A Robotic System for Surface Measurement Via 3D Laser Scanner

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Abstract—**This paper presents a robotic system for surface measurement, and which was designed in the form of "Scanner + Robot + Position-adjustor". Firstly, the main components in the system are briefly introduced and the working principles are described. Then, a series of key problems involved in the system, which mainly including coordinate transformation, data processing and surface reconstruction, are emphatically researched and consequently, the corresponding solutions are put forward. Lastly, the principles and algorithms mentioned are implemented in software, so as to realize the course of measurement. Using this system, the surface model of work piece can be established quickly and conveniently, which have extensive applied foreground.**

Keywords—Surface measurement, Robot, Coordinate transformation, Surface reconstruction

I. INTRODUCTION

At present, the computer technology and the automatic control technology are permeating into all fields rapidly, so it is very significantly to obtain the accurate CAD model of the work piece through the rapid automatic measurement. In surface engineering, the equipment parts that have been subjected to wear, corrosion, chipping off or breaking out in surface section during service are mainly involved, for which laser scanner can be used to 3D surface reconstruction [1,2].

However, if the relative position between the scanner and the part being scanned is fixed, the range of reconstruction will be restricted. In order to extend the scanner scanning range, it is advisable to fix the scanner on a mechanical device and control the mechanical device moving to make the scanner reach more space points [3]. The appearance of the robot, as an automatic controlled mechanical device, makes a new form of total automatic measurement available [4]. In the present work, a robotic system of surface measurement is established, and particularly, a series of key problems involved are presented in this article.

II. DESIGN OF SURFACE MEASUREMENT SYSTEM

Fig.1 shows the basic configuration of the surface measurement system based on robot. The main component parts of installation are: 3D laser scanner, industrial robot IRB 2400, position-adjustor, central computer, as well as other auxiliary accessories (e.g. scanner gripper, cables). Moreover, the special software Trv3DEdit is provided. Considering for releasing full power of 3D scanning technology and modeling technology, it is designed including three subsystems: 3D laser scanning subsystem, data processing subsystem, and reconstruction subsystem.

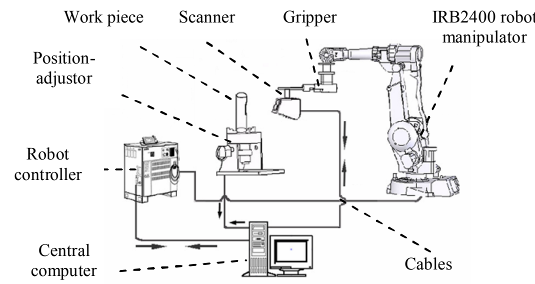


Figure1. Configuration of the surface measurement system

The measurement procedure begins when 3D laser scanner is gripped by the robot and workpiece is fixed on the position-adjustor. According to the type of workpiece, the central computer sends the command to robot controller to execute the special scanning program, which consists of the codes transformed form a series of lines taken by 3D laser scanner during scanning the workpiece surface, and consequently it activates robot manipulator together with scanner moving to arrive all the scanning points. The measuring results are gradually transmitted to the central computer memory and visualized on the monitor as a 3D image of the scanned surface.

III. MATHEMATIC MODEL OF DATA OBTAINING

Through the kinematical relationship when scanning, the positions of the points can be gained, and furthermore data obtaining of the workpiece surface will be achieved. Fig.1 indicates four reference frames in the system, so the basic principle of data obtaining is demonstrated as follows: MSR means the relationship between scanner and robot; MRB means the relationship between robot and base; MPB means the relationship between position-adjustor and base; MPP' means the relationship of position-adjustor centerline of rotary transformation. DS, the data read from scanner, and DB, the final data in the base coordinate, which can be ensured by eq.1.

$$D = M_{PB} \bullet (M_{PP'} \bullet (M_{PB}^{-1} \bullet (M_{RB} \bullet (M_{SR} \bullet D_S)))) \tag{1}$$

A. Scanner calibration

It is normally included interior parameters calibration and exterior parameters calibration. Interior parameters are defined by the scanner company before leaving factory. But exterior parameters need to be defined according to real system circumstance. In this system, the fixed point restriction method is initially designed to solve the key problem of the scanner's TCP (Tool Center Point) calibration that the relationship between scanner coordinate system and robot coordinate system.

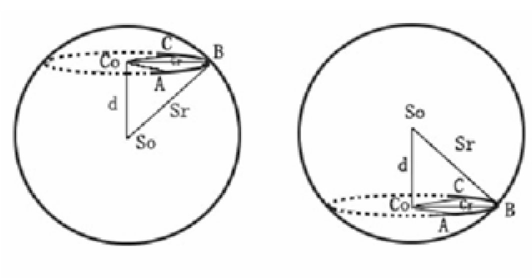
When the laser scanner scans a sphere whose radium is known, the sphere center coordinate can be calculated according to their geometry relationship, but that can get two solutions showing in fig.2, and needs artificial deleting the false value during the experiment. Based on the theory above, eq.2 and eq.3 can be deduced through a series of equations transformation, which indicates that the rotation relationship RT and the translation relationship TT are disassembled successfully. In the calibration process, changing the robot position in demands, scanning the sphere surface many times and collecting many groups experiment data to resolve eq.2 and eq.3, and RT and TT is got [5].

$$R_0 \bullet R_T \bullet (X_{11} - X_{12}) = T_{02} - T_{01} \tag{2}$$

$$X_b = X_B + R_0 \bullet T_T \tag{3}$$

B. Position-adjustor Calibration

The relationship between centerline of position-adjustor and base is invariable, so the calibration work becomes defining the position and the direction of centerline in base coordinate system. The high-low sphere method, which theory is shown in fig.3, is designed. Supposing the line OO' to be the centerline; scanning the sphere fixed on the position-adjustor to get sphere center O1; then rotating position-adjustor and scanning the sphere again to get sphere center O2; …; using the position of sphere centers to fit the centre of circle O. The same way can get O', and OO' easily be ensured.



a. center below b. center above

Figure2. Calculation of sphere center

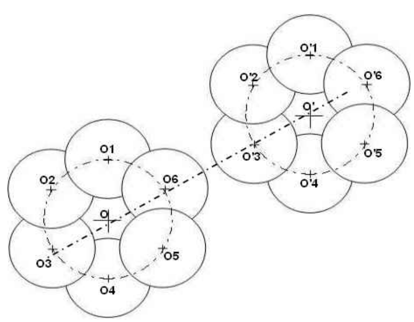


Figure 3. Theory of high-low sphere method

IV. Data Processing

A. Data Arranging

Accordingly to some regulations, data arranging can realize orientation storage, and be endued with specific geometrical and analysissitus significance. The form of final output data is the laser line "dot cloud", but the storage form does not always have this characteristic. Therefore, organizing the data storage configuration is equivalent process to data arranging.

In research work, "dot cloud" is organized by the scanner line in obtained sequence: each scanning line has an only corresponding line ID and each point on same line has an only corresponding point ID. Fig.4 shows the outputting of arranged surface date of a worn axletree. This facilitates data processing in line or point fashion, and especially improving efficiency when doing delete and pick-up operations.

B. Data Filtering

The method used for the handle of the noise points has close relationship with the data arrangement. The arrangement of the data captured by the laser scanning is "dot cloud" data organized by the laser scanning line, so the data can be handled line by line. With these data, the handle of the noise points uses the concepts in the disposition of digit image for reference to recognize the data captured as the Image Data, that means reckon the value of Z as the shade of gray. The methods adopted frequently are automatically Gaussian smoothing, interactive noises-removing (Shown as Fig.5, compared with Fig.4), and so on.

C. Data Reduction

To the high-density "dot cloud", because of the large number of redundant data, it is needed to reduce the quantity of the measuring data. Different kinds of the "dot cloud" can take different ways to be reduced. The scattered "dot cloud" data can be reduced by the way of random sampling; for the scanning line "dot cloud" and polygon "dot cloud", the condense methods of equal in size, multiplying power, and equal in quantity can be used; the net "dot cloud" can use the methods of equal in distributing density and the least embracing zero to be reduced. A new method is put forward, which considers both vector-angle and distance-valve, and so does a good result (shown as fig.6). Reducing handle is only to reduce the quantity of the points but not generate new points.

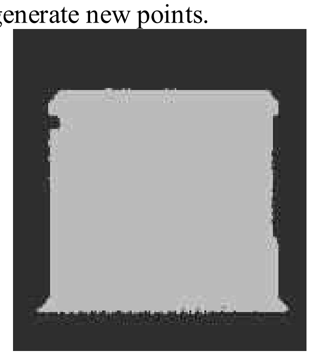


Figure 4. Data outputting map

Figure 5. Data filtering map

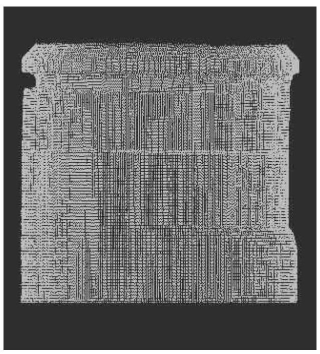


Figure 6. Data reduction map

V. SURFACE RECONSTRUCTION AND MODELING

The method of the curved surface reconstruction based on the measuring points is to build the curved surface directly which meets the least squares fit. In order to increase the accuracy and the speed, the directly triangulations of 3D surface reconstruction is studied and realized. It not only can deal with the regular points but also the scattered ones. As Fig.7shown, it has the advantages of working on a large number of points, obtaining a smooth triangular mesh and supporting the best fitting of the surface.

The complex surface is usually handled by fitting the curved surface which has been divided into many parts. For the data with the characteristic of image, the feature line is captured by the processing of the image; the curved surface is divided into different parts which are fitted by triangulations; and at last joint all parts as a whole. In the present, the modeling technology always needs the slice data, so the common method used approaching CAD model in the system is by many triangles to generate the STL files and then cut these files to get slice data.

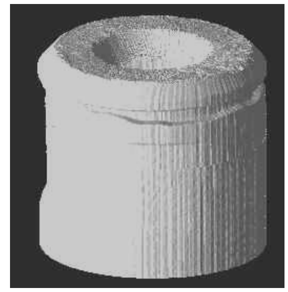


Figure 7. Reconstructed surface

VI. SOFTWARE IMPLEMENT

All principles and algorithms are implemented in software Trv3DEdit. Using Visual C++ and OpenGL on the PC platform, a scanning and model reconstruction system for surface measurement is built. The software integrated data obtaining module, data processing module, displaying and interaction module, model reconstruction module and data I/O module. By using the software, the process, which from data obtaining to data processing and then to surface reconstruction, is realized easily. Some typical examples have verified that, the software running reliably and having better applicability, which can achieve the anticipative goal, and satisfying the actual requirements in project for surface measurement.

VII. SUMMARIES

The 3D coordinate information of the workpiece surface has been gotten, the “dot cloud” data has been processed, including the arrangement of the scanning lines, the filter of the noise points, the reduction of the data, and we acquire the CAD model by the directly triangulations and joint of the curved surface. It is the basic working theory of the surface measurement system based on robot.

Every independent part of the process has been well-researched. But how to make them form a harmonious system needs the further study of the researchers.

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