known in advance. The process of reconstruction of three-dimensional cloud of points of the object is carried out by using a three-dimensional scanner; the scanner is fixed at known distance from the robot manipulator.

The reconstruction results are shown in figure 4.

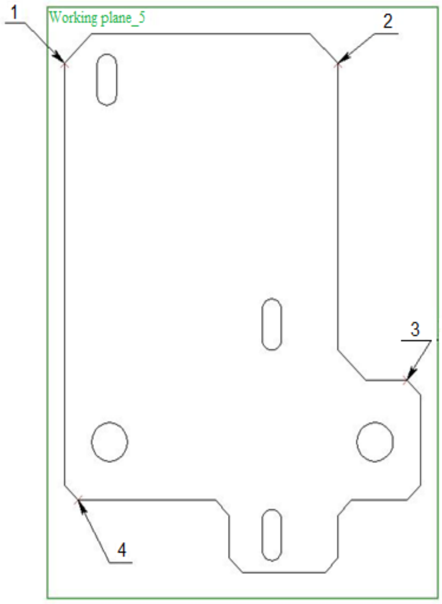

Figure 3. The map of reference points: 1…4 – control points.

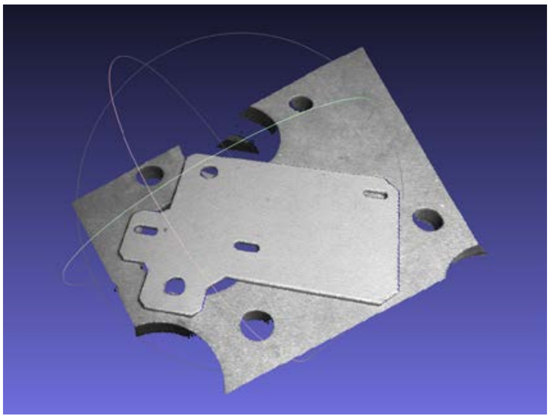

Figure 4. The cloud of points of experimental sample.

The result of the algorithm in this case is a guide matrix, which characterizes the relative position of the object of study in the coordinate system of the ultrasonic tomograph.

Use of this method of measurement shows a significant acceleration of process of calibrating of tomograph and the possibility of excluding of displacement of object at the calibration process.

4. Summary

The presented method allows making the transition from use of a contact method of calibration of the tomograph to noncontact calibration; it significantly reduces the time of the study of object.

The proposed measurement method can significantly accelerate the process of calibration of tomograph and prevent a possible displacement of the object during calibration.

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